



DEPARTMENT OF ENVIRONMENTAL
SCIENCES AND ENGINEERING

CENTER FOR SUSTAINABLE
DEVELOPMENT

SOURCE-TO-SEA LANDSCAPE: A PATHWAY TO THE SUSTAINABILITY OF WATER RESOURCES

PAISAGEM FONTE-AO-MAR: UMA ABORDAGEM PARA A SUSTENTABILIDADE DOS RECURSOS HÍDRICOS

ADRIANE MICHELS BRITO

Master in Sustainable Development

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ADRIANE MICHELS BRITO

Master in Sustainable Development

Adviser: José Carlos Ribeiro Ferreira
Assistant Professor, NOVA School of Science and Technology, NOVA University Lisbon

Adviser: Carlos Hiroo Saito
Full Professor, Institute of Biological Sciences, University of Brasília, Brazil

Examination Committee:

Chair: Tomás Augusto Barros Ramos,
Full Professor, NOVA School of Science and Technology, NOVA University Lisbon

Rapporteurs: Maria Teresa Marques Ferreira,
Full Professor, School of Agriculture, University of Lisbon
Maria Manuela Queiroz Martins Mantero Morais,
Associate Professor with Habilitation, University of Évora

Adviser: Carlos Hiroo Saito,
Full Professor, Institute of Biological Sciences, University of Brasília

Members: Maria José Leitão Barroso Roxo,
Full Professor, School of Social Sciences and Humanities, NOVA University of Lisbon
Tomás Augusto Barros Ramos,
Full Professor, NOVA School of Science and Technology, NOVA University Lisbon

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ACKNOWLEDGMENTS

First and foremost, I thank God and the spirituality that accompanied me throughout this journey, lighting my path, especially in moments of uncertainty, solitude, and transition.

To Professor João Nildo de Souza Vianna (in memoriam), my Master's advisor and friend, who encouraged me to pursue a PhD in Portugal, a path we began outlining during a Conference of Environmental Studies Network of Portuguese-Speaking Countries (REALP), in Aveiro. Amid uncertainties and institutional challenges, he personally came to Lisbon, bringing words of encouragement and a mask, an item scarce at that moment. His plans to support the completion of the cotutelle procedures were interrupted by the country's shutdown. Still, his presence endured, in the path he helped to build and in the memory that accompanied me until the end of this journey. Wherever he may be, may he receive my gratitude and affection.

Significant challenges marked this path, as I did not have a specific doctoral scholarship, which led to periods of uncertainty and instability, particularly due to the complexity of the cotutelle process. I am deeply grateful to my advisors for the opportunities to participate in research projects, research centers, exchange programs, and other initiatives (including INCT/Odisseia, SIARL, PPR-OIL2, MARE, Erasmus+), which enabled me to continue on the academic path:

Professor José Carlos Ferreira, thank you for welcoming me to Portugal with trust and commitment, offering essential guidance and support throughout the entire process.

Professor Carlos Hiroo Saito, thank you for the academic, institutional, and emotional support that was crucial for me to remain and persist on this path. Your encouragement, on all levels, was decisive.

I also thank all those who contributed to making the cotutelle possible, despite the many administrative and logistical challenges involved. Special thanks go to the Head of the Department of Environmental Engineering at FCT/UNL, as well as to the coordination of the PhD program in Environment and Sustainability, and to the staff, Professor Maria da Graça Madeira Martinho, Professor Tomás Barros Ramos, and our dear Sandra Ferreira, in whose names I thank all those involved. I would also like to express my gratitude to Professor Maria Paula Antunes, who made a significant difference at the beginning of my stay.

My sincere thanks to Professor Cristiane Gomes Barreto, coordinator of the doctoral program at the Center for Sustainable Development (CDS/UnB), whose support was instrumental in making the cotutelle process possible at the University of Brasília. To Professor José Luiz de

Andrade Franco, thank you for making it possible for me to take the necessary courses at a crucial moment, a fundamental step in completing the cotutelle.

I am grateful to REALP, which broadened my horizons, and to the Erasmus+ AMIGO program, which provided enriching international experiences through partnerships with the University of Tirana (Albania), the University of Montenegro (Montenegro), and the Abdelhafid Boussof University Center of Mila (Algeria).

To Professors Manoela Morais, Carolina Araújo, and Lia Vasconcelos, for always being a cherished source of inspiration and strength, thank you so much.

I am grateful to the members of the Marine and Environmental Sciences Centre (MARE) who welcomed me, as well as to the professors and staff of the Department of Environmental Engineering, for providing such a rich and inspiring academic environment.

To all the friends who accompanied me with affection, humor, and generosity, your presence made the journey lighter and brighter.

Ambrósio Camuenho, Cláudio Duarte, Daniel Pais, André Manteigas, and Naiara Casagrande for being constant friends and a source of support.

Dear companions of room 103, thank you for your friendship, good discussions, shared lunchtimes, laughter, listening, and support. Catarina Joia, Felipa Ferreira, Francisco, Carolina, Rogério, Luisa Jordão, Diogo Sousa, and Rita Dias, you will always be in my heart! And also, to all those who passed through room 103 along the way.

My chosen family in Portugal, Antônio Lima, João Monteiro, Rafael Lima, Adriana Elias, Ricardo Leandro, Mario Pedro, Mônica Martins, Andrea Fenzl, Naná Maris, and Márcia Cozer, thank you for your patience, companionship, and encouragement on the hardest days.

To my family—my true origin, destination, and flow:

Leander and Mathews, whose support made my coming and staying possible. Your encouragement gave me the courage and strength to cross oceans.

Iann, Victória, and Livia, each one a source of love, light, and inner transformation.

My parents, Paulo and Marli, for their constant presence and unconditional love.

My sister, Andréa, for her love, friendship, and ever-present emotional support, and Armando, brother-in-law, brother, and friend. Thank you both for your warm welcome!

Paulo Henrique and Andressa, always close, even from afar.

The little ones, Arthur, Valentina, Anaís (not so little anymore), and Enrico, bright rivers who bring joy and hope.

To my husband, Eduardo, whose support in this final stretch was both shelter and drive, thank you for reminding me that even the strongest rivers need calm to reach the sea.

"We have to stop trying to gain mastery and learn instead to manage, improve, understand. We have to inscribe in ourselves [...] an ecological conscience, aware that we inhabit, with all mortal beings, the same living sphere (biosphere). Recognizing our consubstantial bond with the biosphere, we can give up the Promethean dream of dominating the universe and nurture our aspiration for conviviality on this earth."

Edgar Morin

ABSTRACT

Water is a vital and transversal element of the biosphere, flowing across ecological, territorial, and political boundaries. However, despite its interconnected nature, the governance and management of water remain fragmented. Over recent decades, several integrative strategies and approaches have sought to promote greater coordination across systems and scales, achieving significant progress. Nonetheless, environmental degradation continues to intensify, and the implementation of these initiatives remains limited by rigid institutional structures, sectoral compartmentalization, and spatial discontinuities along the land-water *continuum*. The Source-to-Sea approach has emerged as a promising strategy to address existing fragmentation by promoting the Integration of flows, systems, and actors along the entire *continuum*, from headwaters to the ocean. Within this framework, the present study aimed to assess whether the Source-to-Sea approach constitutes a substantive innovation or merely a reformulation of principles already established in previous integrative models. To address this, the study adopted a qualitative, analytical-deductive methodology, combining content analysis and analytical matrices, structured in three main articles that provided: (i) a conceptual diagnosis of the Source-to-Sea, Integrated Water Resources Management and Integrated Coastal Management approaches, revealing that the Source-to-Sea approach contributes to a new systemic understanding of the land-sea *continuum*, encompassing ecological and human interdependencies and influences, but lacking an explicit territorial framework that situates water management within a broader spatial unit; (ii) the theoretical formulation of the Source-to-sea Landscape approach, integrating landscape-based concepts to overcome the identified limitation; and (iii) an assessment of the normative applicability of the new approach, through a critical analysis of European directives related to freshwater and marine governance. Based on these three stages, the research consolidated the Source-to-sea Landscape proposal, which distinguishes itself by expanding the territorial, ecological, and social scope of previous approaches and innovatively integrating ecological and human processes into a single governance and management framework. This differentiation is reflected in: the incorporation of an integrated analysis of environmental processes from the land to the ocean, overcoming the compartmentalization between coastal and Inland zones; the expansion of the understanding regarding the relationships between social processes and water bodies, recognizing the land-

scape as an expression of these Interactions and also considering its historical transformation; the incorporating of the hydrosocial cycle perspective, which recognizes the inseparability of land and water; and in the articulation with principles of Integrated Water Resource Management, Integrated Coastal Management, the European Landscape Convention, and the Hybrid Landscape Approach, which Integrates biophysical and sociocultural dimensions into a unified landscape perspective, thereby proposing a coherent methodological structure that is sensitive to the dynamic interconnections between natural and human systems. Furthermore, the approach incorporates principles of adaptive governance and continuous learning, promoting collaborative scenario building, iterative monitoring, management of uncertainties, and feedback across scales and territories. In this way, the Source-to-Sea Landscape constitutes an innovative methodological and normative proposal that articulates territory, society, and water through a hybrid territorial perspective, anchored in the landscape and sensitive to the physical, ecological, social, and cultural dimensions along the land–freshwater–marine *continuum*. Its methodological structure, composed of four iterative steps (Comprehension, Involvement, Planning, Execution & Monitoring), enables adaptive, participatory, and multilevel governance. The critical analysis of the main European directives related to water and marine governance (the Water Framework Directive, the Groundwater Directive, the Marine Strategy Framework Directive, and the Maritime Spatial Planning Directive) revealed both the conceptual alignment of Source-to-Sea Landscape with these instruments and its capacity to identify gaps, synergies, and integration pathways not yet addressed by traditional approaches. By proposing normative mechanisms, multiscale coordination, and collaborative platforms, the approach demonstrates its practical applicability in the European context, as well as its potential for adaptation to other territories. Thus, it contributes to strengthening ecosystem resilience, promoting territorial justice, and consolidating a new paradigm of systemic environmental governance. In this way, the Source-to-Sea Landscape reconstructs the relationship between source and sea, nature and society, vision and action. In doing so, it paves the way for an innovative framework of environmental governance and management, based on systems thinking, territorial cohesion, and normative coherence, thereby consolidating fundamental pillars for achieving sustainable development.

Keywords: Source-to-Sea Landscape, Socioecological sustainability, Land-Water-Sea integration, Hydrosocial cycle, Water governance and management, Freshwater and Marine Systems, Sustainable Development Goals, Global South contexts.

RESUMO

A água é um elemento vital e transversal da biosfera, fluindo através de fronteiras ecológicas, territoriais e políticas. No entanto, apesar de sua natureza interconectada, a governança e a gestão dos recursos hídricos permanecem fragmentadas. Nas últimas décadas, diversas estratégias e abordagens integradoras buscaram promover maior coordenação entre sistemas e escalas, alcançando progressos significativos. Ainda assim, a degradação ambiental continua a intensificar-se, e a implementação dessas iniciativas permanece limitada por estruturas institucionais rígidas, compartimentação setorial e descontinuidades espaciais ao longo do contínuo terra-água. A abordagem Fonte-ao-Mar tem-se afirmado como uma estratégia promissora para enfrentar a fragmentação existente, promovendo a integração de fluxos, sistemas e atores ao longo de todo o *continuum*, desde as nascentes até o oceano. Nesse enquadramento, a presente investigação teve como objetivo avaliar se a abordagem Fonte-ao-Mar representa uma inovação substantiva ou se se limita à reformulação de princípios anteriormente consagrados em outros modelos integradores. Para isso, adotou-se uma metodologia qualitativa, analítico-dedutiva, com análise de conteúdo e uso de matrizes analíticas, estruturada em três artigos principais que forneceram: (i) um diagnóstico conceitual das abordagens Fonte-ao-Mar, Gestão Integrada de Recursos Hídricos e Gestão Costeira Integrada, o qual revelou que a abordagem Fonte-ao-Mar contribui para uma nova visão sistêmica do contínuo terra-mar, abarcando interdependências e influências ecológicas e humanas, mas carecendo de uma estrutura territorial explícita que situe a gestão da água dentro de uma unidade espacial mais ampla; (ii) a formulação teórica da abordagem Paisagem Fonte-ao-Mar, integrando conceitos baseados em paisagem com o objetivo de superar a limitação identificada; e (iii) a avaliação da aplicabilidade normativa da nova abordagem, por meio de uma análise crítica de diretivas europeias relacionadas à governança de águas doces e marinhas. A partir dessas três etapas, a pesquisa consolidou a proposta da abordagem Paisagem Fonte-ao-Mar, que se diferencia por expandir o escopo territorial, ecológico e social das abordagens anteriores, integrando de forma inovadora os processos ecológicos e humanos em uma única estrutura de governança e gestão. Essa diferenciação se manifesta na incorporação de uma análise integrada dos processos ambientais da terra ao oceano, superando a compartimentação entre zonas costeiras e continentais; na ampliação da compreensão sobre as relações entre os processos sociais e os corpos hídricos, reconhecendo a paisagem como expressão dessas intera-

ções e considerando também sua transformação histórica; na adoção da perspectiva do ciclo hidrossocial, que reconhece a inseparabilidade entre terra e água; e na articulação com princípios da Gestão Integrada dos Recursos Hídricos, da Gestão Costeira Integrada, da Convenção Europeia da Paisagem e da Abordagem da Paisagem Híbrida, que integram as dimensões bi-física e sociocultural em uma perspectiva unificada da paisagem, propondo, assim, uma estrutura metodológica coerente e sensível às interconexões dinâmicas entre os sistemas naturais e humanos. Além disso, a abordagem incorpora princípios de governança adaptativa e aprendizagem contínua, promovendo a construção colaborativa de cenários, o monitoramento iterativo e a gestão de incertezas e retroalimentações entre escalas e territórios. Dessa forma, a Paisagem Fonte-ao-Mar constitui uma proposta metodológica e normativa inovadora, que articula território, sociedade e água com base em uma perspectiva territorial híbrida, ancorada na paisagem e sensível às dimensões físicas, ecológicas, sociais e culturais ao longo do *continuum* terra-água doce-marinho. Sua estrutura metodológica, composta por quatro etapas iterativas (Compreensão, Envolvimento, Planejamento, Execução & Monitoramento), viabiliza uma governança adaptativa, participativa e multinível. A análise crítica das diretivas europeias relacionadas à governança hídrica e marinha (a Diretiva-Quadro da Água, a Diretiva Águas Subterrâneas, a Diretiva-Quadro Estratégia Marinha e a Diretiva Ordenamento do Espaço Marítimo) evidenciou tanto o alinhamento conceitual da Paisagem Fonte-ao-Mar com esses instrumentos quanto sua capacidade de identificar lacunas, sinergias e caminhos de integração ainda não contemplados pelas abordagens tradicionais. Ao propor mecanismos normativos, coordenação em múltiplas escalas e plataformas colaborativas, a abordagem demonstra sua aplicabilidade prática no contexto europeu, bem como potencial de adaptação a outros territórios. Assim, contribui para o fortalecimento da resiliência dos ecossistemas, a promoção da justiça territorial e a consolidação de um novo paradigma de governança ambiental sistêmica. Com isso, a Paisagem Fonte-ao-Mar reconstrói a relação entre terra e mar, natureza e sociedade, visão e ação. Ao fazê-lo, abre o caminho para uma estrutura inovadora de governança ambiental, baseada no pensamento sistêmico, na coesão territorial e na coerência normativa, consolidando, assim, pilares fundamentais para o alcance dos objetivos globais de desenvolvimento sustentável.

Palavras chave: Paisagem Fonte-ao-Mar, Sustentabilidade socioecológica, Diretivas europeias, Integração terra-água-mar, Ciclo hidrossocial, Governança e gestão da água, Sistemas de água doce e marinhos

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ACRONYMS

ARs	Atmospheric rivers
CAP	Common Agricultural Policy.
CBD	Convention on Biological Diversity
CDS	Sustainable Development Center.
DPSIR	Driving forces - Pressures - States - Impact - Responses
EBM	Ecosystem-based Management
Eco-GES	Good Ecological Status for the freshwater context.
EEA	European Environmental Agency
ELC	European Landscape Convention.
Env-GES	Good Ecological Status for the marine context.
EQSD	Environmental Quality Standards Directive.
EU	European Union
GCS	Good Chemical Status.
GEF	Global Environment Facility.
GES	Good Ecological Status.
GIS	Geographic Information Systems
GWD	Groundwater Directive.
GWP	Global Water Partnership
HABs	Harmful Algal Blooms.

HLA	Hybrid Landscape Approach.
ICARM	Integrated Coastal Area and River Basin Management
ICM	Integrated Coastal Management.
ICZM	Integrated Coastal Zone Management
IWRM	Integrate Water Resources Management.
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive.
MSP	Marine Spatial Planning
MSPD	Maritime Spatial Planning Directive.
NAO	North Atlantic Oscillation
NGOs	Non-Governmental Organizations.
PES	Payment for Ecosystem Services
PFAS	Per- and Polyfluoroalkyl Substances.
POPs	Persistent Organic Pollutants
PoMs	Programs of Measures.
PPPs	Public-Private Partnerships
S2S	Source-to-Sea.
S2S Landscape	Source-to-Sea Landscape
SDGs	Sustainable Development Goals
SGD	Submarine Groundwater Discharge
SMART	Specific, Measurable, Attainable, Relevant, Time-bound
SPICED	Subjective, Participatory, Interpreted and communicable, Cross-checked, Empowering, Diverse and disaggregated
STAP	Scientific and Technical Advisory Panel.
SwAM	Swedish Agency for Marine and Water Management.
TCs	Tropical cyclones

ToC	Theory of Change.
UnB	University of Brasília
WDF	Water Framework Directive.

INTRODUCTION

1.1 Background and motivation

Water is a cross-cutting element of the biosphere, essential to life and the functioning of natural systems. It flows freely across landscapes, ecosystems, and political boundaries, forming a dynamic and vital link between the atmosphere, land, and sea. In this sense, water can be considered a kind of bloodstream of the biosphere (Ripl, 2003). Furthermore, water is a resource that is difficult to replace and is fundamental to multiple dimensions of human life. It is present in food production, industrial systems, domestic uses, and the development of societies (Falkenmark, 1997). Thus, we must consider water from all its available sources, from the river headwaters to the sea, and understand its *continuum* and cycle.

The hydrological cycle has traditionally been conceived as a natural, continuous process, independent of the presence or absence of human activity (Maidment, 1993). This classical view is anchored in the natural circulation of water below, on, and above the Earth's surface, as described by Horton (1931). Despite this supposed independence, the hydrological cycle can be significantly affected by human activities, such as dam construction, groundwater extraction, land-use changes, or pollution of water bodies, altering water availability, flow patterns, and sediment dynamics. These changes disrupt the speed of circulation, the pulse, and the natural flood rhythms, profoundly transforming the relationship between nature and society.

In this regard, Linton (2008b) argues that the hydrological cycle should not be viewed as an intrinsic feature of nature, while Falkenmark (1997) advocates for a more holistic perspective that captures the complex interactions between society and the water cycle. In other words, we need to consider the socio-ecological nature of water, the hydrosocial cycle, as anthropogenic actions are transforming the contemporary global water cycle.

Climate change has brought a new nature and magnitude to these impacts. Over the past two decades, extreme weather events, droughts, changes in precipitation patterns, and rising temperatures have significantly affected water storage and runoff in various regions. These changes threaten the stability of water systems and intensify conflicts over competing water uses, even in countries with historically abundant water resources (Marengo et al., 2017; Michels-Brito et al., 2021).

It is essential to understand the connections between hydrological processes, ecosystems, and human dynamics along the entire course of water to the oceans and to identify a conceptual framework that considers how these interconnections operate. This will allow us to respond to ongoing transformations and design scenarios that balance competing demands while ensuring long-term benefits for ecosystems and society. One thing is certain: the intensification of human activities leads to a cascade of impacts, from land to coastal zones and the open ocean.

According to Granit et al. (2017b), current water governance and management arrangements are not well-suited to addressing the complexity of hydrological systems. They often fail to balance competing demands and coordinate conflicts among different uses, interests, and management objectives, as well as to align the priorities of multiple social actors and institutional structures across various geographic segments, from headwaters to marine systems. As a result, problems tend to be addressed in a compartmentalized manner, by sector or territory, leading to fragmented and sometimes unsustainable solutions for the system as a whole.

Despite the advancement of contemporary strategies aimed at mitigation, adaptation, conservation, and development in terrestrial, riverine, coastal, and marine ecosystems often promoted under the ideal of sustainability, fragmentation still persists. This reflects both a limited understanding of the interconnections among these systems (since recognizing relationships does not necessarily mean implementing them) and the continued existence of compartmentalized governance and management structures (Berggren & Liss Lymer, 2016; Granit et al., 2017b; Liss Lymer et al., 2018). Such fragmentation has been widely discussed in the academic literature, which highlights the mismatch between ecological and administrative scales, as well as the lack of coordination among sectors, as recurring obstacles to integration and effective water governance (Pahl-Wostl, 2015).

In recent decades, various initiatives have emerged with the aim of promoting integration, with Integrated Water Resources Management (IWRM) being the most widely adopted example (GWP, 2000). However, its implementation within institutionally rigid contexts, without structural changes in governance paradigms, has limited its effectiveness. As Pahl-Wostl (2015)

points out, many of these integrated management instruments operate within systems that retain sectoral perspectives and administrative cultures resistant to change, thereby reproducing the very fragmentation they seek to overcome. Over time, IWRM has also come to encompass nearly all water governance and management approaches under its umbrella, which, while promoting inclusivity, has also blurred its boundaries and weakened its transformative potential (Molle, 2008; Biswas, 2004).

Given these limitations, it becomes evident that a more systemic approach is needed, one that understands water resources through the lens of the water cycle. Freshwater and marine systems should not be treated as separate domains, but as interdependent parts of a single hydrological *continuum*, in which natural and anthropogenic processes interact and affect the system as a whole. This integrated perspective also requires recognizing the human component, along with its sociotechnical, economic, and political transformations, as an intrinsic part of the hydrosocial cycle (Linton & Budds, 2014), breaking with the traditional view of a separation between nature and society.

The Source-to-Sea (S2S) approach has been proposed as an innovative solution to address these persistent gaps in water governance and management (Granit et al., 2017a; Mathews et al., 2018). In this context, a central concern emerges that motivated this research: despite the wide promotion of the S2S approach as a solution to water resources governance fragmentation, it remains unclear whether it truly represents a paradigmatic change or merely reconfigures principles already present in earlier integrated management frameworks. The literature indicates that several integrated approaches have been presented as new paradigms over the past decades, often with converging objectives and similar scope. This invites a more critical examination of what constitutes substantive change in the governance of interconnected socio-ecological systems (Biswas, 2004; Molle, 2008; Pahl-Wostl, 2015; Rahaman & Varis, 2005; Giordano & Shah, 2014; Medema et al., 2008; Merrey et al., 2005).

As Pahl-Wostl (2015) argues, there is a risk that the discourse on paradigm shifts may serve more as symbolic policy than as a driver of concrete transformation, unless it incorporates a critical analysis of power relations and the political conditions that enable or hinder such transformations. In this context, the present research arises from the need to understand how to address the fragmentation of water governance and management, along with the associated landscapes, which are understood here as interconnected socioecological territories. The S2S approach is taken as the central analytical framework and is critically examined in relation to other integrative frameworks. By linking water governance to the spatial, ecological, and institutional dynamics of these territories, this dissertation aims to contribute to the development

of an analytical framework that is better suited to the complexity of socioecological systems and the connections that structure the land–water *continuum*, from upstream to downstream, and from local to transboundary scales.

1.2 Objective and Research Questions

The objective of this research is to critically examine the foundations, limitations, and innovative potential of the S2S approach in the face of persistent fragmentation in the governance and management of water resources and interconnected socioecological systems. The study aims to understand whether the S2S approach constitutes a paradigmatic shift or merely represents a synthesis of principles already present in other integrative approaches, such as Integrated Water Resources Management (IWRM) and Integrated Coastal Management (ICM).

The hypothesis guiding this research is that the Source-to-Sea (S2S) approach, by promoting the integration of flows and interconnected territories along the land-water *continuum*, has the potential to offer a conceptual and operational advance over the limitations of earlier approaches. However, it is assumed that specific critical dimensions, conceptual, spatial (including from the perspective of Interconnected landscape), and institutional, remain underdeveloped, particularly in terms of linking different ecological systems and scales of governance, thereby justifying a more in-depth analysis of their foundations and applications.

The research question guiding this study is:

- Does the Source-to-Sea approach represent a substantive innovation capable of overcoming fragmentation in the governance of interconnected socioecological systems, or does it merely reorganize principles already present in earlier integrative approaches under a new formulation?

1.3 The Path of Water: From Source to Sea - A Brief Review.

The S2S approach adopts a systemic and holistic perspective, aiming to understand the physical, socioeconomic, and governance systems that prevail and interact along the *continuum* of a river system, from source to ocean, as well as their upstream-downstream linkages, before any type of intervention is designed. Part of its goal is to deepen the systemic understanding of the connections between freshwater systems, the terrestrial areas that influence

them, coastal zones, and marine environments, supporting efforts to promote coordinated governance across these systems (Weinberg et al., 2021).

The approach incorporates a critical understanding of the limitations of traditional integration strategies, recognizing that while the concept of integration is widely present in environmental and water governance discourse, it often remains confined to conceptual or sectoral levels. S2S, in contrast, seeks to deepen this integration by emphasizing the need to effectively articulate freshwater, terrestrial, and coastal–marine systems, which are often governed by distinct legal and planning frameworks that require greater coordination and coherence (Granit et al., 2014).

Freshwater, coastal, and marine systems are interconnected as part of the hydrological cycle, moving beyond political and disciplinary boundaries, across land, subsurface, and atmosphere, through exchanges within and between biomes and living systems. This dynamic unfolds across multiple scales, ranging from global to local, from river basins to the oceans. The hydrological cycle transforms the planet into a unified system of living and non-living components, where land, water, and atmosphere are interlinked, with the continuous circulation of water acting as the thread that connects them (Granit et al., 2017b; Rocha Loures, 2021).

What defines the Source-to-Sea system is precisely this vision of a unified system, encompassing river basins, aquifers, downstream receptors, including deltas and estuaries, coastlines, nearshore waters, the continental shelf, and the open ocean. The approach is structured around a set of elements that guide action pathways based on the identification of key flows, a central component of its conceptual framework, that link the various segments of the S2S system. Changes in these key flows, such as water, sediment, pollutants, biota, materials, and the ecosystem services resulting from these interactions (Granit et al., 2017a), can generate environmental, social, and economic benefits or impacts, depending on how they are managed.

1.3.1 Historical Trajectory and Conceptual Foundations of the Source-to-Sea Approach

The Source-to-Sea (S2S) approach emerged from the convergence of scientific insights and political instruments developed since the 1980s, aimed at overcoming the fragmentation between terrestrial, freshwater, coastal, and marine systems. Foundational concepts such as

the River *Continuum* (Vannote et al., 1980) and the blue–green water typology (Falkenmark, 1997) introduced systemic views of the hydrological cycle and upstream–downstream linkages. These ideas were reinforced by increasing evidence of anthropogenic pressures, including pollution, sedimentation, and eutrophication (Ripl, 2010), demanding integrated responses.

Institutional and normative milestones included Agenda 21 (UNCED, 1992), the Dublin Statement on Water and Sustainable Development (Dublin Principles) (ICWE, 1992), and the launch of the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP, 1995). The UN Commission on Sustainable Development (UNCSD, 1997) consolidated the concept of ecosystem-based governance, followed by the Integrated Coastal Area and River Basin Management guidelines (ICARM) (UNEP/MAP/PAP, 1999). The Convention on Biological Diversity (CBD) also played a decisive role, as the ecosystem approach was first introduced in 1995 and formally consolidated in Decision V/6 in 2000 (CBD, 1995; 2000). Subsequent initiatives reinforced this trajectory, including the Brisbane Declaration (2007) on environmental flows, the Aichi Biodiversity Targets (CBD, 2010), the Ridge-to-Reef (GEF, 2004; 2015), the Water–Energy–Food Nexus (Bonn, 2011; Hoff, 2011), and the Manila Declaration (UNEP, 2012), and Delta Alliance Framework for Adaptive Delta Management (2012). The adoption of the Sustainable Development Goals (SDGs) in 2015 created a global normative framework that further legitimized integrative water governance approaches.

The conceptual formulation of the Source-to-Sea approach was led by the Scientific and Technical Advisory Panel (STAP), an independent advisory body established to provide scientific and technical guidance to the Global Environment Facility (GEF). This formulation was consolidated by Granit et al. (2017b), who proposed a framework centered on the management of interconnected flows — water, sediment, pollutants, biota, materials, and ecosystem services — along the source-to-sea *continuum*. This was further operationalized by Mathews et al. (2019) in a six-step guide for implementation. Institutions such as the Swedish Agency for Marine and Water Management (SwAM) in Sweden, as well as declarations like Dushanbe 2018, reflect the growing political uptake of the S2S logic.

Presented as a conceptual and operational innovation, the Source-to-Sea approach is nonetheless grounded in accumulated scientific conceptual, technical, and institutional experience that converges toward a systemic governance model for interlinked flows across land–water–sea interfaces. The timeline shown in Figure 1-1 illustrates this evolutionary trajectory, bringing together key conceptual, normative, and institutional milestones that led to the formulation of the Source-to-Sea approach.



Figure 1-1 - Source-to-sea governance line history

1.3.2 Key Flows: What are they, and how do they propagate?

The conceptual framework of the Source-to-Sea approach is organized around the identification and analysis of key flows that connect segments along the source-to-sea system. Segments refer to the distinct components that connect the terrestrial system (drainage areas) to the open ocean. These flows (water, sediment, pollutants, biota, materials, and ecosystem services) represent interconnected physical, chemical, biological, and ecological processes that sustain and shape the characteristics, functioning, and health of these segments and their associated ecosystems and are influenced and modified by human activities (Granit et al., 2017b).

Changing to these flows can generate environmental, social, and economic benefits or impacts, depending on how they are managed. Understanding these impacts or benefits enables the identification of links between causes and effects, pressures and responses, within a systemic governance logic. To achieve this, these flows must be characterized in terms of their nature, magnitude, and influence on the different segments of the Source-to-Sea system (Granit et al., 2017b; Mathews et al., 2019).

The characteristics of the key flows are:

- Water:

The water flow is the primary vector of connection along the source-to-sea *continuum*, shaping the transport patterns of sediments, nutrients, pollutants, and aquatic organisms (biota). Healthy ecosystems, from headwaters to coastal zones and marine environments, depend on the maintenance of balanced hydrological flows throughout the entire system. Changes in this flow, caused by excessive water withdrawal (abstraction), land use changes, dam construction, or climatic variations, impact habitat integrity and groundwater availability (Galaz & Meacham, 2024; Perumal et al., 2024). Inland and coastal aquifers are affected by both reduced recharge and saline intrusion. Estuaries, wetlands, and agricultural areas near the coast can also experience salinization resulting from decreased freshwater inputs (Bellafiore et al., 2021; Hansen et al., 2023).

These alterations often reduce water residence time in systems and compromise ecological flow. Concepts such as ecological flow, water residence time, and available volume become central to analyzing hydrological impacts and formulating management responses. The water permit, a public policy instrument that regulates water withdrawal, must consider actual water availability and ecological needs to ensure the maintenance of ecosystem services.

Ecological flow corresponds to the minimum flow required to ensure the environmental functions of river systems (Michels-Brito, 2018), while residence time represents the average time a water molecule remains in a given compartment of the hydrological cycle. A long residence time, for example, can intensify water quality degradation processes (Fontes et al., 2009; Lousada & Camacho, 2018). These impacts reverberate through other key flows. Therefore, more than understanding what water transports, it is essential to recognize it as a structuring element of terrestrial and marine ecosystems (Mathews et al., 2019).

- Sediments

Sediments result from the erosion process and are transported and deposited by water along rivers all the way to the sea (Ripl, 2010). Although these processes occur throughout the hydrographic network, the headwaters tend to generate most of the sediment, while the lower reaches function as storage and runoff areas (Granit et al., 2017b). Sediment production is influenced by factors such as climate, relief, rock type, vegetation cover, and basin size. These flows are essential to maintain river morphology, the fertility of floodplains, and the integrity of the coastal zones (Forsberg et al., 2017; Granit et al., 2017b; Latrubesse et al., 2017). Thus, they connect upstream and downstream environments, shaping ecological and physicochemical dynamics along the hydrological *continuum* (Sklar & Browder, 1998; Forsberg et al., 2017; Wang et al., 2021).

Changes in sediment flow resulting from activities such as deforestation, agricultural practices, infrastructure projects, or dam construction can disrupt sediment supply downstream, causing siltation in some stretches and erosion in others, compromising habitats and species breeding grounds (Latrubesse et al., 2017; Nones & Guo, 2023). For example, impoundment of sediments by dams, the acceleration of erosion in degraded areas, increases deposition, generates serious imbalances, including bank erosion, floodplain collapse, loss of upstream-downstream connectivity, and reduced amount of sediment reaching the ocean (Latrubesse et al., 2017; Walling, 2006; Walling & Fang, 2003). This can lead to delta submergence, saline intrusion, and loss of coastal and marine habitats (Sklar & Browder, 1998; Syvitski et al., 2009; Walling & Fang, 2003). Conversely, excessive sediment loads can harm sensitive ecosystems, such as coral reefs and seagrass beds, by causing turbidity and excessive sedimentation (Granit et al., 2017b; Huang et al., 2021; Souter et al., 2021).

When contaminated by industrial pollutants, mining, urban waste, or agricultural effluents, sediments can transport toxic compounds throughout the system to coastal and marine areas, where they can be redistributed by ocean currents and compromise environmental quality in regions distant from the source (Bełdowska et al., 2021; Dendievel et al., 2022; Souter et al., 2021). These contaminants can remain active for decades, being continuously remobilized and reintroduced into aquatic and trophic systems (Dendievel et al., 2022). Like water, sediments are an essential vector of ecological connectivity, and their integrated management is essential for the resilience of river and coastal systems (Granit et al., 2017a; Mathews et al., 2019).

- **Biota**

Biota flow refers to the movement and connectivity of organisms along river, coastal, and marine systems, including species migrations, their ecological interactions, and dispersal processes (Granit et al., 2017a). This flow occurs upstream to downstream and in the reverse direction (Brink et al., 2018), as in the case of migratory species that move from the river mouth to areas further upstream or to the headwaters (e.g. Barthem et al. (2017) - large catfish in the Amazon Basin) in search of breeding habitats, using rivers as true ecological highways in different phases of their life cycles (Brink et al., 2018; Gough et al., 2012).

Longitudinal (upstream–downstream or downstream–upstream), lateral (rivers–floodplains), and vertical (surface–subsurface) connectivity is essential for species migration and for maintaining biodiversity, genetic connectivity, and trophic networks (Fritz et al., 2018; Zorn et al., 2020). Physical barriers such as dams, waterways or poorly planned infrastructure can interrupt these flows, isolating populations, reducing ecosystem resilience and compromising activities that depend on biota, such as fisheries productivity and food security, among others (Barbarossa et al., 2020; Forsberg et al., 2017; Grill et al., 2019).

Furthermore, changes in other flows, such as water, sediments and pollutants, directly affect the quality and availability of habitats essential to the biota (Granit et al., 2017b), including the natural formation and preservation of reefs, the biogeochemical balance and associated ecosystem services, such as fisheries, carbon sequestration and organic matter filtration (Dagg et al., 2004; Molinier et al., 1996).

The reduction of ecological flow or the deposition of fine sediments in spawning zones can drastically reduce the reproductive success of migratory species. On the other

hand, the introduction of invasive species, often facilitated by anthropogenic modifications in water flow and quality, or through ballast water discharge from ships (Teles & Saito, 2009), poses an additional threat to native biodiversity (Granit et al., 2017b). Biota not only serves as an indicator of ecosystem health but also functions as an active flow that plays a key role in shaping the physical environment and maintaining ecological networks.

- Materials

Material flows refer to the movement and transformation of solid and dissolved materials along river, estuarine, coastal, and marine systems, from their origins on land to the oceanic zones. These flows are driven by natural processes but are strongly intensified by human development and infrastructure activities, affecting geomorphology, biodiversity, and environmental quality (Granit et al., 2017a).

Constructions such as dams, culverts, bridges, and embankments, along with wetland drainage and bank hardening in riverine and riparian environments, can alter natural flow and sedimentation patterns, disconnecting habitats and compromising hydrological resilience. Growing urbanization, industrial development, increased river and maritime transport (including docks, ports, bridges, tunnels, and channel alterations), as well as offshore infrastructure (wind farms, oil platforms, cables, and subsea pipelines), also intensify this flow and worsen the impacts on other key flows (Granit et al., 2017b; Mathews et al, 2019; Wright & Thom, 2023).

Therefore, material flows must be understood as fundamental components of the structure and functioning of ecosystems along the source-to-sea *continuum*. Human interventions such as development projects should not be viewed in isolation, as they directly influence other essential flows.

- Pollutants

It refers to the transport and dispersion of pollutants along the source-to-sea *continuum*, impacting ecosystems, biodiversity, and human health. Pollutants can be defined by their physical and chemical properties, such as nutrients, inorganic chemicals, pathogens, and suspended solids, that influence the structure and functioning of freshwater and marine ecosystems. While some pollutants may originate from natural processes, such as volcanic eruptions, most result from human activities that overwhelm the regenerative capacity of natural systems (Baum et al., 2013; Corcoran et al., 2011). Once released, pollutants are transported downstream and may accumulate or disperse depend-

ing on hydrological and oceanographic conditions (Martinez et al., 2009; Pichel et al., 2007). In the source-to-sea systems, contaminants typically enter aquatic environments through point sources, such as industrial effluents and wastewater treatment plants, as well as non-point (diffuse) sources, including agricultural and urban runoff, atmospheric deposition, and polluted sediments (Corcoran et al., 2011; Liss Lymer et al., 2018; Wright et al., 2023).

The impacts are multiple and interconnected. Contamination by heavy metals, pesticides, and pharmaceuticals, and other environmentally persistent contaminants affects organisms and can accumulate in the food chain (Madesh et al., 2024; Rachel Carson, 1962). Eutrophication, driven by excessive nutrients such as nitrogen and phosphorus, promotes the proliferation of harmful algal blooms, oxygen depletion, and the expansion of hypoxic and anoxic zones (Conley et al., 2009). Excessive sediment deposition contributes to siltation, altering aquatic habitats and degrading water quality (Liss Lymer et al., 2018). Ocean acidification, caused by increased dissolved carbon dioxide (CO₂), impacts coral reefs and calcifying organisms, threatening the stability of marine ecosystems (Sunda & Cai, 2012; Huang et al., 2021).

In addition, specific groups of concern, such as Persistent Organic Pollutants (POPs) and microplastics, are highly mobile and transported over long distances by river and ocean currents. They can remain suspended in the water column or accumulate in sediments, extending their impacts across local, regional, and global scales (Rech et al., 2014; Huang et al., 2021).

- Ecosystem services

Ecosystem service flows refer to the conditions or processes of ecosystems that contribute, actively or passively, to human well-being. They represent a significant portion of the planet's total economic value, providing both direct benefits and mitigating environmental impacts. In the source-to-sea system, these services are generated in provision areas and transferred to benefit areas through biophysical or anthropogenic processes. This spatial and temporal connection allows ecosystems to contribute to environmental regulation and resource provision across the *continuum* (Mathews et al., 2019; Zagallo et al., 2017).

It can be classified into four categories (Granit et al., 2017b):

- Provisioning services: water supply for domestic consumption, food production, energy, and industrial use.

- Regulatory services: flood, drought, and disease control, water purification, climate regulation, and navigation support.
- Cultural services: spiritual, symbolic, educational, and recreational values.
- Supportive services: habitat maintenance, nutrient dispersal, and organic matter recycling.

In addition to their direct benefits, these services play a fundamental role in reducing harmful flows by functioning as natural mechanisms for absorbing and protecting against extreme events.

However, changes in the key flows intensified by climate change and human actions compromise the ability of ecosystems to continue providing these services.

The Source-to-Sea approach recognizes that key flows move through a continuous and interdependent system, shaped by both natural factors and human activities. Although the conceptual foundations of the approach (Mathews et al., 2019; Granit et al., 2017a) primarily emphasize the connection between upstream and downstream segments, they also highlight the importance of adapting flow analysis to the specific characteristics of each territory. Based on this methodological flexibility and the theoretical refinement proposed by Michels-Brito et al. (2024) through the Source-to-Sea Landscape concept, developed throughout this research, the analytical typology of flow propagation directions and their respective impacts is expanded.

This systematization aims to demonstrate that flows are not limited to a linear trajectory of rivers to the sea. They are distributed in multiple directions: laterally, vertically, and even in an opposite direction, as occurs in atmospheric flows (e.g., flying rivers) or feedback effects from the ocean (as saline intrusion). Recognizing these directionalities allows for a broader and more accurate understanding of how environmental impacts manifest, supporting the diagnosis of pressures and the planning of actions throughout the hydrosocial system. In the S2S context, flows interact in complex ways with the landscape. Understanding these directions is important for identifying the points of interference from human actions and their effects on ecosystems and their associated social and economic dynamics. There are:

- Longitudinal (Upstream → Downstream): Refers to the natural path of water and everything it transports, such as nutrients, sediments, pollutants, organisms (biota), and materials. Interventions like dams or intense water withdrawals can fragment this flow, generating cumulative effects throughout the system all the way to the sea.

- Lateral (Channel ↔ Riparian Zone): Refers to the lateral exchanges between the main river course and adjacent environments, such as floodplains, tributaries, and seasonally inundated forests. These lateral flows are essential for soil fertilization, biodiversity maintenance, water quality, and biological productivity, especially during flood periods.
- Reverse or Atmospheric (Downstream → Upstream): This encompasses flows that move in the opposite direction to the river's natural course, including atmospheric, oceanic, and biological dimensions. On the atmospheric scale, atmospheric rivers stand out as narrow, elongated corridors of concentrated water vapor that transport large volumes of moisture from tropical regions to mid- and high latitudes. On the oceanic scale, reverse flow includes processes such as saltwater intrusion, in which seawater advances into freshwater systems, affecting water quality and coastal and estuarine ecosystems, especially in contexts of sea level rise or reduced river flow. In the biological dimension, the migration of estuarine and marine species toward the interior of the basin stands out, a flow essential to ecological connectivity and reproductive cycles.

1.3.3 The S2S Framework: Six Steps for Action

The Source-to-Sea Approach is structured into six steps (Figure 1-1) that guide the analysis and planning of connections between different segments and sectors along the S2S *continuum*. Its central objective is to identify and prioritize the main challenges to be addressed in the system, with the goal of designing initiatives that support healthy ecosystems and sustainable green and blue economies.

The process begins with identifying the pressures and drivers that influence key flows. From there, the appropriate scale of intervention is defined, promoting the engagement of both upstream and downstream stakeholders and developing a deep understanding of the institutional and governance context. These elements provide the basis for formulating a theory of change, which guides the planning and implementation of actions.

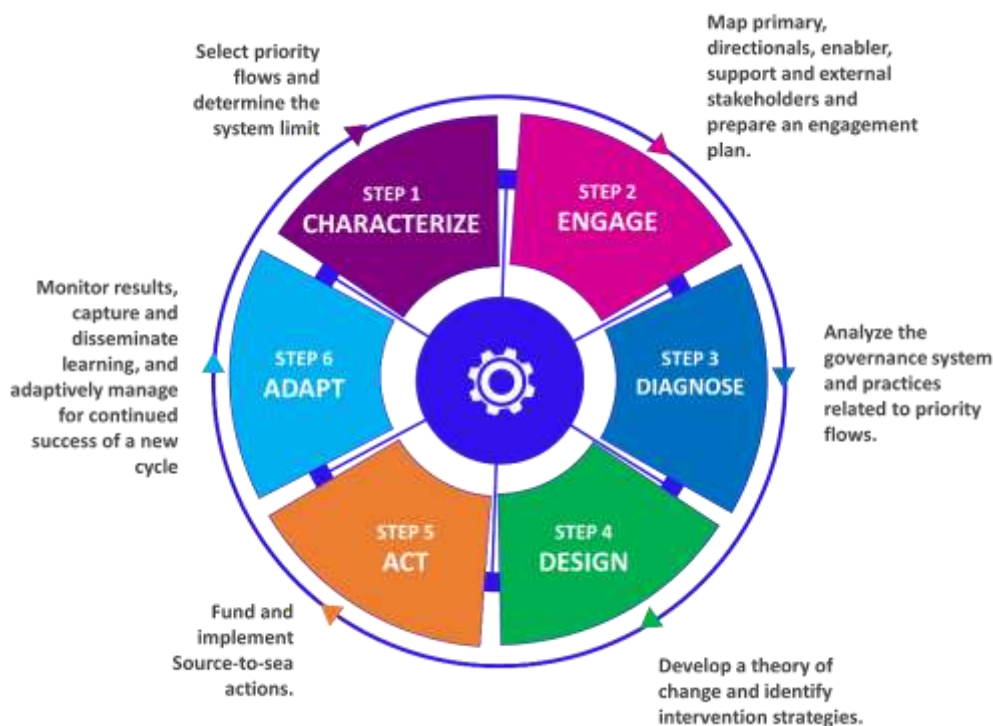


Figure 1-2 Six steps of the S2S Approach

Continuous monitoring and adaptive management allow planning and actions to be reviewed and adjusted as new data or changes in the system emerge, ensuring consistent progress toward desired results. The steps do not necessarily follow a linear. They are iterative and can be revisited and overlapped throughout the process, depending on the complexity and dynamics of the S2S system, enabling continuous learning and adaptation.

These steps are (Mathews et al., 2019):

- Step 1 – Characterize:

This step involves identifying and prioritizing the key flows to be addressed. Characterizing the system requires considering the interconnection of these flows along the *continuum* and identifying specific systemic segments and issues (Granit et al., 2017b). Key flows should be prioritized based on their relative significance, that is, those most affected or that exert the greatest influence on the others, and thus defined as the focus of analysis and subsequent action.

The selection and prioritization of Key flows is based on their characteristics, the ways in which they have been altered, and the impacts resulting from these alterations. To systematically analyze these cause-and-effect relationships, the S2S approach applied the DPSIR (Drivers–Pressures–State–Impact–Responses) framework, originally proposed by

the European Environmental Agency (EEA) in the 1990s (EEA, 2003; Nixon et al., 2003). This framework was successfully applied in GEF case studies (Granit et al., 2016; 2017a) that underpinned the S2S approach. The DPSIR framework formalizes the causal relationships between human activities and the environment, organizing environmental management into a cycle of five interconnected steps (Giupponi, 2002).

The approach recommends adapting well-established analytical tools whenever they prove effective in identifying causes, impacts, and responses associated with changes in key flows. The rationale is straightforward: if tools already exist and work, they should be used and, where necessary, complemented or expanded, rather than creating new methods merely for the sake of novelty, as the example above illustrates. These tools can also be applied across different stages of the process whenever appropriate, enhancing diagnostic capacity and contributing to more targeted and evidence-based interventions.

Once the priority flows have been defined, the next step is to define the system and the appropriate scale of analysis. This definition should consider the identified impacts, their locations, the activities causing them, and the geographic scope required for intervention. The appropriate scale may vary from segment to segment, and in some cases, connections extend globally, for example, due to the effects of climate change.

Choosing the scale of intervention is a strategic step. As noted by Steinke et al. (2022), scale is a decisive factor, especially in the management of transboundary river basins. In the source-to-sea approach, the definition of the system boundary depends on the selected flows, the alterations they have undergone, the resulting impacts, and the activities driving those changes. The starting point for analysis may therefore be where the problem was first identified, for example, within a specific river basin and its downstream receiving water body, from which the affected flows can be traced throughout the *continuum* (Mathews et al., 2019).

Thus, it is important to emphasize that management actions must be considered on multiple scales. Local interventions are essential and should serve as the starting point, but they often need to be expanded. Intersectoral, national, or international cooperation may be necessary to coordinate, monitor, and achieve shared goals. When the geographic area considered in planning is too limited, there is a risk of overlooking indirect or remote impacts. On the other hand, as the scale increases, so does complexity, requiring strategic prioritization of problems and clarity about which flows should be addressed as a priority (Giupponi, 2002).

- Step 2 – Engage:

This step focuses on identifying and mapping key stakeholders and developing an engagement plan. It is a strategic step to build partnerships and ensure the involvement of all relevant stakeholders in S2S management. By bringing together different perspectives, new insights, and opportunities, solutions can emerge. It is important that stakeholders recognize the benefits of engagement, as their participation can lead to improvements in environmental quality, public health, cost efficiency, and increased economic potential for adjacent sectors. It can also generate reputational gains for sectors or municipalities and lead to better decisions through the inclusive representation of marginalized groups.

The main types of stakeholders are:

- Primary (affected): individuals or groups directly impacted by changes in key flows and who stand to benefit from intervention strategies.
- Target (causing impacts): actors or sectors whose practices contribute to changes in key flows and whose behavior is the focus of change strategies.
- Enablers (regulatory institutions): institutions such as ministries, municipal governments, user associations, and certification systems, whose mandates relate to key flows and who hold responsibility for their management.
- Supporters (funders/partners): development partners or funders whose strategies aligned with the expected outcomes and who can provide financial or strategic support.
- External (indirect interest): individuals or groups outside the system boundary, but who share an interest in the results of the project or program.

The engagement process requires a clear understanding of social and sectoral dynamics, the different positions and interests at play, and the power relations among those involved. It must also be adaptable and sensitive to the local context. An engagement plan tailored to each group is developed, focusing on promoting behavioral changes among target stakeholders and creating enabling conditions.

- Step 3 – Diagnose:

The main objective is to analyze the governance system and the practices related to the key flows identified in the previous steps. The success of this approach depends on creating enabling conditions that support the adoption of practices that contribute to achieving the objectives of the project or program. For this reason, it is essential to identify gaps in the existing governance framework and in the practices that affect these flows.

Legal gaps, institutional conflicts, coordination failures, and informal actors with influence must be identified. The aim is to build a narrative, a governance baseline, that provides for a common understanding of the strengths and weaknesses of the current situation and serves as a basis for identifying necessary changes.

The analysis should consider institutions with mandates related to land use (urban, rural, coastal), freshwater management (surface and groundwater, both quantity and quality), natural resource use (agriculture, forestry, mining, fisheries), environmental protection and development policies (economic, energy, transportation), as well as policies, procedures, and regulations within and across the *S2S continuum*. This includes institutions and agreements at the local, national, regional, and global levels, as well as water user groups and resource management agreements at the community level.

Governance system analysis should identify policies, procedures, and regulations with conflicting objectives or that transfer impacts from one segment to another. It is important to assess whether institutions with different mandates are collaborating effectively to achieve common goals or are in conflict, and whether existing policies, procedures, or regulations support S2S management and are being effectively implemented.

This analysis should go beyond government institutions and include other actors who can influence practices, such as the private sector, international standards systems, research institutes, Non-Governmental Organizations (NGOs), and civil society groups. These actors can complement or fill gaps in formal governance systems.

- Step 4 – Design:

At this step, a Theory of Change (ToC) is developed, and intervention strategies are defined. A well-designed ToC serves as the foundation for robust project and program design, implementation, and adaptive management. It describes the expected cause-and-effect relationships between project/program activities and the desired outcomes.

According to Weiss (1995), ToC is a theory of how and why an initiative works. Stein and Valters (2012) further emphasize that it can be understood as a way of describing a set of assumptions that explain both the mini-steps that lead to a long-term goal and the connections between activities and the outcomes of an intervention or program. In this sense, a ToC can be defined in terms of the connection between actions and outcomes, where the articulation of this connection is the key component of the process. It includes both explicit and implicit theories about how and why the program will work (reflecting beliefs and assumptions about change).

To outline the outcomes that lead to long-term impact, the ToC follows a framework of four "Orders of Outcomes" (Figure 1-3) (Olsen, 2003c; UNEP/GPA, 2006). It outlines four progressive levels of response to a S2S program, reflecting changes in social, economic, and environmental conditions, toward the ultimate goal of sustainable forms of development. One of the key aims of applying the Orders of Outcomes is to strike a balance between assessing the management process and validating the effectiveness of its results.

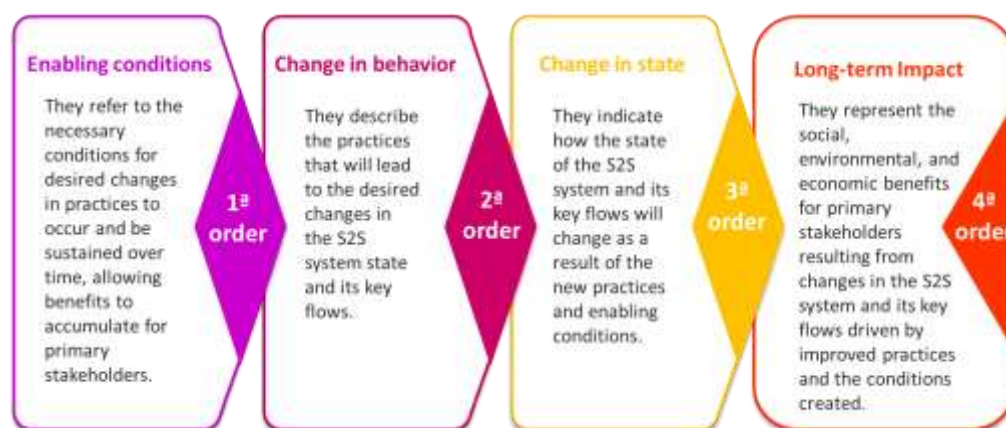


Figure 1-3 The four Orders of Outcome

Intervention strategies are the project/program activities or components most likely to drive transformations across outcome orders. They may focus on a single outcome order, but must be articulated in an integrated plan that leads to the desired long-term impact.

- **Step 5 – Act:**

In this step, the financing strategy and implementation plan are developed, with actions aligned to the ToC's orders of outcomes. The success of S2S management depends on resource mobilization and effective coordination between stakeholders and sectors across the *continuum*.

Funding for interventions can come from multiple sources, including the public sector, bilateral and multilateral donors, the private sector, and philanthropic organizations. The S2S approach can also attract new stakeholders interested in the results, such as upstream and downstream beneficiaries, sectoral groups, and development partners with an intersectoral scope or expanded scale.

For example, alternatives such as integrating S2S priorities into public action plans and budgets can be an effective way to leverage resources; multisectoral engagement

expands opportunities for integration and co-financing; and combining public and donor financing with mechanisms such as Payment for Ecosystem Services (PES), Public-Private Partnerships (PPPs), or green bonds strengthens strategic viability.

The implementation plan defines the specific activities for each intervention strategy, the roles and responsibilities of each stakeholder (identified in Step 2), and a structured timeline for implementing and monitoring the actions. The focus should be on building strong partnerships and strengthening institutional and individual capacities, ensuring the connection between activities, impacts, and results.

The approach is cyclical and adaptive by nature, based on continuous learning, which allows for reviewing strategies, selecting new key flows, and adjusting actions as results are monitored.

- Step 6 – Adapt:

This final step focuses on monitoring results, capturing and sharing the lessons learned, and continuously adjusting intervention strategies based on new evidence. Given the complexity of interactions along the S2S *continuum*, the effects of actions in one segment on another are not always fully understood at the outset. Therefore, this phase seeks to sustain progress through strategic monitoring, critical evaluation, and adaptive management.

Selecting indicators is essential to validate the assumptions underlying the ToC and to provide stakeholders with a clear understanding of the impacts generated. Indicators should cover the four orders of outcomes, starting with process indicators, which assess whether the enabling conditions necessary for change have been established. Stress reduction indicators track shifts in practices adopted by target stakeholders, reflecting behavioral changes that reduce pressure on the system. Environmental state indicators measure changes in the condition of key flows and the overall S2S system. Finally, impact indicators capture progress toward the long-term social, environmental, and economic benefits.

Additional indicators should evaluate the extent to which the approach has been adopted by different stakeholders, including its incorporation into public policies, regulations, funding strategies, research agendas, or formal governance mechanisms.

Monitoring results feed into iterative learning cycles, allowing for strategy adjustments in response to unexpected outcomes, the reassessment of assumptions about the system, stakeholders, and practices, and the refinement of the scale of intervention as ac-

cumulated knowledge strengthens engagement and facilitates the expansion of the approach.

Finally, documenting and sharing results with stakeholders and the broader community is essential. Supporting partners and external stakeholders play a key role in communicating lessons learned and disseminating outcomes globally.

1.4 Methodological Strategy

This thesis adopts a qualitative, interdisciplinary, analytical-deductive, and critical methodological approach, with an ethical and reflective role in the knowledge-building process oriented toward the conceptual, normative, and institutional analysis of the Source-to-Sea (S2S) approach within the field of governance of interconnected socio-ecological systems. The methodological choice stems directly from the research objective, which is to critically examine the foundations, limitations, and innovative potential of the S2S approach in light of the persistent fragmentation in the governance and management of water resources and associated territories.

The qualitative approach is well-suited to investigating complex phenomena, such as those involving the formulation and implementation of integrated environmental governance approaches, precisely because it allows for the understanding of the meanings, values, processes, and contradictions that permeate normative and institutional structures. As noted by Lacey and Luff (2007), qualitative methods enable an in-depth analysis of experiences, discourses, and interactions in their specific contexts, capturing subjective and contextual dimensions essential to understanding dynamic and multifaceted phenomena.

Interdisciplinarity is understood as integration, not juxtaposition. Integration permeates all analysis and interpretation, involving the articulation of knowledge from different disciplines to create new knowledge. It emphasizes the need for a common terminology and operational mode of integration from the outset (Tress et al., 2005).

The Analytical-deductive approach is the methodology that consists of two integrated moves. First, analytical preparation involves systematically decomposing, classifying, and synthesizing the body of documents (laws, policies, plans, and case materials) to surface categories and propositions through structured textual and comparative analysis. Second, deductive application utilizes general principles and frameworks, such as Source-to-Sea, multi-level water governance, and landscape principles, as premises from which case-specific expectations are

derived and then checked for logical entailment, mismatch, or contradiction in the evidence. This sequenced logic follows the Cartesian precepts of analysis, synthesis, enumeration, and completeness, understanding deduction as reasoning from general premises to particular conclusions, thereby ensuring a transparent chain between theory and findings (Descartes, 1637/2008; Teixeira et al., 2014).

The critical dimension of the methodology is committed to problematizing the power structures, epistemological gaps, and institutional fragmentation that undermine the effectiveness of water resource governance approaches, seeking not only to interpret but also to contribute to their transformation.

The researcher assumes an ethical and reflective role in the knowledge-building process, acting as a critical interpreter of institutional messages, norms, guidelines, and practices. This process requires methodological rigor, which manifests itself both in the definition of analytical categories and in the construction of comparative matrices and inferences (Richardson, 2012). Furthermore, qualitative analysis is an iterative process: data collection and analysis often occur simultaneously, allowing new insights to guide the direction of the research.

In this sense, the thesis adopts a philosophical framework based on Greene (2006, 2008), which structures methodological reflection into four interrelated domains: ontological and epistemological assumptions; research logics; practical research guidelines; and sociopolitical commitments. This framework broadens and supports the critical perspective adopted, allowing for the integration of technical research aspects while also critically reflecting on the role of scientific research in transforming governance models and addressing structural challenges related to sustainability and territorial integration.

It is important to distinguish between methodological strategy and research techniques. In this thesis, the overarching strategy is qualitative and analytical-deductive in nature, guiding the research from conceptual and theoretical foundations toward empirical interpretation (Ritchie & Spencer, 1994; Lacey & Luff, 2007; Pickering & Byrne, 2014; Richardson, 2012). Within this framework, specific techniques were employed to operationalize the investigation, including a systematic literature review (Onwuegbuzie & Frels, 2016), content analysis (Bardin, 1979), thematic categorization (Richardson, 2012), and the construction of analytical matrices inspired by Leopold et al. (1971). These techniques were selected and adapted to meet the specific objectives and empirical bases of each article, ensuring analytical consistency throughout the thesis.

In light of the central question guiding this investigation—Does the Source-to-Sea (S2S) approach represent a substantive innovation capable of overcoming fragmentation in the gov-

ernance of interconnected socio-ecological systems, or does it merely reorganize principles already present in earlier integrative approaches under a new formulation?—It was necessary to adopt an exploratory, cumulative, and adaptive investigative strategy that would allow to trace the emergence of conceptual, normative, and operational gaps throughout the analytical process.

In this process, the hypothesis guiding this research—that the S2S approach has the potential to offer a conceptual and operational advance over previous approaches, but still presents critical limitations, especially regarding the articulation between socio-ecological systems and governance scales —revealed the need to incorporate the landscape dimension as a key analytical lens for understanding and integrating flows, territories, and normative instruments. Among the identified gaps, the absence of a more robust territorial dimension within the S2S Approach stood out, which led to the critical incorporation of the notion of landscape as a structuring element of the analysis. In this context, landscape came to be conceived not merely as a descriptive concept but as an analytical category capable of articulating ecological systems, spatial processes, and institutional structures, including the biophysical, social, cultural, and economic dimensions that shape interconnected territories along the land-water *continuum*.

The notion of landscape adopted in this research dialogues with geographic and ecological traditions (Troll, 1971; Zonneveld, 1990; Antrop, 2000; Wu, 2008), but proposes to move beyond them through a hybrid and integrative perspective (Paquette et al., 2005; Saito, 2022), which recognizes the landscape as a hybrid system that articulates natural, cultural, and institutional dimensions. This theoretical orientation proved especially relevant for the development of the S2S Landscape approach, proposed in the second article of the thesis as a conceptual framework that integrates freshwater and marine governance and adjacent territories. This approach also incorporated normative contributions such as the principles and guidelines of the European Landscape Convention (ELC) (Council of Europe, 2000, 2008), and was inspired, among others, by the methodological proposal of Bürgi et al. (2017), which articulates the steps “understand, explore, design and transform” as a basis for governance actions in complex landscapes.

To support this trajectory, the thesis was structured around three scientific articles, which serve as complementary and interdependent pillars of research. Each article has its own specific scope, methodological approach, and distinct empirical basis, understood here as the set of evidence, sources, and analytical strategies employed in each study. The Figure 1-4 provides a

visual synthesis of the research structure and conceptual articulation developed throughout the investigation.

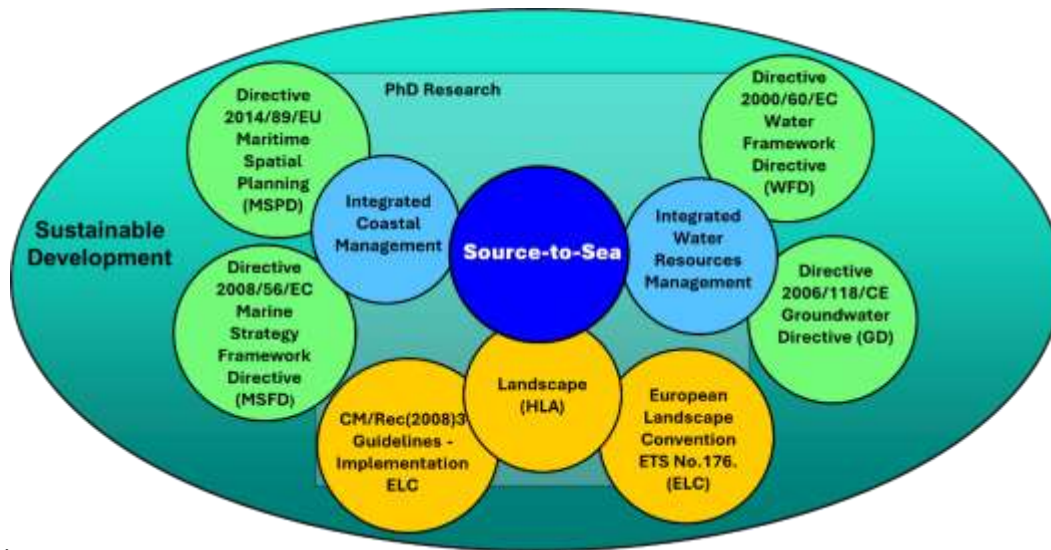


Figure 1-4 General structure of the thesis and conceptual articulation.

As the research progressed, the methodological approach evolved beyond an initial conceptual comparative diagnosis of existing Integrated water governance and management frameworks. It advanced toward a landscape-based theoretical and analytical framework - the S2S Landscape approach, designed to bridge freshwater and marine governance and management along the land-ocean *continuum*. This evolution culminated in its normative assessment within the European regulatory context. This trajectory is reflected in the structure of the thesis: Article 1 provides the conceptual diagnosis, Article 2 formulates the theoretical and analytical proposition, and Article 3 explores its normative applicability within the European regulatory context.

The following presents the specific methodological designs of each article, including their respective development phases, analytical strategies, and their alignment with the overall objectives of the thesis. In addition to the three core articles, a final chapter was dedicated to an integrative analysis of the contributions produced, seeking to highlight the connections among the studies, their analytical convergences, and normative implications, expanding the understanding of the limits and potential of the S2S Landscape approach.

The first article employed a qualitative methodological design, based on thematic content analysis (Bardin, 1977), and was supported by a systematic review of academic and technical literature. The objective was to evaluate the conceptual relationships, principles, and applications of the S2S, IWRM, and ICM approaches (Figure 1-5). The analysis was developed in three phases:

(1) Planning and thematic literature review, including the identification of relevant documents and keywords in major databases such as Scopus, Web of Science, and Google Scholar;

(2) Content analysis, based on a floating reading to finally select and exclude documents, which were then analyzed and subjected to element classification, semantic categorization, aiming at identifying core meaning, and the construction of an analytical matrix. The categorization process followed the criteria of exhaustiveness, exclusivity, concreteness, homogeneity, and objectivity (Richardson, 2012);

(3) Validation, refinement, and interpretation of results. At this stage, a complementary literature review was conducted to address gaps, leading to the final categorization matrix, which was inspired by Leopold's matrix (Leopold et al., 1971) and used for data processing and interpretation.

The analytical process allowed for the identification of complementarities, gaps, and theoretical implications between the analyzed approaches.

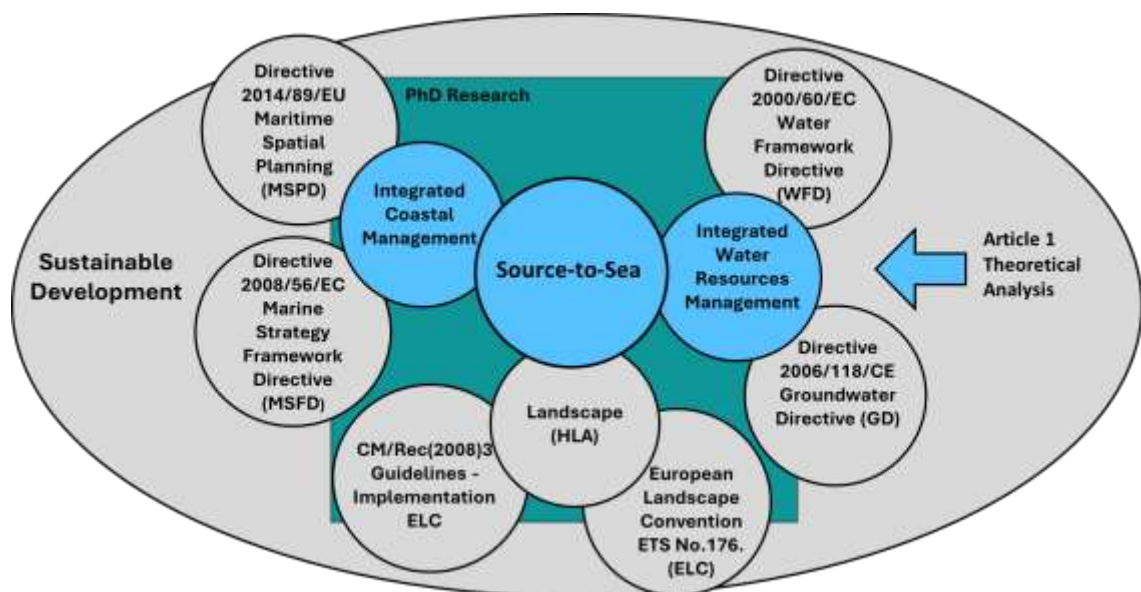


Figure 1-5 Structural synthesis of Article 1

The second article (Figure 1-6) aimed to explore the connections between the S2S approach, landscape-related concepts and approaches, and the European Landscape Convention (ELC), assessing the feasibility of integrating these elements to address the limitations identified in the first article.

The adopted methodology was qualitative, exploratory in nature, and based on an analytical-deductive approach (Lacey & Luff, 2007; Pickering & Byrne, 2014; Ritchie & Spencer, 1994). It was conducted in two main stages, encompassing five methodological phases.

The first stage, focused on conceptual foundations and critical diagnosis, comprised three phases:

1) Phase 1 – problem delimitation, exploratory research and analysis, including mapping of theoretical gaps.

2) Phase 2 – Analysis of the landscape concept, including its historical evolution, holistic nature, and conceptual fragmentations, leading to the adoption of a hybrid landscape view and the identification of the role of the European Landscape Convention.

3) Phase 3 - Critical content analysis (Bardin, 1979), dedicated to exploring the principles and characteristics related to the ELC, the S2S approach, and the Hybrid Landscape approach (HLA), allowing for the classification of levels of adherence and the evaluation of integration feasibility.

The second stage, focused on theoretical integration and methodological structuring, comprised two phases:

1) Phase 4 – Expansion and analytical deepening, aimed at grounding the theoretical integration process.

2) Phase 5 – Methodological integration and systematization process, with classification of methodological elements through floating reading and conceptual analysis, culminating in the structuring of integrated steps that resulted in the methodological proposal for territorial governance and management known as the S2S Landscape approach.

This article marked a turning point by formulating the S2S Landscape approach, which operationalized the thesis hypothesis through an integrated framework capable of connecting ecological and social flows, territories, and governance principles and mechanisms, uniting terrestrial, water, and policy structures.

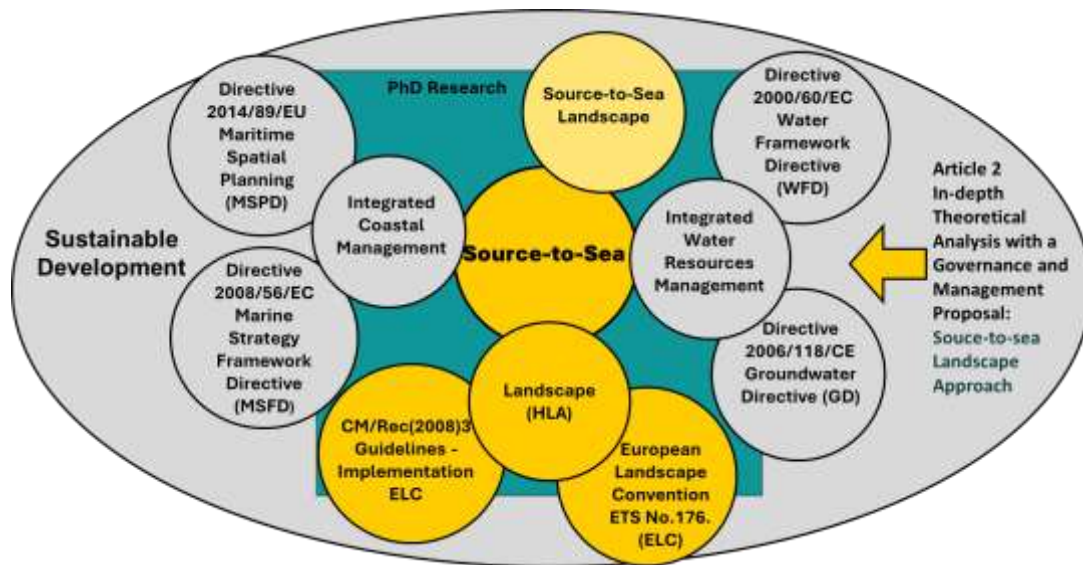


Figure 1-6 Structural synthesis of Article 2

The third article employed a qualitative, analytical-deductive approach (Ritchie & Spencer, 1994; Lacey & Luff, 2007; Richardson, 2012) to assess the normative compatibility of the S2S Landscape approach with key European directives related to freshwater and marine governance. Content analysis (Bardin, 1979) was applied in two stages:

- (1) to interpret the conceptual and political content of these instruments, and
- (2) to define and apply analytical criteria derived from the principles of the S2S Landscape approach.

An analytical matrix inspired by Leopold et al. (1971), along with a complementary comparative matrix, enabled a structured interpretation of regulatory coherence, synergies, and gaps relevant to the institutional applicability of the approach.

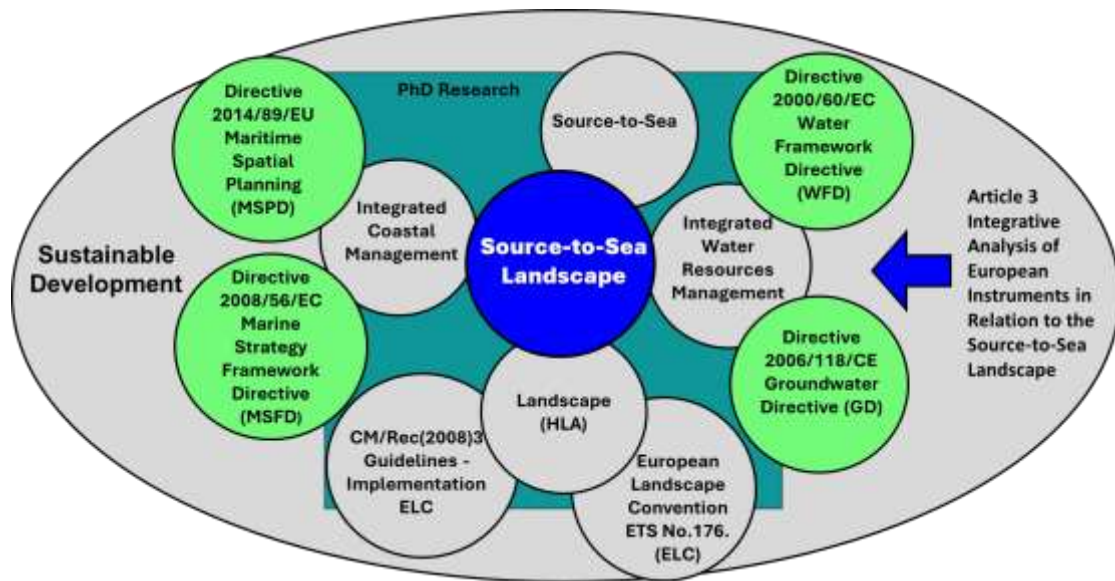


Figure 1-7 Structural synthesis of Article 3

In the following subsections, further details are provided on the specific data collection and analytical methods employed throughout the thesis. These include the content analysis procedures, categorization strategies, the analytical-deductive orientation adopted, and the use of interpretive matrices inspired by Leopold et al. (1971), each of which played a key role in structuring and validating the research findings.

1.4.1 Content Analysis

Content analysis was the central axis of the analytical strategies adopted in this thesis, being consistently applied across the three articles. Grounded in the classic work of Bardin (1979), this technique encompasses a set of systematic and objective procedures for describing the content of messages, aiming to infer both latent and manifest meanings, based on explicit, replicable categorization rules that are subject to intersubjective validation.

The approach followed the thematic-categorical model, articulating three fundamental stages proposed by Bardin: (i) pre-analysis, which involved organizing the corpus with criterios of exhaustiveness, representativeness, homogeneity and pertinence, floating reading, and formulating of reading hypotheses; (ii) material exploration, through coding, segmentation into recording units, and aggregation into categories; and (iii) processing the results through inference and interpretation of the data, focusing on identifying regularities, cores of meaning, and semantic patterns.

This methodological structure enabled the construction of robust analytical categories that were sensitive to the complexity of the examined discourses and their normative and in-

stitutional implications. Content analysis was essential not only for revealing conceptual recurrences but also for supporting the development of the interpretative matrices that guided the three articles and the final chapter, which comprised the thesis.

1.4.2 Categorization and Analytical-Deductive Orientation and Analysis

According to Richardson (2012), categorization is an essential step in qualitative analysis, especially in analytical-deductive strategies. In this process, data are organized based on units of meaning identified in the texts, which are then grouped according to thematic or conceptual criteria. Categorization aims to reduce and structure the empirical material, allowing for the interpretation of patterns, regularities, and relationships.

This approach complements Bardin's (1979) proposal, particularly in terms of coding and grouping recording units, by providing theoretical and operational foundations for defining categories and systematizing inferences. In the context of this thesis, categorization was essential in Articles 1 and 3 to support the construction of analytical matrices and guide the critical interpretation of the discursive and normative content analyzed.

In the second and third articles, the analysis was guided by an analytical-deductive perspective (Descartes, 1637/2008; Teixeira et al., 2014), which consisted of interpreting the documentary and theoretical content in light of previously established conceptual principles - in this case, the foundations of the S2S Landscape approach. This strategy enabled the derivation of analytical categories and the structuring of normative analysis frameworks, such as the comparative matrix used in the third article.

Richardson argues that deductive analysis begins with a clear theoretical framework and seeks to test or apply concepts based on data, in contrast to inductive analysis, which is more open to the emergence of categories during the interpretative process. This model was suitable for the thesis objectives, which aimed to evaluate and operationalize a conceptual proposal (the S2S Landscape) based on a set of institutional documents.

1.4.3 Leopold Matrix as Analytical Structural Reference

The matrix proposed by Leopold et al. (1971) served as a methodological reference in Articles 1 and 3 of the thesis, providing the basis for constructing analytical matrices that compared conceptual approaches (Article 1) and normative evaluations and analysis of regulatory instruments (Article 3). Originally designed to assess environmental impacts by cross-referencing human actions and affected environmental components, its structuring logic was adapted

in the research to organize analytical categories into rows and columns, allowing for a systematic reading of the relationships between analytical criteria and the analyzed content.

In both articles, the matrix served as a systematization and graphical representation tool, allowing for the indication of the presence, absence, or degree of emphasis of key categories in relation to each approach (in Article 1) or each directive (in Article 3). This adaptation expanded the interpretative potential of the analyses by supporting comparisons, identifying gaps and overlaps, and highlighting the coherence or fragmentation between normative and analytical elements.

1.4.4 Final Considerations and Methodological Synthesis

To conclude this section, it is important to highlight how the methodological and analytical trajectory of the thesis converged toward the formulation of the S2S Landscape framework. Based in a qualitative, analytical-deductive, and critical research strategy, the investigation integrated conceptual, normative, and territorial dimensions to address the fragmentation in governance across the land-water *continuum*.

The incorporation of landscape as an analytical and structuring category was essential for bridge ecological systems, spatial processes, and institutional structures. This perspective enabled the articulation of biophysical, social, cultural, and regulatory components that shape interconnected socio-ecological territories.

The figure below (Figure 1-8) presents a visual synthesis of this methodological and conceptual trajectory. It illustrates the interconnection between key European directives, integrated governance models (such as IWRM and ICM), and foundational approaches including the S2S approach. It also integrates landscape-based instruments and concepts (including the European Landscape Convention and the conception of Hybrid Landscape Approach), as well as the main contributions of the doctoral research. This synthesis culminates in the formulation of the S2S Landscape framework as a central outcome of the thesis, aimed at enhancing territorial integration and governance coherence within the broader scope of sustainable development.

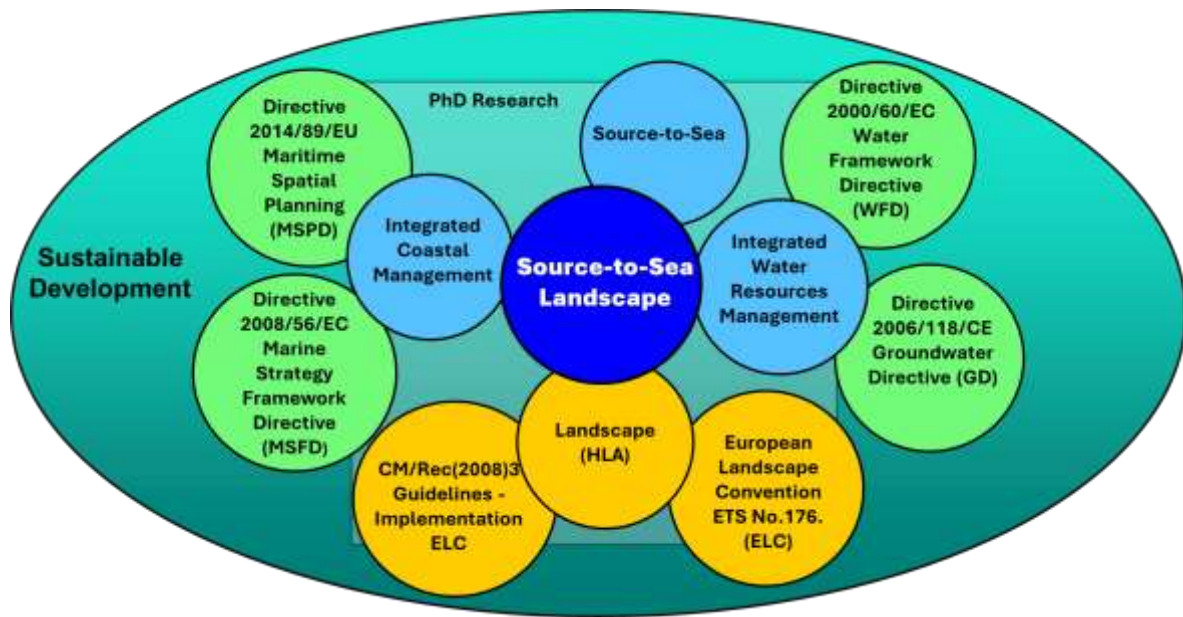


Figure 1-8 Conceptual synthesis of the Source-to-Sea Landscape approach and its normative and analytical articulation.

1.5 Thesis Structure

This thesis is organized into six chapters, structured in a cumulative manner and aligned with the adopted investigative logic. The research trajectory articulates conceptual analysis, theoretical development, and normative application through three scientific articles that form the empirical and analytical core of the dissertation. The introduction, the final integrative analysis, and the conclusion complement this core, providing a general framework, articulating the findings, and projections for future progress.

Chapter 1 - Introduction: Establishes the theoretical, conceptual, and institutional foundations that motivate the thesis, contextualizing the problem of fragmentation in water and territorial governance and the integrative proposal offered by the S2S approach. The chapter formulates the research hypothesis and central question, defines the analytical scope, outlines the research objective, and presents its structure and main contributions. It also presents the overall methodological strategy, which is further developed and operationalized in the articles (Chapters 2, 3, and 4) and in the cross-sectional analysis (Chapter 5). This strategy is anchored in a qualitative, analytical-deductive, and interdisciplinary approach that combines content analysis, thematic categorization, the construction of analytical matrices, and a critical perspective on socioecological governance.

Chapter 2 – Article 1: Conceptual Diagnosis: The first article of the thesis presents a comparative conceptual diagnosis of the S2S, IWRM, and ICM approaches. The objective was to understand the S2S approach and identify its relationships and convergences with these other frameworks, answering the question of whether they are integrative, complementary, or competitive. A qualitative methodological design is adopted, based on thematic content analysis (Bardin, 1979), focusing on identifying the intentions and perceptions associated with the concepts, principles, and dimensions employed by each approach. The analysis is structured through a categorical matrix inspired by Leopold et al. (1971), enabling the systematic organization and interpretation of the analytical criteria. The study identifies convergences, complementarities, and gaps, highlighting the potential contribution of S2S, as well as its limitations regarding the territorial dimension.

Chapter 3 – Article 2: Theoretical and Analytical Proposition. The second article marks a conceptual turning point in the thesis by proposing the Source-to-Sea (S2S) Landscape approach as a response to the limitations of the traditional S2S model and other integrative water and landscape governance frameworks. Based on a qualitative, exploratory, and analytical-deductive strategy, the study integrates elements from the S2S approach with landscape theories, emphasizing the principles of the European Landscape Convention. The analysis unfolds in three main phases: (1) a critical review of the landscape concept and its evolution; (2) an assessment of the compatibility between S2S and landscape-based instruments; and (3) the formulation of a coherent conceptual and operational structure to guide governance along the land-water *continuum*. Through content analysis and conceptual synthesis, the article presents the S2S Landscape approach—an integrated framework grounded in systems thinking, participatory processes, and adaptive management—aimed at connecting biophysical, socio-environmental, and institutional dimensions across the land-sea interface.

Chapter 4 – Article 3: Normative Application of the S2S Landscape Approach. This article applies the Source-to-Sea (S2S) Landscape framework to assess the normative coherence among four key European directives related to freshwater and marine water: the Water Framework Directive (WFD – 2000/60/EC), the Groundwater Directive (GWD – 2006/118/EC), the Marine Strategy Framework Directive (MSFD – 2008/56/EC), and the Maritime Spatial Planning Directive (MSPD – 2014/89/EU). The objective was to evaluate the extent to which these legal instruments align with the principles and operational logic of the S2S Landscape approach, and to identify potential synergies, normative gaps, and areas of convergence. Grounded in a qualitative and analytical-deductive methodology, the study employed normative content analysis (Bardin, 1979), with the construction of a structured set of analytical criteria and subcriteria

based on the core dimensions of the S2S Landscape framework. The research utilized two complementary matrices: an analytical matrix for evaluating directive content and a comparative matrix for identifying cross-directive coherence. This methodological design allowed for a transversal assessment of how each directive supports or constrains integrative governance across the land-sea *continuum*, thereby revealing institutional opportunities and regulatory fragmentation.

Chapter 5 – Cross-analysis and Strategic Synthesis: The fifth chapter consolidates the findings of the three articles through a cross-analysis that deepens the theoretical, analytical, and normative dimensions of the S2S Landscape approach. By integrating the results of the conceptual comparison, the development of the new framework, and its normative application, this chapter articulates a systemic vision of water and landscape governance. It proposes the S2S Landscape as an adaptive, transdisciplinary, and multi-level governance model that overcomes the limitations of previous approaches. The chapter also identifies implementation pathways, highlights institutional and policy innovations, and positions the framework as a strategic contribution to future environmental governance challenges, particularly in the context of the 2030 Agenda and the UN Decade of Ocean Science for Sustainable Development (2021–2030).

1.6 Author's Contribution

Adriane Michels-Brito conducted this research under a co-tutelle agreement between the Faculty of Science and Technology at NOVA University Lisbon (FCT-NOVA) and the Center for Sustainable Development at the University of Brasília (CDS/UnB), supervised by Professor José Carlos Ferreira and Professor Carlos Hiroo Saito.

She was the principal author of all chapters in this dissertation, responsible for formulating the research question, developing the theoretical and methodological approach, and executing all stages of the investigation. This included conducting critical literature reviews, performing a comparative analysis of integrated governance approaches (S2S, IWRM, and ICM), formulating the original Source-to-Sea Landscape (S2S Landscape) approach, and applying it normatively to European freshwater and marine directives.

The researcher developed the analytical matrices, structured the evaluative criteria and sub-criteria based on the proposed approach, conducted the normative content analysis, integrated the findings of the articles into an applied conceptual model, and wrote, revised, and

finalized all dissertation chapters. She also systematized the findings into an analytical structure designed to guide integrated territorial governance along the land–sea *continuum*.

The supervisors provided academic guidance throughout the entire process, contributing with critical review and suggestions during all phases of the work.

The results of this research were presented at more than three international conferences. Additionally, the results led to the publication of two peer-reviewed scientific articles, as well as a third article that is currently undergoing submission and revision for publication. The integrative chapter, which brings together the three articles and analyzes the overall research findings, has been accepted for publication in a book chapter and is now being refined and further developed for final submission.

SOURCE-TO-SEA, INTEGRATED WATER RESOURCES MANAGEMENT, AND INTEGRATED COASTAL MANAGEMENT APPROACHES: INTEGRATIVE, COMPLEMENTARY, OR COMPETING?¹

Abstract

Mitigation, adaptation, environmental protection, and sustainable development on the land and related water bodies are being promoted in a fragmented way. Integrated Water Resources Management and Integrated Coastal Management have been presented as a way to face these problems. The Source-to-sea approach has recently emerged, proposing a new water governance and management framework. This research aimed to understand the Source-to-sea approach and identify its relationships and convergences with the approaches of Integrated Water Resources Management and Integrated Coastal Management, and answer the question of whether they are integrative, complementary, or competitive. Content analysis was used as part of the investigation method so that it was possible to identify the intentions and perceptions of the concepts, principles, and dimensions adopted by each approach. The classification of elements resulted in 8 categories. Based on Leopold's matrix, we created a base

¹ Michels-Brito, A., Ferreira, J. C., & Saito, C. H. (2023). Source-to-sea, integrated water resources management, and integrated coastal management approaches: integrative, complementary, or competing? *Journal of Coastal Conservation*, 27(6), 66. <https://doi.org/10.1007/s11852-023-00999-z>

matrix to analyze the relationships between the approaches. The S2S approach integrates and, at the same time, complements Integrated Water Resources Management and Integrated Coastal Management. For the eight categories, Source-to-sea was fully committed to 6 of them. Integrated Water Resources Management was fully committed to 5 of them. And Integrated Coastal Management was fully committed to only 3 of them. The Source-to-sea approach brings new elements, revitalizes some methods, and strengthens the governance and management structure of freshwater and marine water resources, enabling a new vision in the *continuum* where Integrated Water Resources Management and Integrated Coastal Management are part of the process within a new perspective.

Keywords: Source-to-sea, IWRM, ICM, Sustainability, Governance and management, Key flows

2.1 Introduction

Water is an essential life sustainer on the planet; it is indispensable to life, and in numerous water-dependent processes, a kind of bloodstream of the biosphere (Ripl 2003). It is crucial in the industrial production of goods and services necessary for our daily lives, as well as in the production of food, in social life, and families' daily lives (Falkenmark 1997). Because water is recognized an essential part of the livelihoods, the water right became a central issue, and water security was strongly attached to the human right to water (Saito 2018).

Whether fresh or salty, water is a unique resource, a *continuum* linked by the hydrological cycle that knows no limits, and environmental boundaries cannot contain it. The hydrological cycle is usually understood as a natural and continuous process independent of the presence or absence of human activity (Maidment 1993), and this naturalness of the hydrological cycle is based on the idea of a natural course of water circulation (Horton 1931).

Despite this apparent independence, this cycle can be affected by human activities, damming rivers, withdrawing groundwater, or polluting water bodies, altering the speed of circulation in the hydrological cycle, leading to alteration of coastal and open ocean. Climate change has brought a new nature and magnitude of impacts on water cycle affecting water resources' supply and demand (IPCC 2022; Little et al. 2017; Marengo et al. 2017; Ribeiro Neto et al. 2016; Wilhite et al. 2014). These events draw us into a future scenario with greater water scarcity, where conflicts between water uses become increasingly evident, even in countries with high water availability (Miletto et al. 2017; World Bank and UN-DESA 2017).

The nature of water shows how the management of fresh and saltwater resources is cross-sectoral and linked to many activities and investments in the use of water resources and other sectors. An integrated approach is needed to address these problems and find ways to mitigate, adapt and conserve water resources because water tends to be managed segment by segment or sector by sector. Integrated Water Resources Management (IWRM) and Integrated Coastal Management (ICM) have been presented to find sustainable solutions to these problems. IWRM represents a process promoting the coordinated development and management of water, land, and related resources, increasing economic and equitable social welfare without compromising the sustainability of vital ecosystems (GWP 2000). ICM is a process to maintain or restore ecological integrity and improve quality of life by developing economies in coastal and marine socio-ecological systems (Eger et al. 2021).

2.2 Methods

This research aims to understand the emergence of the Source-to-sea approach and to identify the relationships and convergences with the IWRM and ICM approaches, trying to see if they are integrative, complementary, or competitive.

An issue that permeates the understanding of governance and management approaches is the terminology used. Because there is no general convention, different terms are often used to express the same perception and meanings. Therefore, this requires repeatedly exploring documents, articles, and reports to capture meaning and intent (Monteiro 2020). Depending on how they are placed, meanings vary a lot, demanding interpretation work by the researcher. To face this, content analysis was developed to identify the intentions and perceptions of each approach's concepts, principles, and dimensions. According to Bardin (1977), content analysis is a set of communication analysis techniques aimed at obtaining, through systematic procedures and objectives of the description of the content of messages, quantitative or qualitative indicators that allow the inference of knowledge related to the conditions of communication: production, and reception, of these messages.

Content analysis can help select key issues that can help advance the global debate, analyzing different content of messages, concepts, and knowledge structures and grouping some of them in the same category, even addressed with different names, so that a set of categories is produced.

The research was planned and carried out in 03 stages: Planning and literature review, content analysis, and validation and results.

The first phase: Planning and Literature review. It was the organizational phase consisting of the theme definition, pre-analysis, and selection of documents referring to the three approaches. The defined theme of the study revolved around the innovative Source-to-sea approach. It became clear that knowing if the approach was innovative was important. Therefore, it was deemed crucial to explore its relationship with other pertinent approaches concerning water resources and the coastal zone. Consequently, the research question was formulated to assess and compare the Source-to-sea, IWRM, and ICM approaches and answer if they were integrative, complementary, or competitive. For this, it was necessary to identify documents, articles, and books, among others, that brought concepts, principles, and applications of the three approaches. To proceed with the research, the first keywords were defined, including: "Water resources," "Source-to-sea," "IWRM," "ICM," "Integrated management of water resources," "Integrated management of coastal zones," "Integrated coastal management," "Integrated Coastal planning," and also in a dismembered way such as: "coastal management," "coastal governance" "watershed management." Then, using the "and" operator between them in the search expression, the terms "management," "governance," "concept," "principles," "integration," "implementation," and "practices" were added, among others that emerged as the research progressed due to the high number of documents presented in each research. The process was carried out in 03 steps, each destined to an approach and then the crossing between the steps. For example, in step 1, the search was carried out with the keyword "Source-to-sea," adding the connectors mentioned above. All fields were searched using Scopus, Web of Science, and Google Scholar databases. In this phase, 335 documents were selected.

The Second phase: Content analysis. After a preliminary selection of literature, it was necessary to analyze the elements according to the objectives of this research and classify them. A floating reading of the base of documents selected in the first phase, exclusion and choice of documents. In this phase, 234 documents were removed, and 101 were selected to support the research. The selected documents were submitted to classification of elements, analysis, the definition of categories, and the first version of the matrix were carried out. It's important to emphasize that the analysis occurred in the thematic field. The process of classifying elements according to selected criteria is called categorization (Richardson 2012). To create the categories, which means reducing the text to categories, the texts were cut at a semantic level (unitizing), looking for the core of the meanings. In classifying the categories, an attempt was made to follow the characteristics of exhaustiveness, exclusivity, concreteness, homogeneity, and objectivity (Richardson 2012).

The third phase: validation and results. After a preliminary analysis with an initial set of categories, while the matrix was analyzed, a deeper analysis and complimentary review of the literature was performed to fill in gaps in the preliminary selection of literature. This resulted in the addition of 15 documents, the revision and confirmation of the categories, and adaptation and matrix re-analysis, interpretation, and discussion of the categories.

A matrix containing the final categorization was created based on the Leopold matrix (Leopold et al. 1971) for the treatment and interpretation of the data obtained. The methodological approach applied in this work is represented in Fig. 1. The matrix was used to compare the three approaches (IWRM, ICM, S2S), and it was filled with graphical symbols that could express how each category was considered in each approach based on literature. The discussion section presents the analysis of the matrix results and the theoretical and methodological implications that can guide the understanding, choice, and implementation of these approaches. To start a new chapter, the easiest approach is to duplicate the header of a previous chapter (by copying and then pasting elsewhere) and then replace the text.

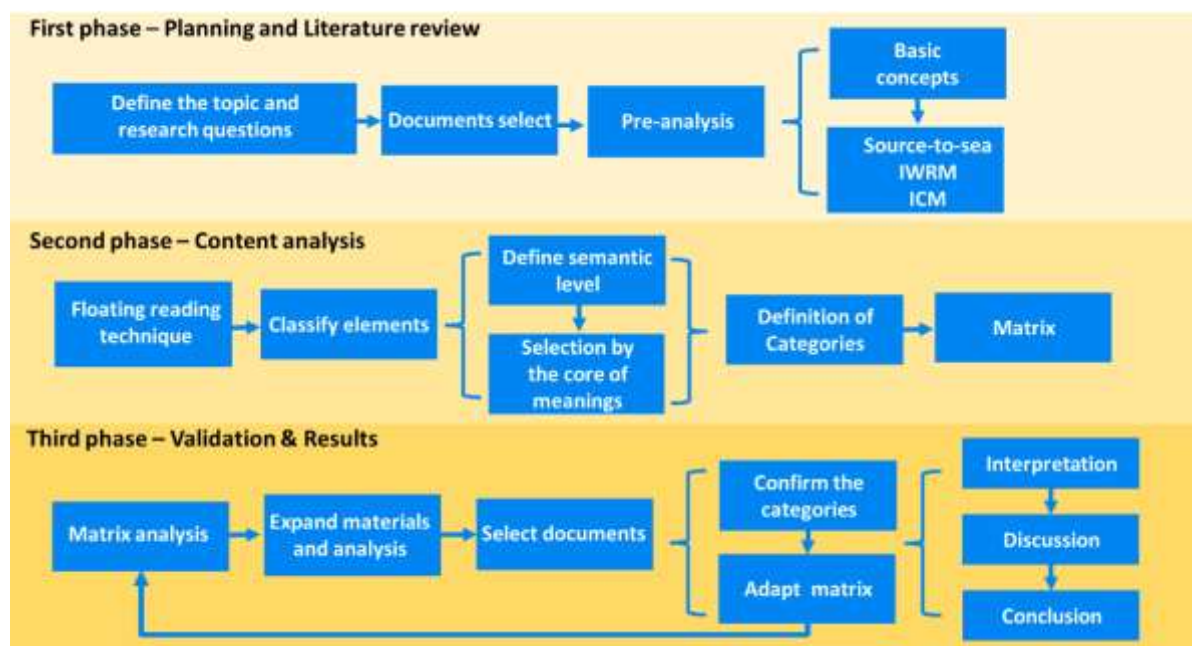


Figure 2-1 - Methodological approach applied in this work

2.3 Results and Discussion

Approaches in a given field encompass principles, guidelines, goals, and objectives with specific focuses that influence the way their structures are proposed. Therefore, it is essential to

analyze and identify how these focuses are addressed in each approach, as well as whether the specificity of one approach is present in others or if they discuss and incorporate such specificity conceptually into their plans. These differences are crucial for the characterization of each approach. The categorization was important to understand these aspects, whether the contributions advance the sustainable use and conservation of water resources and water security or even in which aspects the sole focus is similar or equal concepts and structures but addressed with different names. The results of this categorization originated eight categories: integration, segments, key flows, governance and management, monitoring and evaluation, blue and green economy, gender, and water value. The definitions of each category and the documents used to define and analyze them are presented in Table 2-1. The template defines five text styles:

Table 2-1 - Category Definition

Categories	Definition	References
Integration	The systemic approach, the systems approach, the participatory approach, and the adaptive approach were considered in the category of integration. Regarding the holistic view or holistic approach, it transcends the systemic view and it needs to be further explored as it enters the field of epistemology and ontology of science (e.g., encompassing the issue of spiritual value), and this will not be the subject of this article.	Cicin-Sain et al. 1998; GWP 2000; Hong and Lee 2001; Vörösmarty et al. 2004; Falkenmark 2005; UNEP/GPA 2006; Linton 2008; Rosenberg and Sandifer 2009; UNESCO 2009; Pahl-Wostl et al. 2012; Granit et al. 2014, Granit et al. 2017a; Söderbaum and Granit 2014; Van Beek and Arriens 2014; Varis et al. 2014; Smith and Clausen 2015; Portman 2018; Belete et al. 2021; Eger et al. 2021; Fallon et al. 2022
Segments	Segments are geographical areas that encompass the interfaces of the water bodies and their connections, linking land, freshwater, and saltwater through their interfaces. Segments are divided into: a) Land resources and terrestrial systems, including the river basin; b) Freshwater systems; c) Estuaries/deltas; d) Coastline and Nearshore coast water; e) Adjoining sea and continental shelf; f) Open ocean.	Cicin-Sain et al. 1995; WSSD 2002; Cicin-Sain and Belfiore 2005; Rahaman and Varis 2005; Davis 2007; Savenije and Van der Zaag 2008; Cantasano and Pellicone 2014; Granit et al. 2017a; Godschalk and Burns 2019; Mathews et al. 2019; GWP 2000; Oliveira et al. 2020; SIWI 2020; Rocha Loures 2021; Wang et al. 2021; Weinberg et al. 2021; Eger et al. 2021

Key flows	The core of meaning lies in how the approaches consider the water cycle and how humans interact with nature in this cycle. The socio-ecological nature of water leads to consideration of how water flows interact with other components within the hydrological cycle and how these flows connect different spatial scales, including the ecosystem services that result from this interrelationship.	Schramm 1980; Vannote et al. 1980; Cicin-Sain et al. 1998; Sklar and Browder 1998; GWP 2000; Olsen 2003b; Steffen et al. 2004; Cicin-Sain and Belfiore 2005; Rasch et al. 2005; Sadoff and Muller 2009; Sadoff et al. 2015; Granit et al. 2016, Granit et al. 2017b; Lins-de-Barros 2017; Lu et al. 2018; Jean et al. 2018; Rocha Loures 2021; Broadley et al. 2022
Governance and Management	There is a predominant confusion between governance and management, often leading issues related to governance to be misunderstood and confused with issues related to management. Because of this interplay, they have been grouped together as a single category to make easier the necessary comparison and distinction from each other. It is expected that this clarification could enhance our comprehension of the stages and processes involved in creating an enabling environment and ways of planning and implementing them.	Olsen et al. 1999, Olsen et al. 2011; GWP 2000; Juda and Hennessey 2001; Olsen 2003a; Olsen 2003c; Olsen et al. 2009; Rogers and Hall 2003; Ehler 2003; Rahaman and Varis 2005; Un-Water and GWP 2007; Granit et al. 2014; Varis et al. 2014; Sadoff et al. 2015; Woodhouse and Muller 2017; Mathews et al. 2019; SIWI 2020; Eger et al. 2021; Ferreira et al. 2021
Monitoring and Evaluation	Monitoring and evaluation systems play a crucial role in facilitating decision-making processes. Decision-makers must evaluate the progress of implemented policies, strategies, and initiatives, as well as their impact, to determine if they align with the established objectives. Monitoring and evaluation require effective data collection and a willingness to adapt and adjust plans based on feedback and prognosis.	Weiss 1995; Olsen 2003b; Olsen 2003c; UNEP/GPA 2006; USAID 2009; Stein and Valters 2012; Söderbaum and Granit 2014; Bertule et al. 2017; Granit et al. 2017b; Saito 2019; GWP 2022
Blue and Green Economy	To achieve sustainable development, it is crucial to integrate economic development with effective governance and management procedures to ensure the balance and adequacy of society's economic development to the capabilities of nature. To do that, specific mechanisms and measures, such as the concept of the green and blue economy, are being increasingly incorporated to face the water crisis. The blue economy aims to decouple socio-economic development from environmental degra-	Falkenmark and Rockström 2010; Hoff 2011; UNEP 2011; UNCSD 2012; European Commission 2013; Granit et al. 2017b; World Bank and UN-DESA 2017; UN Environment 2018; Pereira 2020; Lee et al. 2020; Bekmurzaev and Dadaev 2021; Griesinger and Michels-Brito 2022

	ation by valuing and incorporating the true worth of natural resources into economic activities. Similarly, the green economy focuses on improving human well-being, social equity, and reducing environmental risks through sustainable practices.	
Gender	The issues of water care, sustainable development, and gender are intertwined, and it is expected to be addressed in an integrated way. Gender equality is part of the 2030 Agenda for Sustainable Development, and gender concern represents a core value and guiding principle in water issues. Women play a significant role in providing, managing, and protecting water resources, making gender a key analytical category when comparing these three approaches.	GWP 2000; Diamond 2003; Olsen 2003b; Bennett 2005; USAID 2009; Diamond and Lellement 2014; UNGA 2015; Nagel 2015; Berggren and Liss Lymer 2016; Grant 2017; Miletto et al. 2017; Niasse 2017; Tengberg and Valencia 2017; de la Torre-Castro et al. 2017; Pravalprukskul and Resurreccion 2018; Mathews et al. 2019; Water Europe 2019; GWP and UNEP-DHI 2021; Wabnitz et al. 2021
Water Value	Water is a complex resource to replace, a finite resource that demands very careful management. Due to its essentiality for many social, economic and natural processes, the concern of its value emerges and it was listed as one important analytical category for comparison between the three approaches, connecting the hydrological cycle to economic issues because water can be considered an economic good and thus lead to water pricing.	Hardin 1968; UNCED 1992; Rogers et al. 1998; Ostrom et al. 1999; GWP 2000; P7 Summit of the World's Seven Poorest Countries 2000; Savenije and van der Zaag 2002; Bakker 2007; HLPW 2018

The results obtained through the content analysis are represented in the results matrix (Fig. 2). The matrix presents eight categories and the relationships between the approaches within each category, so it was filled in considering the characteristics defined in each category.

For the eight categories, S2S was fully committed to 6 of them (Integration, Segments, Key flows, Governance and Management, Monitoring and Evaluation, Blue and Green Economy, Gender, and Water Value), and it was partially committed to 2 of them (Gender, Water Value). IWRM was fully committed to 5 of them (Integration, Governance and Management, Monitoring and Evaluation, Gender, and Water Value), and it was partially committed to 3 of them (Segments, Key flows, Blue and Green Economy). And ICM was fully committed to only 3 of them (Integration, Governance and Management, Monitoring and Evaluation) and partially committed to the other 5 categories (Segments, Key flows, Blue and Green Economy, Gender, Water Value). The segments category was analyzed as a composed result of its sub-categories,

and only S2S was considered fully committed because it presented this commitment in all its sub-categories representing segments of the water bodies.

CATEGORY		IWRM	ICM	S2S
Integrated approach		●	●	●
Segments	Land resources and terrestrial systems	●	●	●
	Freshwater systems	●	◐	●
	Estuaries/deltas	●	◑	●
	Coastline and Nearshore coast	◑	●	●
	Adjoining sea and continental shelf	◐	●	●
	Open ocean	◐	◐	●
key flows		◑	◑	●
Governance and Management		●	●	●
Monitoring and Evaluation		●	●	●
Blue and Green Economy		◑	◑	●
Gender		●	◑	◑
Water Value		●	◑	◑

Figure 2-2 - Matrix with the results of the 08 categories. The black full circle means that the characteristics are present in the approach, the circle with partial filling is used when the approach has part of the defined characteristics, and the unfilled (empty).

2.3.1 Integration

The integration in the three approaches seeks to apply a systemic vision to deal with water resources. Thus all of them were classified as fully-committed to this category.

For IWRM, integration must occur within and between two categories: the natural system and the human system considering the variability of time and space (GWP 2000). Integration into the natural system is associated with the recognition of the requirements for the coastal

zone and the *continuum* that unites them through the flow of water, and it is concerned with the integration between surface and groundwater, catchment and basin management, water quality and quantity, and upstream and downstream water. Human system integration involves understanding the natural system, its capacity, vulnerability, and limits. This means ensuring that government policies consider the implications for development, risks, and uses of water resources. Intersectoral integration needs an enabling environment: clear institutional roles and functions of the various administrative levels, stakeholders, and management instruments. It also includes ensuring stakeholders' participation in decisions. Thus, considering the system natural and human, the ecosystem approach and participatory approach are included within the concept (UNESCO 2009; Smith and Clausen 2015). IWRM aims the integration and coordination of planning, development, management, and policy formulation in the water and cognate sectors, linking social and economic development with the protection of natural ecosystems (Van Beek and Arriens 2014; Varis et al. 2014).

The integrative approach is also essential for ICM because, in addition to allowing internal consistency between policies and programs, it makes planning associated with the reality of implementation, encompassing for example Marine Protected Areas (MPA) networks, Marine Spatial Planning (MSP), and Integrated Coastal Zone Management (ICZM). Integration in the coastal/marine context considers the dimensions of intersectoral integration (horizontal integration); spatial integration (between the aquatic and terrestrial environment), intragovernmental (vertical integration); and interdisciplinary science and management integration (Cicin-Sain et al. 1998; Hong and Lee 2001; Portman 2018). In the ICM, the cumulative impacts of the relevant activities on the ecosystem and its services become the organizing framework for management. It is intended to directly address the long-term, sustainable delivery of ecosystem services and the resilience of coastal and marine ecosystems to perturbations (Eger et al. 2021; Rosenberg and Sandifer 2009).

The Source-to-sea approach is based on systems thinking to deal with complexity (Granit et al., 2017a). S2S adopts a systemic approach that looks at the water resource through the prism of the water cycle: marine water and fresh water are part of the same *continuum*, of the same cycle, and what happens in this *continuum* (the anthropogenic intervention) impacts this system as a whole (Belete et al. 2021; Falkenmark 2005; Granit et al. 2014; Linton 2008; Vörösmarty et al. 2004). In this way, it adopts ecosystemic, participatory, and adaptive approaches that recognize human beings, with their cultural diversity, are an integral component of many ecosystems. The associated human population and economic/social systems are considered integral parts of the ecosystem (UNEP-GPA 2006). International integration is high-

lighted in diplomatic relations between administrative borders and political processes (Fallon et al., 2022; Pahl-Wostl et al. 2012; Söderbaum and Granit 2014).

The Source-to-Sea (S2S) approach stands out for its comprehensive and integrative perspective compared to the IWRM and ICM approaches. While the other approaches focus on managing water resources in their specific contexts, S2S transcends these boundaries. It seeks to innovate by considering the complete water cycle and its connections across different environments. It adopts a holistic view of the water cycle, considering the interdependence between natural, human, economic, and social systems. The approaches also have a lot in common, such as considering participation and being adaptive, for example. Therefore, even though S2S advances in integration, including the proposal to integrate the two approaches, it should consider the experience that IWRM and ICM have accumulated over time and bring this accumulated knowledge together with its broader vision in negotiations and in diplomatic relations between administrative borders and political processes.

2.3.2 Segments

There are many arguments, proposals, definitions of IWRM and how to implement it, as well as the appropriate scales for intervention. What predominates are approaches at national policy, river basin, and sub-basin levels. It was emphasized at the Johannesburg World Summit on Sustainable Development – WSSD that water should be managed in a basin-wide context, under the principles of good governance and public participation (WSSD 2002). Water resources boundaries rarely coincide with administrative boundaries, whether surface or groundwater. At this point, IWRM emphasizes that legal frameworks need to be conceived from an international level into regional and national levels (Davis 2007; GWP 2000; Rahaman and Varis 2005; Savenije and Van der Zaag 2008; SIWI 2020). Therefore, the main IWRM targeted segments are Land resources and terrestrial systems – river basins, freshwater systems, and estuaries and deltas. It also recognizes the need for freshwater managers to identify the needs of coastal zones and for coastal plans need to support IWRM .

ICM focuses on coastal zones, their relationship with the sea, territorial ordering, and the use of coastal waters. It aims at integration with regional development at national and cross-border policy levels. It also recognizes that the complexity of water resources in coastal zones goes beyond administrative limits and the search for cooperation and transboundary policies (Cicin-Sain et al. 1995; Cicin-Sain and Belfiore, 2005; Eger et al. 2021; Godschalk and Burns 2019; Oliveira et al. 2020). The dynamic balance of coastal regions requires integrated and

multiple approaches capable of considering ecological, social, and economic characteristics as integral parts of a system as a whole. This comprehensive view of coastal management must include coastal and catchment areas in the same landscape unit, as human pressures on these regions can affect coastal landscapes and vice versa. In this open system, changes in land use and transportation resources or the supply zones of the basins on both sides of the river corridors are reflected downstream to coastal waters, affecting the integrity of marine ecosystems (Cantasano and Pellicone 2014). Therefore, ICM's main targeted segments are Land resources and terrestrial systems, including coastal and urban areas, estuaries and deltas, coastline and nearshore waters. It also recognizes the upstream-downstream connections and the need for dialogue and harmonization between IWRM, Marine Management, and Land Use Plan.

The Source-to-sea approach aims to improve understanding of the linkages between freshwater, terrestrial, coastal, and marine systems, to support efforts to promote coordinated governance of all these systems and provide a foundation for decision-makers and planners (Weinberg et al. 2021). Fresh, coastal, and marine waters are interconnected as part of the hydrological cycle, moving across political and disciplinary boundaries, on land, underground, through the air, and through exchanges within and between biomes and beings. They are at various scales, from global to regional and local to river basins to oceans. What defines the Source-to-sea system is precisely this vision of the single system, which includes rivers basins, aquifers, downstream receptors, including deltas and estuaries, shorelines, and near-shore waters, maritime and continental shelves, and the open sea. (Granit et al. 2017a; Rocha Loures 2021). In the S2S approach, in defining an appropriate scale for analysis in a particular source-to-sea system, the scale can range from one or more segments that are closely connected to a river basin and downstream recipient, a sea and its drainage area to the connections of the global system (Mathews et al. 2019; Wang et al. 2021). Consequently, S2S main targeted segments are Land resources and terrestrial systems, including watersheds, freshwater systems, estuaries and deltas, coastline and nearshore waters, adjoining sea and continental shelf, and open ocean.

As shown in Fig. 3 the Source-to-sea encompasses all the segments that the other approaches (IWRM and ICM) only partially include in their analysis.

2.3.3 .Key Flows

The first Dublin Statement principle, water as a finite and vulnerable resource, recognizes that a fixed amount of water per period of time is available by the hydrological cycle and that

this total amount cannot be significantly altered by human actions, even considering the progress in water desalination in some countries. However, it also recognizes that humans can affect water resource productivity and reduce water availability and quality by altering flow regimes in surface water systems (GWP 2000).

However, integrated river basin planning already recognized that water flow unites the physical and human characteristics within a river basin (Schramm 1980). IWRM considers the environmental flow as the quantity, quality, and timing of water flows necessary to sustain ecosystems. The condition in which ecosystems and their services are sustained is essentially a socio-political decision: it can be established by international conventions or national policies, and environmental flow allocation can be negotiated between water users to maintain ecosystems in the desired condition (Sadoff and Muller 2009; Sadoff, et al. 2015).

Coastal zones are complex and dynamic due to their elements and interactions. The coastline undergoes constant changes, as it is a place of integration and a buffer zone between land and ocean. Therefore, the category of key flows is also partially present in the ICM considering three aspects of water flow: freshwater and saltwater flows and the interface between them. In the analyzed articles, the references to flows are mainly to ecosystem services or the impacts often generated by this land-ocean interaction (Broadley et al. 2022; Cicin-Sain and Belfiore 2005; Jean et al. 2018; Lins-de-Barros 2017; Lu et al. 2018; Rasch et al. 2005; Sklar and Browder 1998).

The comprehension of the upstream-downstream interactions is crucial because of the sediment balance, changes in the water flow, and the increasing loads of nutrients and a variety of chemicals that impact downstream the health of coastal and marine ecosystems. The impact also happens upstream, such as the rise in river water levels due to tides, which are related to flooding and saltwater intrusion into deltas. The Coastal ecosystems adjust to this cyclical effect, but coastal morphology changes can lead to saltwater intrusion further inland. Although arguing in favor of integration with IWRM, the first one encompassing the latter and vice-versa depending on the point of view (Cicin-Sain et al. 1998; Olsen 2003b), in practice, key interconnections and flows still remain in the perception and solutions remain fragmented into the *continuum*.

The S2S approach looks at the water resource through the prism of the water cycle: marine water and fresh water are part of the same *continuum*, of the same cycle, and what happens in this *continuum* impacts this system as a whole, including the human component and its changes as part of this cycle (Granit et al. 2017b; Rocha Loures 2021; Steffen et al. 2004). The S2S approach is similar to and supported by the River *Continuum* Concept (Vannote et al.

1980). This means the centrality of the flow driven, that is, focused and sustained in the flow processes, seeking, from the flow, to establish lateral connections (in the case of a river continuous, the connection between the light energy input, the production of biomass and the interactions between the physical environment and the biotic environment; in the case of S2S, the interactions between the diagnosis of pressure and impacts, management and governance).

Thus, the first element of the S2S conceptual framework is the key flows - water, sediments, pollutants, biota, materials, and ecosystem services - that connect subsystems in the *continuum* (Fig. 3) at different spatial scales and that bring impacts or benefits to the system (Granit et al. 2016). The state of each flow can be affected by activities in the other flows. Thus, the approach is structured in the combination of elements set that help identify courses of action that are suitable for a given S2S system, starting by identifying the flows and issues that are priorities.

For this category, it was the S2S approach the only one that was classified as fully-committed to this category. The others presented a weak and thus partial commitment, with focus only on isolated flow such as water or sediments.



Figure 2-3 - Key flows that connect geographies from source-to-sea

2.3.4 Governance and Management

The three approaches have water resources governance and management in their proposals and thus, all of them were classified as fully-committed to this category.

There is no single definition of governance, and depending on the context, different approaches and different views and definitions can emerge. Additionally, there is frequently a certain confusion about what governance is and what concerns management (Varis et al. 2014; Woodhouse and Muller 2017). The distinction between governance and management is an important aspect that permeates the ICM and S2S approach. Governance deals with the values, policies, laws, and institutions by which a set of issues is addressed, defining the scenario in which management takes place. Management is the process by which human and material resources are harnessed to achieve a known objective within a known institutional framework and it can be seen as the time to apply the approach after building the enabling environment through governance (Olsen 2003a).

There is a great convergence in the proposals/guide of implementation plans of the approaches in terms of establishing a progressive spiral process (loop cycles) with steps to be followed, where each cycle brings the lessons learned (learning and adaptive approach) and may indicate new scopes. Depending on the approach, these spiral processes differ in some aspects, but in terms of the theoretical vision of continuity and evolution, they are similar.

For the IWRM, water governance is the range of political, social, economic, and administrative systems in place to develop and manage water resources and deliver water services at different levels of society, and achieving good water governance requires creating an enabling environment that facilitates efficient public and private sector initiatives and stakeholder involvement. The enabling environment involves policies, legal frameworks, investment and financing structures (GWP 2000; Rogers and Hall 2003; Sadoff et al. 2015). IWRM is moving towards distributed governance, and the Dublin principles clearly reflect this concept, addressing the relevance of meaningful decentralization at the lowest appropriate level (Rahaman and Varis 2005; SIWI 2020).

IWRM proposes national IWRM plans to plan the coordinated development and management of water resources that provide frameworks and guidance on how to address development problems, including issues of water allocation and pollution. This roadmap is proposed to guide changes from fragmented approaches to more integrated approaches, identifying actions and a set of management instruments embedded in a broad framework of policies,

legislation, funding structure, and institutions with clearly defined roles (UN-Water and GWP, 2007).

For the ICM, governance requires thinking in terms of nested systems because different environmental and social issues, conditions, and actions impact and are impacted at higher and lower levels of an ecosystem and hierarchy of governance (Eger et al. 2021; Olsen et al. 1999). ICM is an umbrella term for other related processes, tools, and concepts such as Coastal Management or Coastal Resource Management, ecosystem-based management (EBM), marine protected area (MPA), and marine spatial planning (MSP), among others (Ehler 2003). The choice of an issue or a set of issues to be addressed must consider how responsibility and decision-making authority are distributed within a layered governance system, and consider relevant issues and proposed objectives of the immediately higher level of the governance system (Olsen et al. 2009).

Management in the ICM approach aims to restore or improve the specific qualities of coastal ecosystems and their human societies, enabling development and conservation in specific places, whether from a community to the coast of a nation. It also emphasizes that the instruments, indicators, and their management processes must be designed for periods longer than 4 to 6 years than currently used by governments to make possible to monitor the progress of initiatives and promote their adaptation and expansion of scope (Olsen 2003c; Ferreira et al. 2021).

The S2S approach takes a critical view of current water resources governance and management arrangements. Part of the problem is that there are many overlapping management frameworks on the *continuum* of water resources from land to open sea - it is several approaches to be applied to the same body of water, such as IWRM, ICM, MPA, and MSP, among others (Fig. 4), and that governance structures typically deal with freshwater and saltwater separately, where institutional and administrative structures of governments, as much as laws, have different departments for marine and freshwater issues (Granit et al. 2014). To design an appropriate course of action, S2S proposes a thorough governance analysis to understand past and existing governance and management systems - their strengths, weaknesses, or absences - and to consider the issues that are priorities for setting the governance baseline and identify the consequences of actions that did not take the system as a whole into account (Juda and Hennessey 2001; Olsen et al. 2011). The S2S management cycle helps understand the pressures and drivers of changed key flows, selecting the appropriate scale of intervention and stakeholder engagement, and establishing a Theory of Change (ToC) that will guide planning and implementation (Mathews et al. 2019).

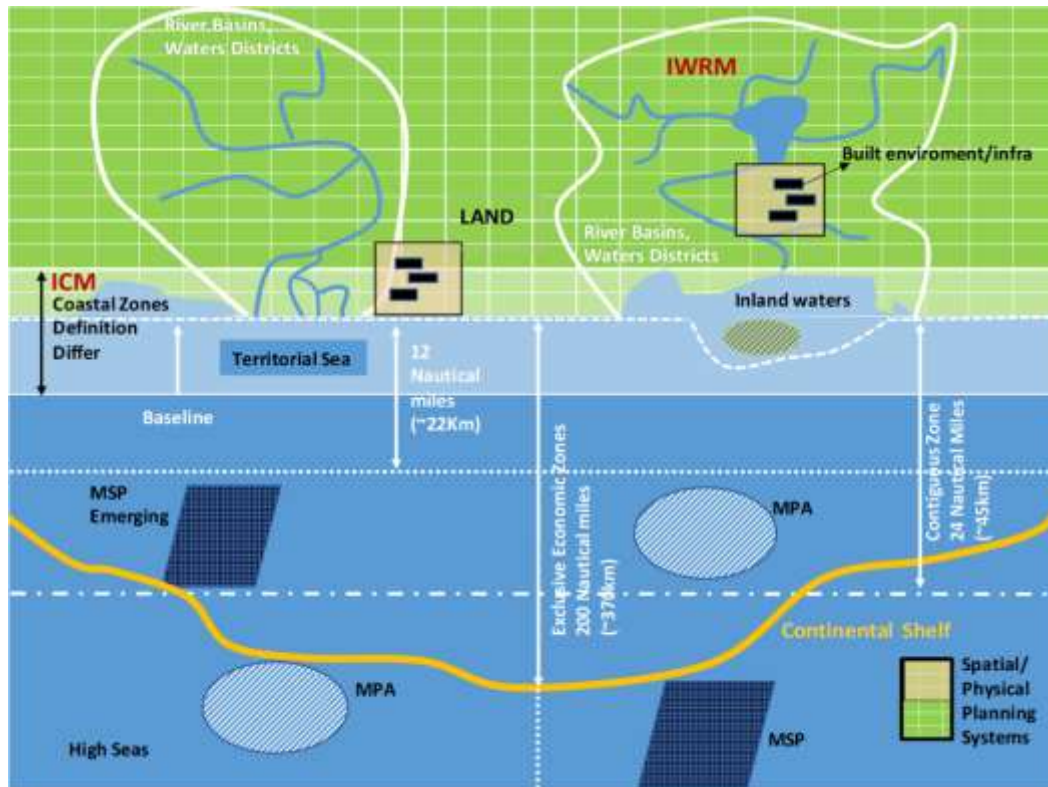


Figure 2-4 - Overlapping or weak governance and management frameworks in the water *continuum* - Adapted from Granit et al. (2014)

2.3.5 Monitoring and Evaluation

IWRM defends the need to develop a monitoring and evaluation system to accompany the implementation process, monitor the results, and evaluate progress to learn from the information obtained and refine the projects, programs, policies, plans, or strategies. The availability of this information is also necessary to promote the participation and support of civil society while ensuring accountability and generating public and private political support for the investment made. An important part of this process is the creation of indicators (Bertule et al. 2017). The GWP Toolbox suggests some criteria that can be used to guide and assess the quality of indicators, such as the SMART criteria (Specific, Measurable, Attainable, Relevant, Time-bound) and the SPICED criteria (Subjective, Participatory, Interpreted and communicable, Cross-checked, Empowering, Diverse and disaggregated) (GWP 2022).

In the ICM, the implementation of projects or programs matures through the completion of each management cycle and it is essential to analyze and understand the results that coastal management works to achieve. Usually, the first cycle starts with the most pressing issues

linked to a specific geographic area. Thus, it is important to understand the sequences of impacts that accumulate as the plan develops and is implemented. The ICM suggests using The Orders of Outcomes to build this trajectory. This framework groups the results along this trajectory to make it possible to understand progress and trace new advances toward more sustainable forms of development. The structure establishes 4 orders, 3 intermediate and one final which measure sustainable coastal development, that is, at what level the balance of social and environmental qualities has reached in terms of intergenerational equity and perspectives on social and environmental conditions and trends (Olsen 2003b, 2003c; USAID 2009).

S2S advances the proposal for a monitoring and evaluation framework. It incorporates the observations, concerns, and recommendations from the IWRM and ICM approaches and extends the process. In the structure proposed by S2S, it is necessary to develop a ToC to guide the process of adaptation and change and the application of the structure of The Orders of Outcomes for monitoring and evaluation. According to Weiss (1995), ToC is a theory of how and why an initiative works. Stein and Valters (2012) add that this can be understood as a way of describing a set of assumptions that explain both the mini-steps that lead to a goal of long-term and the connections between these activities and the results of an intervention or program. A defining feature of the structure of the theory of change proposed by the S2S approach is precisely this recognition of complexity in which economic, political, and diplomatic factors are as important as science and engineering in governance and management (Granit et al. 2017b; Söderbaum and Granit 2014; Stein and Valters 2012). GWP also hinted at adopting ToC in its latest IWRM global strategy for 2020-2025 (Saito 2019).

In this process, the concern is whether the necessary results (reports, trained people) have been generated, whether the quality of program activities is adequate, and how the program is responding to external events that are shaping the socio-political context in which the program is inserted and operating. In S2S, the systems thinking together with the Order of Outcomes structure can help fill gaps in water management and monitoring where frequently it is not clear the process for achieving this objective or how the progress in this direction will be monitored and evaluated. ToC in S2S can help monitoring and evaluation as it offers a sequence of tangible results that, if pursued over long periods, can lead to increasingly sustainable stages (Granit et al. 2017b; UNEP/GPA 2006).

It can be said that all of them (IWRM, ICM, S2S) were classified as fully-committed to this category.

2.3.6 Blue and Green Economy

In order to achieve sustainable development, the issue of economic development has to be integrated with more emphasis on governance and management approaches to ensure the balance and adequacy of society's economic development to the capabilities of nature. For this to be consolidated, specific mechanisms and measures are being incorporated, such as the concept of the green and blue economy (Bekmurzaev and Dadaev 2021; Lee et al. 2020; UN-Environment 2018; World Bank and UN-DESA 2017; European Commission 2013; Falkenmark and Rockström 2010; UNCSD 2012).

UNEP (2011) defines the green economy as a low-carbon, resource-efficient, and socially inclusive economy, resulting in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. The IWRM has brought up the issue of green growth in some case studies. However, the discussion is still in its infancy, and a long way needs to be traced so that, within the policies and plans linked to the water sectors, they are integrated with other sectors in search of efficiency. In this aspect, the conceptual framework nexus water-energy-food (Hoff 2011) has complemented the discussions in the IWRM approaches. Its framework seeks to promote actions toward a green economy because it deals with the interdependencies between key sectors; seeks to determine and resolve trade-offs between increasing demands; and aims to achieve water, energy, and food security without compromising sustainability (Griesinger and Michels-Brito 2022).

In relation to the blue economy, the ICM has advanced in the discussion of governance and in the design of its management initiatives. The blue economy concept has developed alongside the green economy to consider the economic benefits generated by coasts and oceans in all aspects of economic activity (Pereira 2020). The Blue Economy partly encompasses the concept of ocean-based economies, however, this concept goes far beyond that, conceptualizing the oceans as development spaces.

The framework of the S2S approach aims to improve the understanding of systems linked to the water cycle, including the economic development of societies, and it explicitly embraces "green" and "blue" economic development theories. In this way, S2S identifies economic growth sectors with the potential to enhance environmental sustainability in general (green) and in coastal and marine areas in particular (blue), showing the opportunities for sustainable economic growth in interconnected systems by the fresh and salty water *continuum* (Granit et al. 2017b). As a result, it breaks with the molds of the "brown" development model, where the oceans are perceived as a means of free resource extraction and waste disposal and incorpo-

rate oceanic values and services in economic modeling and decision-making processes (UNCSD 2012).

In summary, the blue and green economies are contemplated in the S2S approach and partially reflected in the IWRM and ICM. The S2S has as one of its main objectives in its conceptual structure to guide the design of future initiatives to support “green” and “blue” growth. Developing the green and blue economy through good governance and management is to outline the path to sustainable development. The IWRM and ICM work with the green and blue economy in some programs and forums, but they do not have the blue and green growth as an objective contemplated in their framework

2.3.7 Gender

IWRM has advanced in the context of governance and management of water resources so that the understanding of what gender integration means have expanded, going beyond the issue of women's integration. The Integration must take place from all gender perspectives, from differences in needs, uses and practices, employment, and entrepreneurship to access to resources, adaptability, and mitigation of men, women, and non-binary individuals in water planning and management, ensuring participation in all decision-making forums. Gender equality and social inclusion became core values at IWRM, and they are presented in this way in the Dublin Statement (GWP 2000). This means mainstreaming gender into all policies across the board, linking water and other relevant policy areas (GWP 2017) (Grant, 2017). This direction is in line with what today proposes the goals of Sustainable Development Goals 6, 5, and 14 (GWP and UNEP-DHI 2021; Niasse 2017; UNGA 2015; Water Europe 2019).

The gender issue in the ICM has also been discussed and introduced in many programs and projects (Olsen 2003b; Bennett 2005; de la Torre-Castro et al. 2017; Pravalprukskul and Resurreccion 2018; USAID 2009; Wabnitz et al. 2021). This insertion was both to enhance the participation of stakeholders and to promote equitable benefits distribution, reducing inequalities. However, the question is not structured at the principle level, as in the IWRM. The gender discussion has appeared with more emphasis when addressing vulnerability to climate change (Diamond and Lellement 2014; Miletto et al. 2017; Nagel 2015). Nonetheless, the ICM recognizes the need to analyze basic social information, including gender and demographic variables, so operational strategies are more effective.

According to Diamond (2003), the need for gender mainstreaming in the planning and implementation of ICM programs needs to be much more than a simple matter of adding more

female staff or adding a female member to a committee or just scheduling a small generation activity income for women in an ICM program. Many experiences have been accumulating in ICM approaches, and the perception that equity is not an optional choice but a transformative perspective necessary for coastal management to become more integrated and inclusive has been consolidating. We do not argue that ICM programs and projects are not developing approaches to gender mainstreaming, but in the conceptual articles analyzed in this work, gender mainstreaming does not feature prominently.

The S2S approach has its structure focused on the sustainable promotion of human well-being, equity, and social justice. However, the gender issue appears incipient in the articles dealing with the approach, perhaps because the approach is recent, despite its construction having taken place over time based on results obtained in different programs. For example, Berggren and Liss Lymer (2016), in their study on the links between the freshwater and marine targets in the 2030 Agenda, seek, in addition to understanding these links, to identify the gaps between SDGs 6 and 14 through the S2S vision, the issue of vulnerability of women and girls excel in sanitation and hygiene.

Mathews et al. (2019) show in the S2S implementation guide that ensuring gender representation increases engagement and strengthens the strategies and objectives outlined. Tengberg and Valencia (2017), on identifying the main aspects of integration and evaluation of implementation in natural resource management projects through systemic thinking, highlighted the need for equity to be brought into planning. The projects presented showed that where there was a priority to integrate women, the success of the programs was higher.

Therefore, in this category, IWRM stands out against the ICM and S2S approaches and can contribute to these approaches evolving in the integration of gender for coastal zones and marine environments in a complementary way, sharing experiences and tools.

2.3.8 Water Value

IWRM brings in its conceptual structure the question of the value of water. The value of water begins with a principle 1 approach, where there is a recognition that water is a finite resource. Because it is a finite resource, the management of this resource needs to be judicious, and its value must be included in this aspect. Seeing water as a free common good, without considering its value, can lead to harmful competition, overexploitation, and degradation of the resource (Hardin 1968; Ostrom 1999). This is why IWRM principle 4 considers water as an economic good, and thus having value (Rogers et al. 1998).

The discussion of water as an economic good and its value generates different interpretations and great confusion. Agenda 21, in chapter 18, sought to direct the issue by referring to water as an economic good but also as a social good, bringing a distinction between valuation (use value that involves regulatory and economic means) and charging (economic instruments that are complementary used to guarantee institutional control over access and use) (UNCED 1992). This confusion persists and two major schools of thought can be distinguished when considering water as a economic good, according to Savenije and Zaag (2002): 1) the first one defends that water should be priced according to its economic value and the market will guarantee the balance of uses; 2) the second one argues that water as an economic good is a decision-making process integrated into allocation decisions without necessarily involving financial transactions. However, in a different way of thinking, water can be valued as a common, not as a good: water can be viewed as part of humanity's common heritage, and thus, water is not merchandise (P7 Summit of the World's Seven Poorest Countries 2000). Bakker (2007) recognize the political differences between the "Commons" versus the "Commodity" nature of water.

The GWP (2000) states that the total value of water includes its economic value (value to users of water, net benefits from return flows and from indirect uses, and adjustment for social objectives) and the intrinsic value. O High-Level Panel on Water (HLPW) outcome document – Making Every Drop Count (HLPW 2018), suggested five principles to value water: 1) recognize and embrace the multiple values of water, including deep interconnections between human needs, well-being social and economic, spiritual beliefs and the viability of ecosystems; 2) Reconcile values and build trust in an equitable, transparent and inclusive way, dealing with trade-offs and emphasizing that inaction generates higher costs; 3) Valuing, managing and protecting all water sources; 4) Promote education and public awareness of the intrinsic value of water, and 5) Invest and innovate.

The issue also is approached from different avenues within IWRM, such as the value of ecosystem services and the need for healthy systems for these services to be maintained.

The three approaches explore the issue of service provision, economic instruments, and financing, but this topic is not the subject of discussion as Water Value category within ICM and S2S. ICM and S2S do not present water's value in their principles; the theoretical debate does not take place in both ICM and S2S.

Therefore, in this category, IWRM stands out from the ICM and S2S approaches and it can contribute to these approaches evolving in this debate.

2.3.9 Comparing the three approaches - a quick overview

The IWRM, ICM and S2S approaches bring their own principles, guidelines, goals, and objectives, which influence the way their structures are proposed. The categorization helped to establish key points to focus comparison, so that this effort can result productive to help advance water management. Categorization also helped to clarify how each approach addresses the sustainable use and conservation of water resources and water security or even in which aspects these approaches present similar or equal concepts and structures but addressed with different names.

The Integration category is present in all three approaches. However, the integrative view of the S2S approach is based on systemic thinking to deal with complexity, which expands the systemic view of the water resource, turning its concerns to the interaction between the parts, the flows, processes and control mechanisms. Therefore, S2S considers the water cycle as a hydrosocial cycle and proposes that the integration is between river basins, coastal areas, and the marine system. In the segments category, S2S stands out because its main targeted segments encompass all segments that the IWRM and ICM include, and, in addition, it adds the open ocean segment. Regarding the Key-flows category, the S2S approach was the only one that was classified as fully compromised. The first element of its conceptual structure is the main flows that connect subsystems in the *continuum* at different spatial scales and that bring impacts or benefits to the system.

The three approaches were rated as fully-committed to the governance and management category. However, the S2S approach takes a critical view of current water resource governance and management arrangements. Considers that part of the problem is the fact that multiple approaches are applied to the same body of water (in the same *continuum*), and governance structures are also segment driven and sectorally fragmented. This fragmentation in the way of approaching water resources has deep roots. For example, university programs usually deal with freshwater and saltwater separately; marine sciences are taught in one department and terrestrial ecosystems in another. A similar situation exists in governance structures, where ministries and local authorities have different departments for marine and freshwater issues. The approach advocates for the need to break these silos and understand interconnections to enable better actions across sectors and administrative boundaries. At the core of the approach are Key Flows that link the terrestrial system to the oceans, showing impacts and connections between sectors and guiding solutions that address these diverse trade-offs and nexuses. This doesn't mean that actions shouldn't be coordinated at the most appropriate level,

but rather that systemic thinking must be present to identify solutions that not only improve the problem locally but also avoid causing larger impacts and problems in other interconnected areas or in the whole system.

Regarding the monitoring and evaluation category, IWRM, ICM, and S2S were classified as fully-committed. S2S advances the proposal for a monitoring and evaluation framework. It incorporates the observations, concerns, and recommendations from the IWRM and ICM approaches and extends the process. Monitoring needs to occur at all stages of the management cycle to enable adaptation during implementation and governance adjustments to ensure a conducive environment. In the S2S approach, systemic thinking, combined with the use of the Theory of Change, has demonstrated the capacity to fill gaps in water monitoring and evaluation.

The blue and green economies are contemplated in the S2S approach and partially reflected in the IWRM and ICM. The S2S has as one of its main objectives in its conceptual structure to guide the design of future initiatives to support "green" and "blue" growth. The IWRM and ICM work with the green and blue economy in some programs and forums, but they do not have the blue and green growth as an objective contemplated in their framework. In the Gender Category, IWRM stands out against the ICM and S2S approaches. IWRM can contribute to these approaches evolving in the integration of gender for coastal zones and marine environments in a complementary way, sharing experiences and tools. Finally, for the Water Value category, IWRM hegemonically recognizes water as an economic good as one of the fundamental principles that guide its structure, in opposition to the idea of water as commons. This principle generates a critical debate within the water sector that influences governance and management. ICM and S2S do not present the Water Value in their principles. At this point, IWRM can bring an excellent contribution for these approaches to evolve in this debate, not least because water is the link and permeates all sectors and resources that generate values in which the approaches are engaged.

Therefore, taking into consideration these "Gender" and "Water Value" categories, the S2S approach needs to deepen the discussion and incorporate the advancements that IWRM has achieved to strengthen its objective of guiding green and blue growth, as indicated by the "Blue and Green Economy" category so that in fact this growth truly represents sustainable development guided by the principles of the SDGs.

The IWRM and ICM are complementary. Nonetheless, their vision remains fragmented in practice because, as we saw in this study, governance and management occur separately despite the recognition that they are interconnected by the upstream-downstream flow. At this

point, the S2S approach comes to contribute by uniting them in a common point: water. The S2S approach integrates and, at the same time, complements IWRM and ICM. S2S is based on understanding Earth as a unique system and fresh and marine water systems as a single *continuum*, acting strictly “in this common ground” between IWRM and ICM, with the key flows connecting the segments and, in consequence, these two approaches.

2.4 Conclusion

This research aimed to understand the Source-to-sea approach and identify its relationships and convergences with the approaches of IWRM and ICM and answer the question of whether they are integrative, complementary, or competitive. We used content analysis as part of the investigation method so that it was possible to identify the intentions and perceptions of the concepts, principles, and dimensions adopted by each approach. The classification of elements resulted in 8 categories. Based on Leopold's matrix, we created a base matrix to process and analyze the relationships between the approaches.

The categorization was useful to establish key points to focus comparison, so that this effort can result productive to help advance water management. Because categorization worked with the core of the sentences meaning and not with precise words employed to communicate ideas, it also helped to clarify if these approaches present similar or equal concepts and structures but addressed with different names.

Based on the key points (categories), S2S, IWRM and ICM were compared to see if they were integrative, complementary, or competing. At the end, it was concluded that the S2S approach brings new elements, revitalizes some methods, and strengthens the governance and management structure of freshwater and marine water resources, enabling a new vision in the *continuum* where IWRM and ICM are part of the process within a new perspective.

Nonetheless, It is important that this review can be expanded addressing more case studies. It is also critical to identify relationships and connections with landscape approaches. The approach encompasses interdependence and ecological and human influences, which makes it essential to understand how this human-space-water-climate interaction occurs. Considering these aspects, landscape approaches can probably contribute to the S2S approach in understanding these relationships.

THE SOURCE-TO-SEA LANDSCAPE: A HYBRID INTEGRATIVE TERRITORY MANAGEMENT AP- PROACH²

Abstract

Whether fresh or salty, water is a unique resource, a *continuum* interlinked by the hydrological cycle. It forms a complex system connected to the landscape. When the landscape is altered, water flows and their benefits are impacted. Degraded land compromises water resources. The governance and management of landscape and water resources are handled in a fragmented manner and in separate contexts. The Source-to-Sea approach offers an integrative vision based on systems thinking that focuses its concerns on the interaction among parts, flows, and processes. It proposes a framework for the governance and management of freshwater and marine water but does not bring the landscape into the context of the approach. This research used an analytical-deductive method to explore the interactions and connections between the Source-to-sea approach, landscape concepts and approaches, and the guidelines of the European Landscape Convention. The main objective was to identify and assess the feasibility of integrating these elements. The integration resulted in a governance and management approach termed the S2S Landscape approach. It is grounded in systems thinking, practical learning, active participation, and adaptive governance and management, providing an integrated vision between landscape and water. The approach includes four essential steps (Comprehension, Involvement, Planning, and Execution and Monitoring) that address the complex connections that freshwater and marine water maintain in the landscape, considering physical, bio-

² Michels-Brito, A., Ferreira, J. C. R., & Saito, C. H. (2024). The Source-to-Sea Landscape: A hybrid integrative territory management approach. *Science of The Total Environment*, 931, 172961. <https://doi.org/10.1016/J.SCITOTENV.2024.172961>

logical, socio-environmental, and economic aspects across all segments, from the land to the open sea. This S2S Landscape approach may be the path to address the challenges of governance and sustainable management of resources in an interconnected and constantly changing world.

Keywords

European Landscape Convention, Governance, Landscape Management, Water Resources, Systems Thinking, Sustainability, Environmental Planning

3.1 Graphic Abstract



Figure 3-1 - Graphic abstract of Souce-to-Sea Landscape Approach

3.2 Introduction

Whether fresh or salty, water is a unique resource, a *continuum* connected by the hydrological cycle. Thus, its natural occurrence occurs through meteorological events; its distribution is subject to the atmospheric climatology and the morphological characteristics of the earth's surface (Şen, 2020). As its main characteristics, water is cross-cutting, and it is present in different socio- environmental processes. Furthermore, water is a resource that is difficult to replace (Griesinger and Michels-Brito, 2022). The hydrological cycle is usually understood as a natural and continuous process regardless of the presence or absence of human activity (Maid-

ment, 1993). However, this cycle can be affected by human activities. For example, damming rivers, withdrawing water, or polluting water bodies, changing the speed of circulation in the hydrological cycle, the pulsation, and rhythms of floods, leading to the alteration of oceans in a way that the nature-society relationship can be profoundly altered.

Social development is centered on the availability and adaptation of the water resources systems to natural events of droughts and floods, and anthropogenic causes variations (IPCC, 2023; Şen, 2020). Water forms a complex system linked to the landscape. If the landscape is altered by development and land use, water flows and their benefits will also change. If the land is degraded, water resources will also be affected (Limburg et al., 2002; SIWI, 2018). In this way, water resources and the landscape are under pressure from the activities of human societies, including the effects of climate change. This brought a new magnitude of impact on the water cycle (IPCC, 2022; Little et al., 2017; Marengo et al., 2017; Ribeiro Neto et al., 2016; Wilhite et al., 2014). Climate change is the change of water (SIWI, 2018) and, therefore, the landscape. The increase in global temperature affects the water cycle, leading to changes in precipitation patterns, increased melting of glaciers, causing changes in river flows and the sediments cycle, and altering the dynamics of river basin, coastal, and marine ecosystems. (Ferreira et al., 2021b; van der Laan et al., 2023).

The Source-to-sea (S2S) approach (Granit et al., 2017a) has an integrative vision based on systems thinking to deal with complexity, which expands the systemic view of the water resource, turning its concerns to the interaction between the parts, the flows, processes, and mechanisms control. It proposes a new structure for water governance and management, addressing the entire system along the *continuum*, that is, looking at the water resource through the prism of the water cycle: marine water and fresh water are part of the same *continuum*, the same cycle, and what happens in this *continuum* impacts this system as a whole. Also, it considers human influence as part of this cycle. This implies that, in addition to the importance of understanding the major fluxes through ecological interactions and biogeochemical processes shaping these ecosystems along the *continuum*, it is recognized that social, economic, and cultural interactions influence and are influenced by the system (Granit et al., 2017a; Mathews et al., 2019). In the text, the "*continuum*" refers to the continuity of the water system from land to ocean.

This perspective allows the S2S to also serve as a link between Integrated Water Resources Management (IWRM) and Integrated Coastal Management (ICM). IWRM is a strategic approach that seeks to harmonize the use and management of water, land, and other related

resources in a coordinated and sustainable manner. Its goal is to optimize economic and social well-being fairly without compromising the viability of ecosystems essential for future life (GWP, 2000). ICM is a continuous decision-making process, a management strategy aimed at coordinating sustainable use, development, and protection of coastal zones and their resources. This process focuses on maintaining or restoring ecological integrity and improving quality of life through economic development in coastal and marine socioecological systems (Michels-Brito et al. 2023; Eger et al., 2021; Cicin-Sain et al., 1998), when comparing the three approaches to determine if they were integrative, complementary, or competing, concluded that the S2S Approach, in addition to integrating, complemented IWRM and ICM, acting in this common ground: water, with the main flows connecting geographical segments and going beyond sectoral fragmented management. It also noted that because the approach encompasses interdependence and ecological and human influences, it would be important to understand how this human-space-water-climate interaction occurs. The importance of this understanding is underscored by the fact that, despite the positive efforts of these approaches, degradation continues to occur. Therefore, extending the analysis to identify possible relationships and connections with landscape approaches would be important.

There is a need to think of water resources policies as part of a broader policy focused on environmental and climate change, as a structuring element of the landscape and life cycles, and not just as an economic instrument (Saito and Laques, 2021). The European Landscape Convention (ELC) represents this effort by a new conceptual framework for the landscape and, consequently, for the territory's management that influences water management (Council of Europe, 2000). Considering these aspects, landscape approaches can probably contribute to the S2S approach in understanding these relationships and vice-versa.

This research aims to identify possible connections between the Source-to-sea approach, landscape concepts and approaches, and the guidelines of the European Landscape Convention and assess the feasibility of integrating them. Additionally, it sought to answer the question: Can successful integration be achieved among landscape concepts, ELC guidelines, and the S2S approach?

3.3 Method

In order to achieve the objectives of this qualitative research (Lacey and Luff, 2007; Pickering and Byrne, 2014; Ritchie and Spencer, 1994), which is exploratory and follows an analytical-deductive approach, the methodological procedures were divided into two stages encompassing 5 phases outlined below (Figure 1).

The first stage of the study encompassed three distinct phases. In the first phase, identifying and defining the research topic were pivotal and aimed at ensuring its originality and consistency. For this, it sought to locate works that could potentially encompass interconnections and convergences between approaches related to landscapes, governance, and landscape management, as well as approaches related to governance and water resource management, both in river basin environments and coastal and maritime zones.

The search did not produce relevant results for work that aimed to establish a connection or integration of governance and management approaches between these two research areas. Key terms such as "landscape," "landscape approach," "landscape practices," "landscape concepts," "landscape governance and management," "landscape management," and "landscape governance" were employed. Subsequently, terms like "water," "water resources," "integrated water resource management," "integrated coastal management," "integrated coastal zone management," "river basins," "coastal zones," "marine waters," "source-to-sea," and others were added.

The second phase (Figure 1) involved the exploration of the landscape concept, encompassing its historical evolution, holistic and integrative nature, along with the process of fragmentation followed by a return to the original conceptions. This was carried out to comprehend how this process influenced and impacted the governance and management of water resources. For this analysis, the identification of documents, articles, books, and other sources that brought forth concepts, principles, main characteristics, and applications of landscape-related approaches was essential. New keywords needed to be added using the connector "and" such as "landscape ecology", "landscape science", "landscape representations", "ecology", "geographic", "biology", "history", "heterogeneity", "scale", "biodiversity", "land use", "concept" and "principles". A total of 152 publications were identified, and 20 were selected. In this phase, an understanding was reached regarding what the publication considers as the landscape concept, adopting a hybrid view of the landscape and identifying and identifying the emergence of the European Landscape Convention (ELC). The third phase involved the

exploration of the characteristics and principles. The aim was to identify and better understand the connections and relationships among the characteristics and principles linked to the ELC, the hybrid landscape view, and the S2S approach (with IWRM and ICM being considered in this process), to confirm and validate the degree of adherence: strong, moderate, or if there is no adherence. In this critical content analysis (Bardin, 1979), 30 more documents were added. The research question and how it aligned with the initial objectives became apparent, and the integration among approaches could be further explored.

The research was conducted comprehensively, encompassing all available fields in the databases, and no filtering criteria were applied regarding the year of article publication. For the second stage, two more phases were added (4 and 5). The process of exclusion and inclusion of the selected materials (titles, abstracts, full texts, books, documents, reports, etc.) from the obtained sample occurred based on relevance according to the following criteria:

- **Comprehensive Approach:** Encompasses conceptual, historical, and empirical studies related to the landscape.
- **Explicit or Implicit Characteristics and Principles:** Includes the presence of principles, whether they are explicit or implicit, addressing the theme of the landscape or the Source-to-sea approach or the European Landscape Convention and its recommendations.
- **Planning and Implementation:** Involves studies that address various forms of planning and the implementation of specific landscape-related approaches or the Source-to-sea approach or the European Landscape Convention and its recommendations.
- **Coherent Methodology:** Considers the inclusion of studies presenting a clear and appropriate methodological approach for implementing landscape approaches or the Source-to-sea approach or the European Landscape Convention and its recommendations.

After the exclusion of documents, it was performed a theoretical integration process between the different concepts of landscape, which led to the conception of a hybrid landscape approach (HLA). This HLA, combined with the guidelines of the European Landscape Convention and the S2S approach, resulted in the emergence of the S2S Landscape. The goal of the fourth phase was to assess, confirm the feasibility, and proceed with the integration between the approaches. For this purpose, the analysis of the already identified documents was expanded. New research was necessary to be conducted in databases to identify proposals and

practical implementations of landscape approaches, as well as emerging themes that arose throughout the integration process. In addition to the keywords used in the initial phase, we have incorporated "geographic information system," "Information and Communication Technologies," "integrated landscape approach," and "integrated landscape management." We have also included terms such as "investment," "financing," "technologies," "indicators," "monitoring and evaluation," "participatory," "participatory approach," "participation," "methodology," "methods," "practice," and "implementation," using the connector "and." One hundred and ten (110) new records were identified, raising the total number of identified records to 262. The critical analysis of the records resulted in the selection of 55 records to support the process of integrating the approaches.

In the last phase (fifth phase), the floating reading technique was used to examine the materials, classify the elements in accordance with the methodological approach, and identify the steps of each approach, along with how these steps interrelated internally and the external connections among the approaches. The steps defined as the basis for HLA integration were inspired by Bürgui et al. (2017) because, as well as simplifying the process, it allowed the other models presented by the different selected documents to be part of the basis of these steps.

The ELC was also structured in steps, following the guidelines proposed by Recommendation CM/Rec(2008)3, Part II, "The General provisions", item II.2., "Criteria and instruments for landscape policies", which presents "the fundamental stage in the process leading to landscape action". Through the core meaning of methodological concepts and analytical analysis, the steps of each approach that could be integrated were identified, considering the cyclical foundation for application. Basic characteristics related to the landscape concept, such as "past, present, and future", "integrity, heterogeneity, complexity", and "patterns, processes, scales," were also taken into account. The integration of these steps resulted in a governance and management approach, which we refer to as the S2S Landscape.

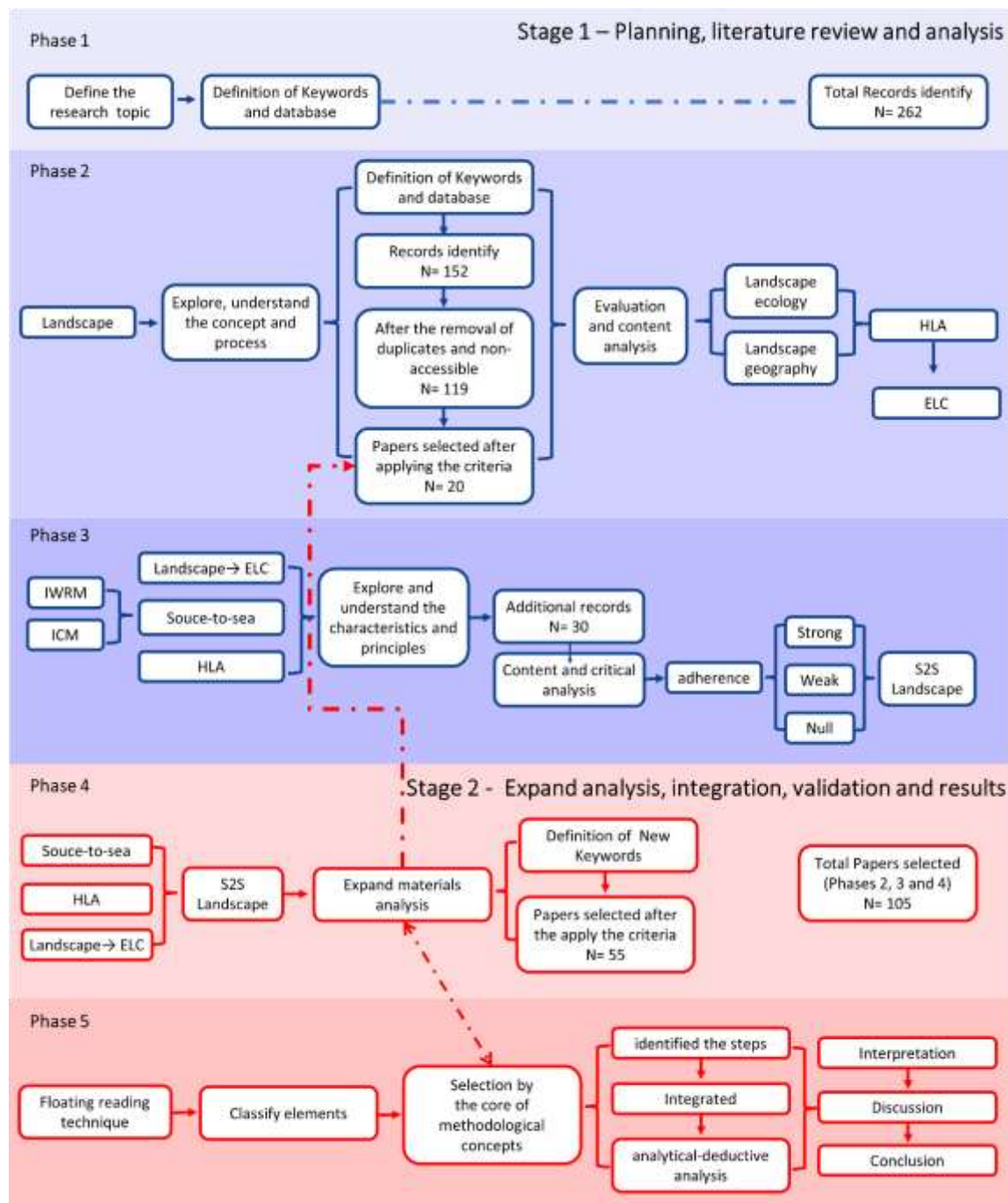


Figure 3-2 - Methodological approach applied in this work.

3.4 Results and Discussion

3.4.1 Brief overview about Landscape

The fragmentation of knowledge, particularly in the study of interactions between landscapes, ecosystems, and human activity, has led to a fragmented view of the relationships in nature, although pretended deeper specialized knowledge. This trend toward specialization and disciplinary division obscures the view of the whole, leading to disjointed approaches that often neglect the interdependence among natural systems. This fragmented reasoning has also set human beings apart from nature, with strong impact on the way we propose to manage the environment (Morin, 1999). Reexamining the holistic foundations of the landscape can unveil new paths and theoretical tools that challenge the existing fragmentation that has limited our capacity for effective governance and management. Furthermore, this reflection aims to explore how the resurgence of interest in the original concepts of landscape can influence the analysis, contribute to the planning and implementation of governance and management structures for water, such as the Source-to-Sea approach. Understanding this process is essential to also assess the possibility of integration for coordinated and sustainable actions between landscape and water resources management approaches.

The notion of landscape accompanies human development, but the development of concepts manifested itself more clearly from the descriptions and observations of artists (writers, painters, etc.) both in the West and the East (Maximiano, 2004; Naveh and Lieberman, 1994). In the West, the naturalist Alexander von Humboldt started the path of a more scientific understanding of landscape analysis, holistically connecting the elements of nature and human action. He defined that landscape would represent the total character of an area of land (Antrop, 2013; Farinha, 2022; Zonneveld, 1995).

In France, Paul Vidal de La Blache showed how the local population influenced the organization of the landscape where the differentiation went beyond natural characteristics but in the patterns of settlement and territory, implicitly including perception (Antrop, 2000). Sauer (1963) classified landscape as a complex concept that integrates physical and cultural elements, emphasizing its unique identity, organic structure, and interconnections within a general system. With the advent of quantitative approaches from the '60s onwards, most of the sciences began the path of scientific specialization, amplifying the divergences between human and natural sciences, losing focus on a more holistic approach (Antrop, 2000). a more holistic approach. The impact persists to this day, affecting the fresh and saltwater resources governance

and management, as stated by Erős and Lowe (2019), leading to the disconnection of the landscape as a general system and considering aquatic ecosystems as subunits.

Inspired by the spatial standardization of landscapes provided by the interpretation of aerial photographs. Carl Troll recognized the need to integrate the geographic approach with the ecosystem approach, thereby coining the term 'landscape ecology' (Antrop and Van Eetvelde, 2000; Wu, 2008). Thereby, landscape ecology emerged in Europe to encourage collaboration between geography and ecology by combining the spatial interaction of phenomena with studies of the functional interactions of a given place: a horizontal approximation of the geographer with a vertical approximation of ecologists (Troll, 1971).

Zonneveld (1990) argues in the same way when he states that Troll's goal with Landscape Ecology was "a marriage between geography (landscape) and biology (ecology)". The attempt of landscape ecology was to resume the systemic, holistic, and more integrative view of the sciences when looking at the landscape. However, what developed over time was a distancing between geography and ecology, leading to a certain dichotomization of landscape studies into two main approaches: the geographic approach, which follows the European line, and the ecological approach that began its consolidation with the Allerton Park Conference in 1983 in the USA (Wiens, 2008).

The geographic approach includes the human dimension and social and cultural land use practices so that spatial patterns reflect sociocultural aspects. It is influenced by human geography, phytosociology and biogeography, and geography and architecture disciplines related to regional planning. These characteristics make it possible to meet territorial planning, understand man transformed landscapes, expand analysis, and pay greater attention to macroscales. The ecological approach has a greater focus on natural landscapes and the conservation of biodiversity, valuing the elements of nature as constituents of the landscape. This approach is derived from island biogeography, and it is influenced by ecosystem ecology, modeling, and spatial analysis. In this approach, geotechnologies play a leading role, and it is considered, in general, the landscape ecology itself.

As Saito (1998) points out, the lack of this integration and the preference of the ecological approach for the recognition of structural components, morphology, and spatial arrangements are what bring the structuralist bias of landscape ecology. This bias emphasizes mechanistic aspects, reinforced by the Cartesian view of the subject and object, which merits attention (Cosgrove, 1985).

Bertrand and Tricard (1968) already defended that the landscape resulted from the combination of physical, biological, and anthropic elements that interact dialectically with each

other. For Paquette et al. (2005), in addition to objectivity versus subjectivity between the two approaches to landscape ecology, there is a need for a third conceptual position, in which the landscape must be associated with the existing dialectic relationship between the approaches and not just be referred to as a physical reality objective-spatial or limited to a subjective assessment of the gaze.

Discussions regarding the path that landscape approaches are taking have shown the need to reconsider it in an integrative view (Saito, 2022) and the necessity of a broader view to deal with the continuous changes in the landscape. In this way, this article adopts a vision of a Hybrid Landscape Approach (HLA), which seeks to understand the landscape as an integrated system, a unique synthesis between a region's natural and cultural characteristics, aligned with Antrop (2005) and Paquette et al. (2005). Furthermore, it highlights the potential benefits of technologies in integrating the human-cultural and natural-technological dimensions. When it comes to governance, management, and planning, all these approaches deal with specific land and water resource areas, so they need transdisciplinary synthesis and cooperation. In response to environmental and climate change challenges, as well as the dynamic alterations in the region's cultural diversity, the European Union has recognized the necessity of prioritizing landscape on its policy agenda. This led the Council of Europe to draw up the European Landscape Convention (ELC) (Antrop, 2013, 2005).

3.4.2 Characteristics and principles

The ELC adopted an integrative view by defining landscape as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (Art.1) and in the scope when it includes land, inland water and marine areas (Article 2) (Council of Europe, 2000). The ELC recognizes that the landscape has a strong capacity to integrate and reconcile a wide range of actions by populations at the local level, in addition to representing a fundamental component of the cultural and natural heritage. This definition of the landscape brings back the original concept where the landscape is seen as an integrative synthesis of interplay between natural and cultural aspects, converging to HLA, and it also highlights inland water and marine areas as part of the same system.

The ELC considers technological advances but also emphasizes the need for the landscape approach to be holistic and integrated. The ELC seeks to bring about, through general principles, common objectives and cooperation, a cultural change and a development of belonging beyond the national borders of each Member State in creating a collective identity. The ELC was adopted by the Committee of Ministers of the Council of Europe and opened for

signature by member states in October 2000, entering into force on March 1, 2004, and it can be seen as a means of operationalizing the HLA. Among the recommendations that came later, we highlight Recommendation CM/Rec(2008)3 which provides theoretical, methodological, and practical guidance for implementing the ELC (Council of Europe, 2008).

The HLA integrates ecological, geographical, and other related approaches, providing tools for a holistic and multifaceted perspective of landscapes. This vision emerged from the need to synthesize knowledge and methods from both the natural and social sciences, in order to recognize integration and interdependence, addressing the landscape as an integrated system. Holistic landscape management requires an approach that transcends traditional disciplinary barriers. In this way, it integrates and incorporates the principles expressed in these approaches, aligning with the concept that the ELC revives. Thus, the HLA reflects the principles promoted by the ELC, highlighting the consonance between both.

In analyzing the characteristics of ecological and human interdependencies and influences, the integration of their processes, and the principles of the S2S approach in relation to the characteristics and principles of ELC and HLA, it is considered that the principles and characteristics of IWRM and ICM are intrinsically incorporated in S2S. This integration and complementarity, as elucidated by Michels-Brito et al. (2023), demonstrate how S2S introduces new elements, revitalizes some methods, and strengthens the governance and management structure of water resources. This allows for a new vision in the *continuum*, where IWRM and ICM are part of the process within a new perspective, considering the flows and processes from the source to the open ocean. Thus, when analyzing the S2S approach in relation to ELC and HLA, the S2S is interpreted through this integration and complementarity.

The ELC explicitly incorporates the principle of subsidiarity as a guiding principle for landscape management and decision-making. Thus, the convention aims to ensure that decisions related to the landscape are taken at the level closest to the affected communities, promoting the participation and involvement of local actors. This principle is not mentioned in S2S, but there are connections in how the approach deals: with stakeholder involvement, in regional collaboration and cooperation between different regions, countries, or jurisdictions through which water resources flow to coordinated action and shared responsibility and in management adaptive and multi-level governance, for recognizing that decisions must be taken at the appropriate level of governance, considering the scale and nature of the issues addressed. In Article 2 of ELC, attention is directed to the entire territory, without distinction between the parts or between its elements. It considers the whole and includes land spaces, inland waters, and the sea. This vision is reinforced in the general principles by "Considering the territory as

a whole" emphasizing the integration of different aspects, such as natural, cultural, historical, and social elements, as well as the diversity and quality of the landscapes. Thus, it adopts a holistic approach and is aligned with the systemic and ecosystemic approach, as they share the recognition of the interconnection and interdependence between the different components of a system. S2S also considers the Earth a single system and adopts systems thinking to deal with complexity. The approach looks at the water resource through the prism of the water cycle: marine water and fresh water are part of the same *continuum*, and what happens in this *continuum* impacts the entire system. It considers, by extension, the socioecological nature of water. Therefore, this hydrological cycle is actually a hydrosocial cycle. Thus, S2S and HLA also seek to promote a holistic view as a guiding principle and employ systemic and ecosystemic approaches.

However, the analysis of principles and characteristics reveals that the S2S lacks the integrated landscape vision present in the ELC and HLA, which considers the landscape to be a unique synthesis of natural, social, and cultural elements. On the other hand, the ELC and HLA do not adequately emphasize water processes and flows, a gap that the S2S approach fills with its focus on the hydrosocial cycle, integrating freshwater and marine waters as parts of the same cycle. Integrating these principles and characteristics will provide the necessary breadth for understanding the system, strengthening the perception of interdependence and interactions between natural and human processes. This fills one of the main gaps contributing to fragmentation in the governance and management of water resources and landscape and reinforces an integrated and holistic approach to socio-environmental sustainability and the resilience of ecosystems.

The general ELC principles "Recognise the fundamental role of knowledge", "Promote awareness", and "Make use of public participation" are essential to ensure active participation in the identification, description, and assessment of landscapes. They emphasize the importance of integrating morphological, historical, archaeological, cultural characteristics and natural resources, as well as valuing the public's perception of landscapes' historical and current significance. Berlinck and Saito, (2010) highlight that awareness and effective engagement of people depend on the accessible dissemination of knowledge. Furthermore, Saito (2020) underlines that combining scientific and traditional knowledge is crucial for fully understanding the landscape.

The S2S highlight that awareness and effective engagement of people depend on the accessible dissemination of knowledge. Furthermore, Saito (2020) underlines that combining scientific and traditional knowledge is crucial for fully understanding the landscape. (Granit et

al., 2017a; Mathews et al., 2019; Olsen and Nickerson, 2003). This focus highlights the importance of active community involvement in management processes, aiming to co-create sustainable solutions that empower communities and improve the transparency and efficacy of these processes (Ferreira et al., 2021a; Vasconcelos et al., 2021). Moreover, the effective interpretation and understanding of management concepts and principles depend on creating an environment conducive to knowledge sharing, considering the natural and cultural diversity and the uniqueness of each location, fundamental elements for building identity and preserving biodiversity. The participatory approach plays a central role in a Hybrid Landscape Approach (HLA), integrate different knowledge and perspectives into landscape management. This principle is evidenced by Luz (2000), Sandker et al. (2010), and Simensen et al. (2018), who demonstrate how participation enriches landscape management. Effective problem-solving in HLA involves combining and synthesizing knowledge from multiple domains, facilitating collective reflection on complex issues. Social participation, in this process, really promotes the capacity building of the State (Abers and Keck, 2009; Granit et al., 2017a; Parson, 1997).

In summary, the ELC prioritizes public engagement for comprehensive appreciation and understanding of landscapes, while the S2S focuses on community inclusion in water resources management, aiming for transparency and sustainability. Meanwhile, the HLA seeks to unite diverse knowledge and stakeholders' perspectives in collaboratively solving complex landscape challenges. Although the participatory approach is a pillar for all, the way it is implemented and the outcomes each achieves vary, offering complementary tools and perspectives. Thus, the potential to promote integration of these approaches can bring new insights and instruments of participation and create a robust environmental management system where participation is not only valued but also adapted to meet the specific needs of each context, contributing to sustainable and effective environmental governance.

The ELC principles "Define landscape strategies", "Integrate the landscape dimension in territorial policies", and "Integrate landscape into sectoral policies" are linked to integration, scales, and time. Strategies should be elaborated and linked by landscape quality objectives suited to the characteristics of places at national, regional, and local levels. Transnational and global collaborative strategies are important in water and landscape governance and management. It is also recommended to integrate the horizontal and vertical landscape in the territorial management policies and systematically include the landscape dimension in all the policies that influence the quality of the territory. The vertical and horizontal Integration in the S2S approach is fundamental to achieving good governance and management, preservation, conservation, and sustainable development of fresh and marine water resources. Likewise, the HLA

embodies the same ELC principles. The ELC contributes this point to creating the environment for both approaches' implementation.

The S2S approach is a multi-level, adaptive, and resilient approach. Adaptation, learning, and resilience are essential elements to respond to governance and management challenges and achieve long-term results (protection, conservation, and sustainable development) of water resources. The HLA incorporates a vision of the landscape as an interconnected system, where terrestrial and aquatic landscapes are not separate entities but integral parts of a cohesive whole. It is also a multi-level and adaptive approach, driving comprehensive, integrated, and participatory landscape management and conservation strategies. This holistic perspective aligns with the European Landscape Convention (ELC) principles and guidelines. Therefore, we can consider that the principles that support the S2S and HLA approaches and the ELC have a strong degree of adherence and complementary.

The integration of these approaches, along with the guidelines for the implementation of the ELC, can enhance the governance and management framework across the *continuum* to address complex challenges related to the use, preservation, and conservation of water resources and landscapes.

Therefore, it can be considered that the characteristics and principles underpinning the S2S and HLA approaches, and the ELC, converge or complement each other in various aspects. The existing gaps in each approach can be filled through integration among them. This integration, henceforth referred to as S2S Landscape, not only enables a new, more robust, and integrated approach to the governance and management of landscape water resources but can also be the path to overcoming fragmentation by adopting a holistic and integrated view of the system's flows and processes as a whole. This will allow the governance and management of resources to move towards sustainability.

In summary, the S2S Landscape can overcome:

- the spatial limitations of the S2S approach by encompassing socio-environmental processes beyond the water basin (including the continuity of vegetation patterns beyond the watershed and cultural organizations extending to the other side of the relief's summit);
- the spatial limitation of ICM by encompassing the entire water basin and the freshwater that reaches the coastal zone and the sea;
- the spatial limitation of IWRM by encompassing the coastal zone and the sea, beyond the watershed borders;
- the scale limitation of HLA and the ELC by encompassing the water basin as a *continuum* from the source to the sea.

The new perspective can fill in all these gaps and limitations into an integrative and systemic framework, still considering the interplay between natural and social processes to governance and management, which in a certain way was addressed by the others in their scale and spatially limited areas.

Below, tables 3-1 to 3-4 show the main characteristics and limitations of the approaches and how the S2S Landscape can bring a new perspective. The main characteristics and limitations were based on Antrop (2005), Arts et al. (2017), Bürgi et al. (2017), Cicin-Sain et al. (1998) Cicin-Sain and Belfiore (2005), Council of Europe (2000, 2008) Eger et al. (2021) Freeman et al. (2015), Fry (2001), Granit et al. (2017a, 2017b), GWP (2000), Hong and Lee (2001), Michels-Brito et al. (2023), Rahaman and Varis (2005), Turner (1989), Van Beek and Arriens (2014), Varis et al. (2014), and Wiens (2002).

Table 3-1 - Ecological Interdependencies and Influences

Approach	Main characteristics	Limitations
S2S	It considers Earth as a single system, emphasizing that both freshwater and marine water are part of the same continuum, the same cycle, and changes in this continuum affect the entire system. It addresses water flows and processes, focusing on the water continuum from the source to the sea, connecting ecosystems and highlighting the importance of understanding key flows (water, biota, materials, sediments, pollutants, and ecosystem services) that shape these ecosystems along this path. It centers on water as a connection medium but also considers a wide range of ecological interactions and biogeochemical processes between aquatic and terrestrial ecosystems.	It recognizes the mutual influence between environmental processes and social processes without properly considering the interdependence among the water basin, the terrestrial environment, and the landscape.
ICM	Recognizes the importance of upstream to downstream connections, addressing processes from estuaries to the sea and ocean, with a focus on the flows of freshwater and saltwater and their intersection. These dynamics significantly impact ecosystem services, including habitat provision and biodiversity maintenance. ICM promotes understanding and management of the complex interactions between terrestrial and aquatic systems, aiming for the conservation of coastal and marine ecosystems through integrated and sustainable management of these critical zones.	It addresses processes from estuaries to the sea and ocean without properly considering the water basin and the terrestrial environment.
IWRM	It deals with continental water processes. Integration into the natural system is associated with the recognition of the needs of the coastal zone. It considers environmental flow as the quantity, quality and timing of water flows necessary to sustain ecosystems. Therefore, it is concerned with the integration between surface and groundwater, the management of water catchment and the river basin, the quality and quantity of water.	It is focused on fresh water and the management of water basin, without properly considering the estuaries, the sea and ocean, and the boundaries beyond the watershed limits.
HLA	It proposes an integrative and comprehensive view of the territory, recognizing it as a unified system where patterns and processes operate on spatial scales that are fundamental to the dynamics and functionality of ecosystems and their connectivity. It aims to understand the interdependence and ecological influences beyond the specific boundaries of terrestrial or aquatic habitats, as it considers the landscape as a system that is both integrated and interconnected, in which terrestrial and aquatic landscapes are not separate entities, but rather integral parts of a cohesive whole.	It addresses the whole landscape without properly considering the water flows and their influence on the landscape production that should include estuaries, the sea and ocean that are neglected.
LANDSCAPE - ELC	The focus is on analyzing terrestrial processes and water bodies integrated into the landscape. The convention extends the conventional approach, which often limits itself to landscape units without fully covering watersheds, to consider the territory as a whole. This includes land areas, inland waters, and the sea, emphasizing the importance of each part of the ecosystem in maintaining environmental balance. It encompasses all landscapes, from those of exceptional universal value to the most common, ordinary, and degraded ones, recognizing the complex relationships that sustain biodiversity and essential natural processes and promoting a deep understanding of ecological dynamics.	It addresses the whole landscape without properly considering the water flows and their influence on the landscape production that should include estuaries, the sea and ocean that are neglected.
S2S LANDSCAPE	Incorporates the analysis of processes in water bodies from the source to the sea (S2S), going beyond the geographically compartmentalized approach (ICM in the coastal zone or IWRM up to the coastal zone). It integrates the terrestrial landscape with water bodies (landscape approaches) but with a territorial scope broader than the landscape unit, encompassing the entire space from the source to the open ocean and considering in this space the entire set of interactions of environmental processes among themselves (water cycle, biodiversity flows, etc.). Thus, it emphasizes that land-water is a single system, not separate parts.	

Table 3-2 - Human interdependencies and influences

Approach	Main characteristics	Limitations
S2S	It recognizes the socio-ecological nature of water and considers the social processes impacting the environment from source to sea. Its structure is focused on the sustainable promotion of human well-being, equity, and social justice, and recognizes the importance of involving stakeholders and local communities in water resources management.	It recognizes the socio-ecological nature of water and considers the social processes impacting the water bodies and flows from source to sea without properly considering the interdependence among the water basin, the terrestrial environment, and the landscape.
ICM	It considers the complex and dynamic relationship between human activities and coastal ecosystems, in which human actions, such as urbanization, pollution, and coastal development, negatively impact the ecosystems. Concurrently, society depends on these same ecosystems for essential services, such as protection against climatic events and resources for subsistence. It also recognizes the need to analyze basic social information and demographic variables to make operational strategies more effective.	It recognizes the socio-ecological nature of coastal water and considers the social processes impacting the water bodies and flows in estuaries, sea and ocean, without properly considering the water basin and the terrestrial environment, and the distant origin of pollutions and sediment loads.
IWRM	Considers how human activities, such as urbanization, agriculture, and industrial processes, directly interfere with water quality and exert significant pressure on water resources. These activities contribute to the pollution of water bodies and lead to increased withdrawals for consumptive uses, impacting the availability and sustainability of water resources. This highlights the complex interdependencies between human welfare and ecosystem health, underscoring the critical need for mindful management of human actions to safeguard water resources for future generations.	It recognizes the socio-ecological nature of coastal water and considers the social processes impacting the water bodies and flows in water basins, without properly considering the estuaries, sea and oceans, and the landscape and terrestrial ecosystems beyond the watershed limits.
HLA	It concerns how social and cultural aspects of the landscape change patterns and processes at a spatial scale, influencing and modifying the dynamics and functionality of ecosystems. It emphasizes that the condition in which ecosystems and their services are sustained is, essentially, a sociopolitical decision.	It recognizes the socio-ecological nature of landscape production and development, without properly considering the water processes and flows.
LANDSCAPE - ELC	Considers how the history of human actions shapes the landscape. Development in agriculture, forestry, industrial and mineral production techniques, as well as in regional planning, urbanism, transportation, infrastructure, tourism, recreation, and the economy, accelerate the transformation of landscapes. It is aware of and takes into account the sensory and emotional perception of populations regarding their environment, along with the recognition and appreciation of the unique historical and cultural characteristics of each location. This is essential for maintaining community identity and enriching society, also highlighting the impact of these actions on the landscape.	It recognizes the socio-ecological nature of landscape production and development, without properly considering the water processes and flows.
S2S LANDSCAPE	The S2S Landscape approach is broader because it incorporates the analysis of how social processes act on water bodies from the source to the sea (something that S2S does), going beyond the geographically compartmentalized approach (such as ICM, which focuses only on the coastal zone, or IWRM, which extends to the coastal zone). However, beyond human action on water bodies and human dependence on these water bodies and their historical process, shaping the terrestrial landscape with water bodies for social, cultural, and economic use (something that landscape approaches do), it has a territorial scope larger than the landscape unit, encompassing the entire space from the source to the sea and considering, in this space, the entire set of interactions of social processes among themselves (land use and occupation, economic activities, cultural aspects, etc.). It considers that human interventions not only alter the physical landscape but also affect biodiversity, ecosystem services, and, in turn, the human communities themselves.	

Table 3-3 - Integration of human and ecological processes

Approach	Main characteristics	Limitations
S2S	Considers the entire system along the continuum (from source to sea), that is, looks at the water resource through the prism of the water cycle, incorporating human influence, thus considering it a hydrosocial cycle: marine water and freshwater are part of the same continuum, and what happens in this continuum impacts the system as a whole, both the human and natural system. This implies that beyond the importance of understanding the main flows through ecological interactions and biogeochemical processes that shape these ecosystems along the continuum, it recognizes that social, economic, and cultural interactions influence and are influenced by the system.	It recognizes the mutual influence between environmental processes and social processes, without properly considering interdependence among the water basin, the terrestrial environment, and the landscape.
ICM	It focuses on coastal zones and their relationship with the sea, addressing land use planning and the use of coastal waters by considering the flows of fresh and saltwater and the interface between them. It aims to balance ecological management with human activities at the land-ocean interface, promoting the conservation of coastal and marine ecosystems and the sustainable use of resources. It integrates policies and practices from various sectors impacting the coastal zone—including tourism, fishing, industry, urban planning, and environmental conservation—in response to challenges such as rising sea levels and extreme weather events. It uses scientific data and traditional knowledge to underpin strategies that understand ecological systems and increase the resilience of coastal zones and the communities that depend on them.	It recognizes the mutual influence between environmental processes and social processes, without properly considering the water basin and the terrestrial environment, and the distant origin of pollution and sediment loads.
IWRM	It promotes ecological and human water management within the natural boundaries of watersheds, allowing for a more holistic understanding of water flows, ecological processes, and human impacts. This involves assessing water availability and quality, ecosystem requirements, and human demands to ensure the long-term sustainability of water use, seeking a balance between use and conservation. It recognizes that water is a finite and vital resource for ecosystems and human societies.	It recognizes the socio-ecological nature of coastal water and considers the social processes impacting the water bodies and flows in water basins, without properly considering the estuaries, sea and oceans, and the landscape and terrestrial ecosystems beyond the watershed limits.
HLA	The approach recognizes the complexity of the landscape and seeks to overcome disciplinary and sectoral barriers, promoting a comprehensive and integrated view of the landscape that considers environmental, social, economic, and cultural aspects, and their interactions in the dynamics of processes, in order to understand, evaluate, and promote a realistic analysis of the landscape and its elements, aiming for holistic management. It encompasses both aspects related to human and cultural relations as well as the inherent benefits of technologies. Thus, it seeks a balance between ecosystem conservation and socioeconomic development, aiming to reduce conflicts and consider the multifunctionality of the landscape.	It recognizes the socio-ecological nature of landscape production and development, without properly considering the water processes and flows.
LANDSCAPE - ELC	It adopts the concept that the landscape is a unique synthesis of the natural, social, and cultural characteristics of a region, highlighting the integration and interaction of different aspects, as well as the diversity and quality of landscapes. It defines landscape as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors." It emphasizes the importance of evaluating the entire landscape to better understand how ecological processes function, how human interventions affect these processes and are also affected, and how they impact the landscape. Thus, it considers that the landscape has a strong capacity to integrate and reconcile a wide range of actions by local populations and represent a fundamental component of cultural and natural heritage.	It recognizes the socio-ecological nature of landscape production and development, without properly considering the water processes and flows.
S2S LANDSCAPE	It incorporates the vision of the hydrosocial cycle, considering fresh and marine waters as part of the same cycle (which encompasses IWRM and ICM), and adopts the concept of the landscape as a unique synthesis of natural, social, and cultural characteristics. It highlights the interaction and interdependence among different aspects by recognizing that water resources are an integral part of the landscape. Thus, the S2S Landscape approach expands because it integrates land-water (hydrosocial cycle), understanding that these are interconnected processes that impact the sustainability of natural and social ecosystems, integrating the evaluation and analysis of physical-biological-social-cultural (human and ecological) interactions of patterns and processes in the landscape.	

Table 3-4 - Integration and complementarity between approaches

Approach	Main characteristics	Limitations
S2S	It adopts systems thinking to handle the complexity and fragmentation in understanding water resources. Recognizing the Earth as an integrated system, it sees freshwater and marine systems not as separate entities but as parts of a single continuum, where key flows play a crucial role, facilitating ecological and human interactions (hydro-social cycle). This perspective allows S2S to act as a connecting link that integrates and complements IWRM and ICM. By focusing on water as the 'common ground,' S2S facilitates the connection between different geographic segments, transcending mere awareness of the interconnections between them.	It recognizes the mutual influence between environmental processes and social processes, in a systemic view. Nevertheless, the systemic view is limited to the river bed and the drainage area.
ICM	ICM is a process to maintain or restore ecological integrity and improve quality of life through developing economies in coastal and marine socio-ecological systems. ICM acknowledges IWRM as an input, illustrating the impact of actions in watersheds on the coastal zone. It highlights the effect of upstream-downstream water flow and how sea level rise and saltwater intrusion influence interface zones. However, governance and management between them are not integrated.	It recognizes the mutual influence between environmental processes and social processes but the view is limited to coastal zones and the sea.
IWRM	IWRM aims for the coordinated development of water, land, and related resources to promote equitable economic and social well-being without compromising ecosystem sustainability. It emphasizes environmental flow as the quantity, quality, and timing needed to sustain ecosystems, with socio-political decisions. Principles of gender equality, social inclusion, and water valuation stand out, offering contributions through shared knowledge and experiences. However, it discreetly mentions integration with ICM as an output, meaning its actions impact ICM. While recognizing the need to identify coastal zone and coastal plan demands to support IWRM, governance and management integration with ICM remains limited.	It recognizes the mutual influence between environmental processes and social processes, in a systemic view, but its view is limited to the water basin and focused on fresh water.
HLA	In the HLA, the landscape is seen as a cohesive whole that incorporates natural and human elements, considering the benefits that technologies can bring by integrating the human-cultural and natural-technological parts. It focuses on patterns, relationships, and spatial processes, rather than on the substrate or the environment. This approach expands the way water resources are perceived and managed, thus enhancing and complementing the S2S approach, which in turn integrates and expands the scope of IWRM and ICM.	It recognizes the mutual influence between environmental processes and social processes, in a systemic view, but its focus is on landscape unit, which is, in the most part of the time, smaller than the water basin, and has no focus on drainage system.
LANDSCAPE - ELC	The Landscape approach highlights how water management influences land-water relations within the landscape unit. In coastal landscape units, it can integrate IWRM and ICM within that specific region but doesn't extend the analysis from source to sea due to the spatial limitation of the landscape unit. However, the ELC, by encompassing terrestrial, inland, and marine areas in its definition, revisits the original concept where the landscape is seen as a unique blend of natural and cultural characteristics (Antrop, 2005), considering inland waters and marine areas as parts of the same system. This concept enables the expansion and provision of a holistic and non-fragmented complementarity to water resources management and governance.	It recognizes the mutual influence between environmental and social processes within a systemic view, but it focuses on the landscape unit, which most of the time is smaller than the water basin and lacks focus on the drainage system.
S2S LANDSCAPE	S2S Landscape understands that the landscape is a unifying concept within environmental integration. By integrating the S2S approach (which integrates and complements IWRM and ICM) with the landscape concept, HLA, and ELC, it expands and innovates as it promotes a comprehensive view of the landscape. It thus understands how water moves through it and the complex interaction and interdependence between natural and human systems. S2S Landscape offers a holistic and cohesive perspective capable of addressing complexity and promoting the system's sustainability as a whole. By recognizing that land and water are elements that support the structuring of the landscape, it proposes a management and governance of water resources that transcends water-centered analysis, considering its complete cycle and the natural flows that connect different parts of the landscape. Ignoring these dynamic connections can lead to a fragmented approach, increasing the risk of environmental and social disasters and compromising the sustainability of ecosystems.	

3.4.3 Source-to-sea Landscape

The S2S approach concerns key flows and the processes that connect subsystems in the *continuum* at different scales from land to ocean, covering all land area that is drained by a river system, its lakes, and tributaries (the river basin), connected aquifers and downstream receptors, including deltas and estuaries, coastlines and near-shore waters, the adjoining sea and continental shelf as well as the open ocean (S2S segments) (Granit et al., 2017b). The main flows of water, biota, sediments, pollutants, and materials from the source to the sea interact

to set the ecosystem services that the drainage system provides. They are elements to guide the understanding, analysis, and planning that aims at a common framework for the elaboration of a theory of change (ToC) having as one of the objectives to guide the design of future initiatives destined to support the green and blue growth in S2S approach (Granit et al., 2017a; Mathews et al., 2019). The S2S approach represents a significant advancement in the governance and management of water resources, integrating and complementing existing approaches. However, it also presents limitations by not fully incorporating water within the broader context of the landscape. This restriction ultimately leads us to continue fragmenting the governance and management of water resources, regardless of the effort to integrate. Therefore, the proposal of this research is to advance in this field in theoretical construction, proposing a broader and more holistic integration, recognizing that the landscape is integral to the Earth's interconnected system.

Integrating the concept of landscape can increase effectiveness, as it encompasses not only the physical environment but also the cultural, historical, and social dimensions that influence the dynamics and functionality of ecosystems. This effort aims to contribute to the preservation and life of the terrestrial system through governance and management based on a truly holistic view.

Achieving governance and management in the source to sea *continuum* sustainably and holistically means advancing land-water, social-natural, surface-underground integration and understanding the landscape as a single system; that is, the vision supports the understanding of space and time, and the analysis needs to be conducted by systems thinking. This requires transdisciplinarity between the social and natural sciences. Transdisciplinarity involves collaboration among different areas of knowledge, including the participation of individuals from outside the academic environment, to enhance knowledge, better understand relationships and processes, and create innovative and integrated solutions to complex problems, encompassing both science and society. This approach values the knowledge of traditional communities and considers the experience and living conditions of various stakeholders in the process. Active participation and continuous learning are at the foundation of transdisciplinarity, which combines interdisciplinarity with a participatory methodology (Tress et al., 2005), making science more engaged and socially responsible (Bernstein, J. 2015). Water has multiple and complex roles in the landscape – both terrestrial and marine. Land use can change this role and landscape as well as water degradation, and the *continuum* alters ecosystems and, therefore, the larger landscape and Earth system. The presence and distribution of water influence not

only the natural aspects of the landscape but also have significant impacts on the social, cultural, and economic interactions that occur in the landscape. For example, the anthropogenic transformation of the natural environment occurs whenever humans modify the landscape to meet specific needs and utilize available natural resources. This transformation, driven by socio-cultural, economic, and technological factors, significantly influences water dynamics and landscape configurations, impacting both ecological functions and human well-being. (Ferreira et al., 2009). Governance, planning, and management strategies must assess and combine the preservation of landscape diversity with the sustainable use of land resources (Simensen et al., 2018) and realize that they are intertwined with water resources. Fry (2001) and Sayer et al. (2013) consider the landscape a unifying concept within environmental integration. Land and water are elements that support the structuring of the landscape, and approaches to governance and management of water resources need to be integrated with the HLA and sustained for political instruments such as the European Landscape Convention.

The integration of both approaches, combined with the guidelines for implementing the European Landscape Convention, called from this point on S2S Landscape, can enhance the governance and management practice in the *continuum* to address complex challenges related to the use, preservation, and conservation of water resources and landscapes. These challenges, often referred to as wicked problems (Balint et al., 2011; Sayer et al., 2013), include issues such as pollution (marine litter – Lincoln et al., 2022; Mathews and Stretz, 2019; Rech et al., 2014), nexuses that involve interconnections between different elements, such as the water-biota-ecosystem nexus (Palmer and Ruhi, 2019), water-food-energy nexus (Hoff, 2011), food production-biodiversity conservation-provision of ecosystem services-poverty reduction nexus (Estrada-Carmona et al., 2014), forest-agriculture-water nexus, among others. According to Brito et al. (2021), the S2S approach expresses the scale and necessary elements to address complex governance systems and vast territories, and it demonstrates that the integration of actions goes beyond the processes that occur within the *continuum*, as the social, economic, cultural, and environmental characteristics of the entire system need to be considered. Integration with an HLA approach can contribute to a better understanding of the relationship between governance, people, and space, enabling stakeholders to minimize trade-offs.

The S2S Landscape offers a new perspective to fill gaps in governance and management practices of landscapes and water resources. It proposes a holistic strategy to combat fragmentation with an integrative approach, encompassing natural and social processes across various scales and geographical boundaries, thus overcoming traditional approaches' spatial

and scale limitations. Figure 2 demonstrates the integration synthesis of the proposed S2S Landscape approach. We interpret this approach as a circle of joint learning, negotiation, and reflection, representing one of the possible ways to integrate water resource governance and management proposed by S2S approach, combined with a hybrid landscape approach. Additionally, we consider the guidelines and implementation suggestions of the European Landscape Convention. The integration process drew from various sources to build the S2S Landscape approach. Granit et al. (2017a, 2017b) and Mathews et al. (2019) formed the foundation for the S2S approach. Arts et al. (2017), Bürgi et al. (2017, 2004), Freeman et al. (2015), Frost et al., 2006, Hersperger et al. (2010), Reed et al. (2020, 2016, 2014), Sandker et al. (2010), Sayer et al. (2013), Terêncio et al. (2021) and Thaxton et al. (2017) contributed to the hybrid landscape approaches (HLA) in harmony with the European Landscape Convention (ELC) and its recommendations (Council of Europe, 2000, 2008).

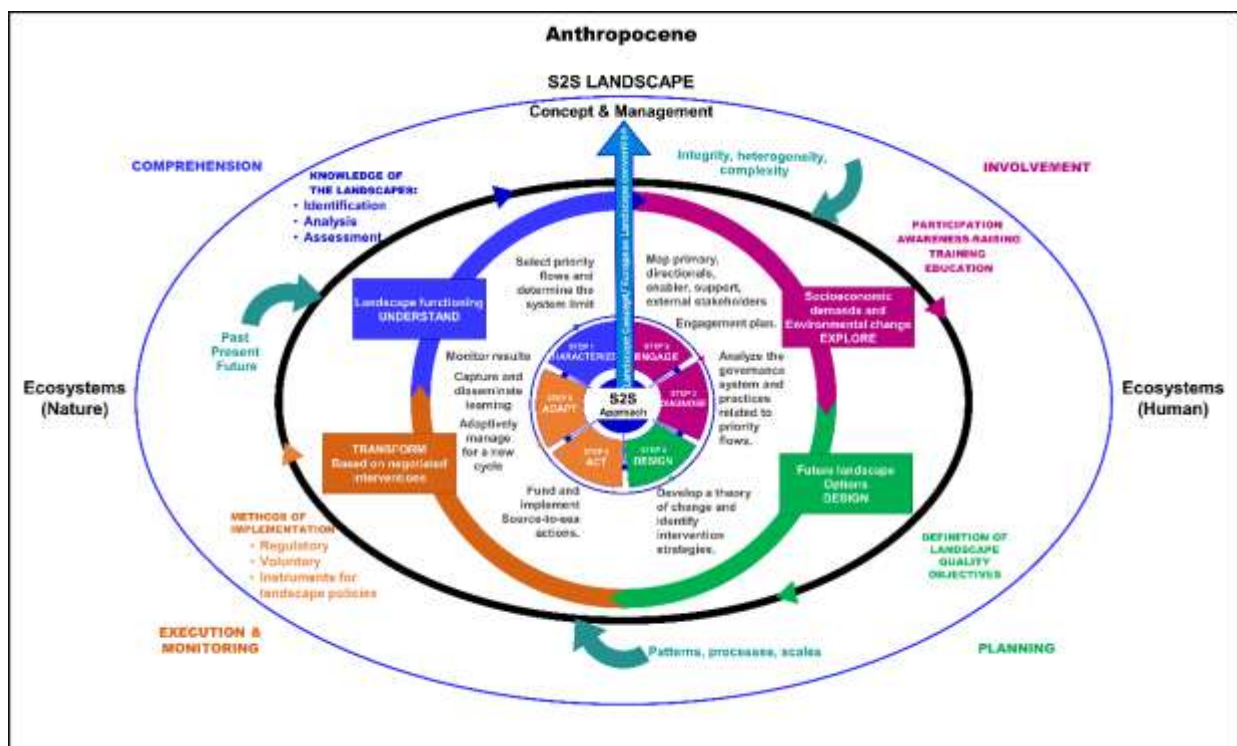


Figure 3-3 - Integrative Source-to-sea Landscape approach, built from the interaction between Source-to-Sea approach (S2S), Hybrid Landscape Approach (HLA) and European Landscape Convention (ELC). Source: authors.

The first cycle at the center of Figure 2 represents the proposed governance and management structure of the S2S approach, as proposed by Granit et al. (2017a, 2017b) and Mathews et al. (2019). This structure consists of 6 steps that consider the linkages between segments and sectors in order to identify and prioritize the issues to be addressed in the system: Characterize, Engage, Diagnose, Design, Act, and Adapt.

The second cycle, represented in Figure 2, which involves the governance and management cycle of the HLA approach, consists of four steps: Understand, Explore, Design, and Transform. The colors assigned to each step demonstrate their convergence with the S2S approach. However, these steps are not strictly sequential, as they can interact with others within the S2S approach and among themselves. These steps were inspired by the work of Bürgi et al. (2017) and adapted as a foundation to meet the needs of an HLA within the context of integrating with the S2S approach.

The subsequent third cycle represents the ELC (European Landscape Convention) and the recommended steps outlined in the CM/Rec(2008)3 Recommendations for the implementation of the Convention, which aims to establish rules for the protection, management, and planning of all landscapes based on a set of principles in Europe. Although non-binding, these guidelines serve as a framework for governance and management based on landscape sustainability and suggest fundamental steps in the process leading to landscape action: Knowledge of the landscape, Definition of landscape quality objectives, Participation, Awareness-raising, Training, Education, and Methods Implementation.

The final fourth cycle represents the proposed S2S Landscape approach and its steps within a broad Anthropocene vision, where we seek to integrate both Human and Natural Ecosystems, places where these complex processes and interactions occur. Throughout the entire process, elements such as integrity, heterogeneity, complexity, patterns, processes, scale, and the relationship with the past, present, and future are considered. The foundation of the approach is guided by a learning cycle and systems thinking. We will conduct the analysis following the four steps of the S2S Landscape approach to examine this integration.

3.4.4 Step 1 - Characterize - Understand - Knowledge (Comprehension)

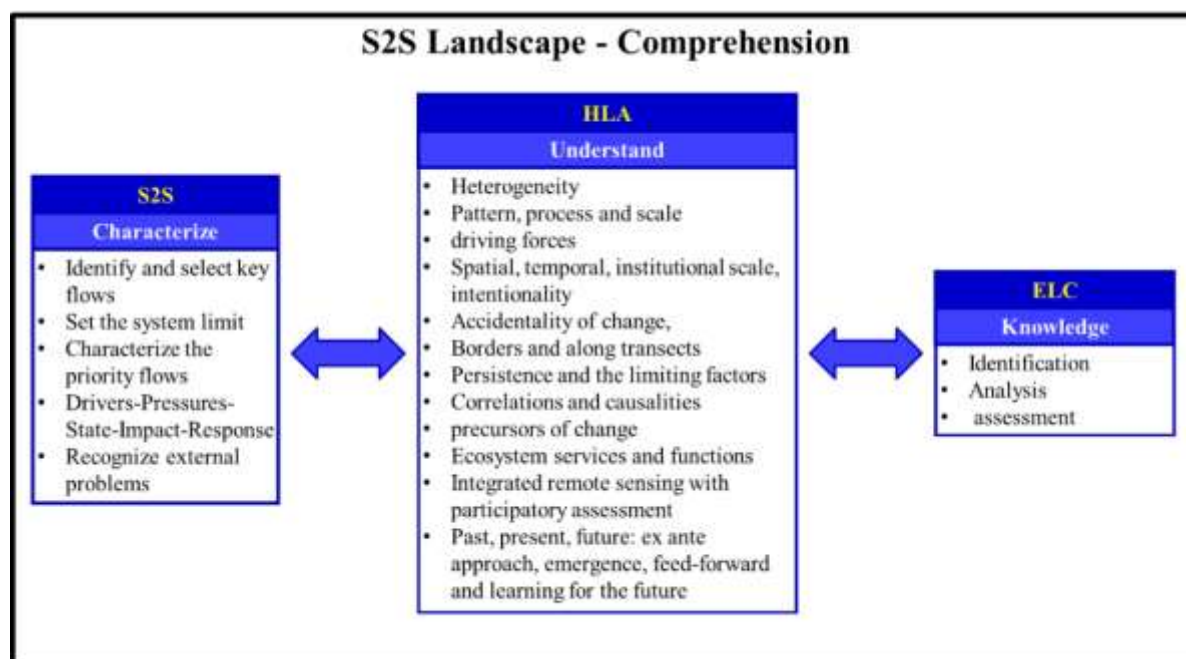


Figure 3-4 - Interaction between Characterize, Understand, and Knowledge steps that are encompassed by the Comprehension step in the S2S Landscape approach.

This step (Figure 3) integrates and enhances the elements of "Characterize" from the S2S approach, "Understand" from the HLA, and "Knowledge" from the ELC, forming the "Comprehension" step of the S2S Landscape approach. This integration not only aligns but deepens and advances the vision, knowledge, and understanding of the system in a holistic view that interconnects water, land, and human action. The spatial heterogeneity of the landscape, characterized by diverse ecosystems and varied attributes, is influenced by the presence and flows of water. The interdependence between water and the landscape profoundly impacts ecosystem functions, such as nutrient cycling, primary productivity, and species interactions.

It is necessary to characterize and select the main flows, defining which ones will be addressed and determining the system boundary in which it intends to operate. These flows connect subsystems (segments) in the *continuum* at different spatial scales and bring impacts or benefits to the system (Granit et al., 2017a). All flows have natural ranges of variation to which biodiversity and human activities have adapted over time. However, any variation beyond these natural ranges can disrupt species' life cycles, negatively impact human health, alter ecosystems, and disturb the social and economic systems that depend on these flows.

Therefore, comprehending water-related environmental processes is crucial. This entails recognizing the role of water in shaping the landscape, both in physical and biological terms,

and considering its socio-environmental significance. Water plays a vital role as an integrator of the landscape, operating across both space and time. The spatial heterogeneity of the landscape, characterized by diverse ecosystems and varied attributes, is influenced by the presence and flows of water. Hydrological processes and interactions between the natural and cultural components of the landscape are directly linked to water. This interdependence between water and the landscape profoundly impacts ecosystem functions, such as nutrient cycling, primary productivity, and species interactions.

To characterize and understand the entire system in the S2S Landscape approach, it is essential to integrate the concept of landscape towards its complexity. By considering water as a structuring element of the landscape and life cycles, we broaden our understanding of water-related environmental processes, moving beyond a merely utilitarian and fragmentary approach. Water is a much more effective agent in connecting landscape elements in space and scale. According to Wiens (2002), the conventional distinction between land and water does not play an important role in landscape ecology. What matters are patterns, relations, and spatial processes, not the substrate or the medium.

It is necessary to understand the drivers, pressures, and impacts of changes in the selected flows to delimit the system boundary. This delimitation of boundaries is important to focus on the impact and define the geographic scope of the study (Wang et al., 2021). However, the S2S Landscape approach emphasizes the importance of recognizing issues that originate outside the delimited system and establishing mechanisms for coordination and collaboration to explore joint solutions and synergies through partnerships. Other methodologies can be used in system characterization, but the Drivers-Pressures-State-Impact-Response (DPSIR) framework stood out, as it was identified that this methodology helps identify and avoid the risk of underestimating or neglecting system linkages (EEA, 2003; European Commission, 1999; Gari et al., 2015;; Kristensen, 2003; Nixon et al., 2003; Terêncio et al., 2021).

The persistence of the landscape (the capacity of a landscape to maintain its characteristics or spatial patterns over significant periods), as well as limiting factors and constraints to change, deserves the same attention as analyzing landscape change itself, as the existence of persistence does not imply the absence of driving forces. If appropriate driving forces, such as regulations and subsidies, counteract the forces of change, landscapes can exhibit temporal stability. Therefore, it is essential to discover how fast the landscape has changed, that is, to study the rate of change (Antrop 2000, Bürgi et al. 2004).

Methodologies using remote sensing, geographic information systems (GIS), or landscape mapping assist in the characterization of the area under the S2S Landscape approach

but should be complemented with expert assessments as well. The resolution level of an image or map determines whether elements of specific sizes within the S2S *continuum* area appear as landscape elements or not, and the order of flows provides a widely accepted framework for categorizing different streams (for example) as distinct landscape elements. Additionally, it is possible to categorize rivers as landscape elements based on their importance to human activities and culture. Categorizing coastal and marine features is equally essential to understanding the dynamics of both marine and coastal ecosystems and the connections of the *continuum* from river headwaters to the open ocean. This includes identifying areas of ecological importance and how impacts spread to coral reefs, estuaries, and marine life habitats, which play key roles in the sustainability of the marine environment (Bagheri et al., 2021; Nemec and Raudsepp-Hearne, 2013).

The HLA also includes tools that can help S2S Landscape approach to implement the holistic and systemic vision. For instance, landscape metrics are useful for quantitatively describing spatial patterns of the landscape (Leitão and Ahern, 2002). The composition and pattern of the landscape can be captured by metrics that can be arranged to show a landscape signature, unique for each type of landscape (Silva et al. 2020).

These processes align with the recommendations of the ELC as they provide integration of different approaches and enable the creation of a shared database that stakeholders can access. Sharing information on system characteristics facilitates and expands analysis, bringing transparency and organization to the process and facilitating the exchange of experiences among states, regions, and territorial communities at various levels and scales.

This step will lead to a comprehensive understanding of the whole system under the S2S Landscape approach. The outcome will be an assessment and diagnostic document that addresses the main flows, their alterations, and their impacts on the system, encompassing their characteristics and interdependencies in the landscape. It's important to note that stakeholders begin to be mapped during the diagnostic process so that the diagnosis can later be discussed, adapted, and validated. The participatory process introduced in the next step is not an isolated step but an aspect that permeates all stages of the cycle, highlighting the importance of adopting an inclusive approach from the beginning. Above all, this cycle is conceived as a learning cycle. This diagnostic will facilitate understanding the demand for ecosystem services (ES), enhance the mapping and the development of stakeholder engagement plans, and the analysis of the governance system.

3.4.5 Engage – Diagnose – Explore – Participation (Involvement)

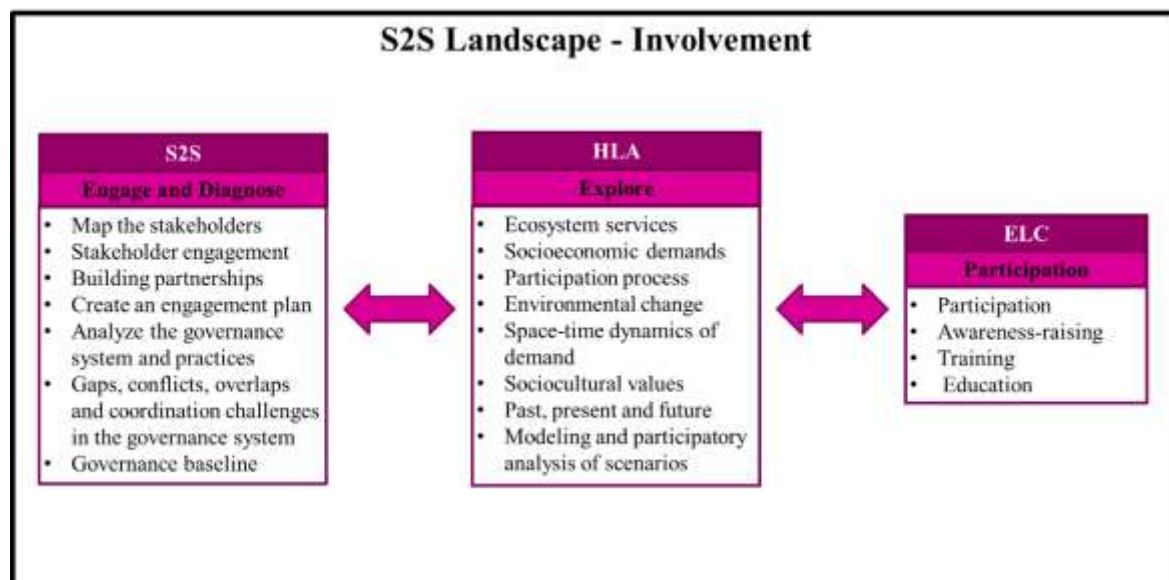


Figure 3-5 - Interaction between Engage, Diagnose, Explore, and Participation steps that are encompassed by the Involvement step in the S2S Landscape approach.

Designing a course of action requires a comprehensive understanding of the social and sector dynamics involved in the system. This involves distinguishing the primary stakeholders who are affected by the change of the defined flows and the target stakeholders who contribute to the change of the flows, the facilitating stakeholders who are institutions that provide or should provide conditions for changes to occur, the supporting stakeholders who are development partners or funders whose strategies may align with the desired outcomes and the external stakeholders who are individuals or groups outside the system boundaries but share interests in the outcomes (Mathews et al. 2019; OECD, 2015). The identification and mapping process starts in the previous step, as the diagnosis must be validated with the perceptions and knowledge of those directly involved, whether through workshops, meetings, digital feedback platforms, or other in-situ data collection methods. In any case, a database needs to exist, be updated periodically, and be freely accessible. This implies identifying who the main stakeholders are and how they are organized concerning the use and management of resources within the system (Granit et al., 2017b; Király et al., 2019) and creating a plan for their engagement (Ferreira et al., 2021a).

This step (Figure 4) is important to understand how the stakeholders are organized concerning the use and management of resources within the system (Granit et al., 2017b; Király et

al., 2019) and to create a detailed and clear plan for their engagement and outlining how they can input at each process phase, besides analyzing governance gaps and conflicts.

The functioning of the landscape is closely related to the production of ecosystem services (ES) (Metzger et al., 2021), and the scale at which ecosystem services can be used determines which stakeholders benefit from these services, including the sociocultural values of ecosystem services (Tengberg et al., 2012). Including the demand for ES in the S2S Landscape approach provides an understanding not only of the supply of ES but also of the degradation that can occur and the need for the preservation and conservation of these services for future generations, contributing to the understanding of stakeholders involved in both exploitation and conservation.

Understanding types of demand is also important so that we can work with process-driven indicators, including vulnerability, climate variability, disaster risk, cognitive and behavioral studies, political ecology, and evolutionary studies that can help link these social indicators to biophysical ones (Lin et al., 2021; Wolff, 2015). These studies are essential for understanding changes in social and environmental ecosystems and finding ways to raise awareness about the effects of our patterns and behaviors, moving beyond a purely monetary interpretation of value (Scholte et al., 2015) and emphasizing the importance of conserving and preserving ecosystems for human well-being. Lastly, they provide data for negotiation and engagement mechanisms. Hence the importance of it being participatory studies and processes as they reveal contradictions arising from the diversity of advocated value systems and enrich the process, allowing for knowledge validation, awareness, stakeholder responsibilities, and goal and action definition. Scholte et al. (2015) delve into various participatory approaches, providing insights into these processes.

Understanding the spatiotemporal dynamics of demand and how it drives ecosystem changes requires attention. There may be trade-offs between services and the stakeholders involved. For example, maintaining water flow in a watershed can benefit downstream communities but restrict direct access to water for upstream stakeholders (Scholte et al., 2015). Similarly, raising awareness and changing practices among upstream farmers and industries can reduce the transport of pollutants through watercourses, decreasing marine pollution (Francis and Herat, 2020; Mathews and Stretz, 2019). The objective is to understand the origins of current practices to identify specific paths for change, pairing socio-environmental conflicts as problems to positive actions as ongoing or possible solutions (Saito, 2013). The process can often lead to re-analyzing steps already being addressed and provoke an adaptation based on

the learning that accumulates as an action-research spiral coupled with the empowerment of the involved stakeholders in a participatory process (Berlinck and Saito, 2010).

Upon reaching this point, there is already a comprehensive understanding of the problem impacting the S2S Landscape system, including its characteristics, interdependencies within the system, landscape analysis, mapping of internal and external stakeholders, as well as the preferences for ecosystem service demands that drive the impact and change in the landscape and the S2S drainage area. The analyses and data collected so far constitute a solid foundation to initiate the analysis of how the governance system has contributed to and operates within the system.

In this way, it is necessary to analyze the gaps, conflicts, overlaps, and coordination challenges in the existing governance system and the social practices that are impacting the prioritized flows. The objective is to understand the origins of current practices to identify specific paths for change, pairing socio-environmental conflicts as problems to positive actions as ongoing or possible solutions (Saito, 2013). The analysis provides a governance baseline that allows for an understanding of the strengths and weaknesses of the current situation, leading to the identification of necessary changes. This analysis will reveal where the management of connections between segments in an S2S system is weak or absent and identify the consequences of actions that did not consider the system's functioning as a whole (Granit et al., 2017a).

As the S2S Landscape approach is based on systems thinking, it allows us to understand and deal with complex systems by recognizing the interdependence and interconnections among their governance elements. This helps us comprehend the system composed of various subsystems, processes, and stakeholders. It involves understanding the feedback and feedback loops of the past and current systems that sustain the implemented policies and practices (including collecting feedback from stakeholders such as local communities, scientists, environmental activists, and governments). We need to consider the long-term effects and systemic implications of actions taken in the present.

This means identifying conflicting policies, procedures, and regulations that may even be transferring impacts of activities from one segment to another, assessing collaboration between institutions to determine if they work together or are in constant conflict, and identifying existing policies, procedures, and regulations that can support S2S Landscape approach management. The understanding of how the governance system in a specific location responded or did not respond to the ecosystem change trajectory is also necessary (Olsen et al., 2011).

These institutions can be at the local, national, regional, or global levels, including community groups and resource management agreements.

According to Olsen et al. (2009, 2011), a "governance baseline" has two parts. In the first part, all documents are collected, and an analysis is conducted on how the governance system in a specific location responded or did not respond to the ecosystem change trajectory. In the second part, a new strategic approach will be described to design a new program or adapt an ongoing program to address the local ecosystem management issues and reduce its weaknesses. An important aspect that permeates this phase is the distinction between governance and management made by Olsen et al. (2009) and Olsen et al. (2003a, 2003b). Governance pertains to the fundamental objectives, institutional processes, and structures that are the basis for planning and decision-making, and it establishes the stage at which management occurs. On the other hand, management is the process through which human and material resources are utilized to achieve a specific objective within a defined institutional structure (Granit et al., 2017b; Olsen et al., 2009; Olsen, 2003a, 2003b).

In summary, the analysis of the existing governance system and the historical process that led to this structure helps to integrate elements of the natural sciences of the planning process with the governance dimension, allowing a better understanding of the factors that allow or resist the successful transition from the assembly and formal approval of an S2S Landscape project or program to success, or failure, in its implementation. The governance baseline can also help practice adaptive governance by providing a basis for comparative analysis and collaborative learning. This is useful for understanding the constant change of the ecosystem and the governance system. The Orders of Outcomes framework can be used to categorize governance outcomes into a sequence of 4 Orders (Step 3) to elucidate which combinations of actions and forces will be most effective in contributing to desired outcomes.

Furthermore, upon completing these steps, it becomes feasible to construct an interactive process that integrates the exploration of gathered and analyzed data and information with scenario modeling. This interactive process entails continuous stakeholder involvement to grasp how the system will react in the future under the current circumstances and how it might evolve if we take into account characteristics of the problem already identified in the previous step. At this point, a transition to the next step can be initiated by introducing a reflection and a predefinition of the desired environment for the area under the S2S Landscape approach we are working on in the future - that is, the quality objectives we desire.

Scenario analysis facilitates the process of observation, analysis, reflection, questioning, adaptation, awareness, and learning. By cross-referencing demand with needs, supply, and behavioral changes, we can identify potential positive and negative outcomes. This analysis also allows us to ascertain whether the mapping of stakeholders and the developed engagement plan effectively capture the different perspectives, interests, and needs. Thus, it allows the project team to tailor their communication and engagement strategies to meet the specific requirements of each stakeholder group and how they will be involved throughout the project's life cycle.

Through scenario analysis, it will be possible to better identify stakeholders' interests, positions, power, and influence, as well as the reasons behind the governance gaps and overlaps, including potential conflicts among stakeholders that influence adopted laws and policies. Scenario analysis is a powerful tool that enables stakeholders to think beyond current challenges and visualize different future conditions. This approach will help consolidate participation (it is important to have workshops), awareness-raising, show the need for training workshops (should be designed in the next step) in addition to developing environmental education and guide the planning and design of the Theory of Change (next step) options based on societal needs and requirements for change in the S2S Landscape system.

3.4.6 Step 3 - Design, Future options, Quality objectives (Planning)

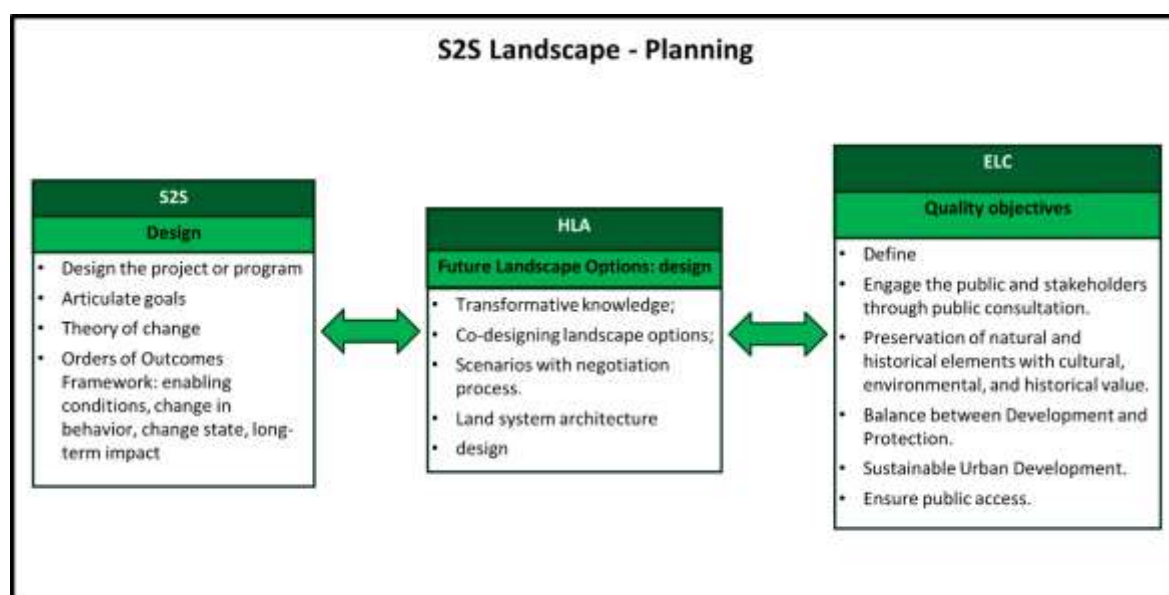


Figure 3-6 - Interaction between Design, Future options, and Quality objectives steps that are encompassed by the Planning step in the S2S Landscape approach.

In this step (Figure 5), the program or project takes place, where we define quality objectives and necessary activities to achieve the desired results by formulating a Theory of Change (ToC) (Stein and Valters, 2012; Weiss, 1995). The Theory of Change helps establish a logical chain and cause-and-effect relationships between the project or program's activities and the desired outcomes, assisting in the definition of clear objectives and strategies that align all project actions and lead to long-term impacts. The ToC essentially represents the link between the activities we undertake and the results we expect to obtain, recently becoming popular in Integrated Coastal Management (ICM), Marine Spatial Planning (MSP), IWRM.

With the results from the previous two steps and the participatory scenario-building exercise, the ToC registers what has been learned and highlights the relationships among them. When planning activities, identifying their connections, and setting goals that lead us to the desired outcomes, we utilize the Orders of Outcomes framework (Olsen, 2003b; UNEP/GPA, 2006) to understand the distinct steps and outcomes. The Orders of Outcome provides a method for organizing, defining, and measuring sequences of tangible results at different stages, which, if successfully achieved over time, and it can create progressively more sustainable conditions, facilitating monitoring and evaluation at each project or program stage. The structure categorizes the different levels of outcomes that can be achievable through intervention strategies.

The S2S Landscape approach and the ELC are aligned in favor of a participatory process in the definition of landscape quality objectives. The following step considers, the construction of scenarios that helps stakeholders in understanding the situation, identifying problems, aware their roles in the process, and designing what would be best to achieve environmentally sustainable results, respecting historical and cultural values. This helps prepare the project or program for uncertainties, as it allows for planning various possible futures, understanding how external variables can impact outcomes, and testing the robustness and resilience of the ToC in a dynamic environment. From this point, the need for changes in behavior can be perceived, as people go awakening of critical consciousness and empower themselves. Legal protection and subsidies can be used or envisaged and placed for consultation, establishing specific landscape and water resources regulations and studies, ensuring planning the promotion of the economic and social value of S2S Landscape approach to the fullest extent for long-term sustainability.

Therefore, the S2S Landscape approach comprises four orders of outcomes: enabling environment, behavioral change, implementation of interventions, and the identification of long-term impacts. It is important to emphasize that the use of the ToC integrated with the Orders of Outcomes during the planning and implementation phases provides a solid foundation for structuring and preparing the project or program, ensuring that it is well-founded, adaptable, and capable of responding to environmental changes and stakeholders' needs. This integration documents the relationships between interventions and their effects. During implementation, it guides all actions towards the desired outcomes, using clear benchmarks to assess progress and the effectiveness of interventions. In monitoring, the framework allows for continuous and accurate assessments, facilitating evidence-based adjustments to respond to emerging challenges. Finally, in the adaptation phase, the flexibility of the approach helps to adapt the program or project to environmental changes and stakeholders' needs, ensuring that changes are sustainable and continue to generate long-term benefits.

First-order outcomes establish the enabling conditions for changes to occur and be sustained in the long term (Enabling Environment). Governance is important in this step, both in terms of sector convergence and diplomatic relations, as it sets the conditions for change. It is essential to define intervention strategies with goals that will lead to increased technical, or governance capacity based on the governance diagnosis conducted in Step 2.

To achieve success, strategies must be designed to foster engagement and build political support by actively involving stakeholders in the decision-making process. These strategies should encompass mechanisms and tactics for coordination, cooperation, and collaboration

between different segments. It is necessary to implement changes in the behavior of key partners and stakeholders within the sphere of influence of the management activity. This includes changes in how people use the resources of the delimited S2S Landscape system, such as energy production, fishing, or tourism. Additionally, it is important to look at spatial planning to promote integrated management and planning of territorial use, considering the S2S *continuum* in its drainage area.

Spatial planning can encompass the protection of aquifer recharge areas, conservation of coastal ecosystems, and regulation of urban and industrial development, among other measures. The S2S Landscape dimension should be included in all territorial planning and development instruments, as well as in sectoral policies and instruments. Indicators are also defined to monitor institutional changes (such as the creation of new policies or regulations), behavioral changes (changes in how people use resources), and social and environmental changes (such as improvements in water quality and biodiversity). Additionally, the science of design can be used to create innovative and adaptable solutions for the identified challenges, considering the needs of stakeholders and future changes.

Second-order results are the "behavioral change" resulting from intervention strategies designed to support new practices and the suggested policy reforms associated with problem analysis aimed at restoring relevant aspects of the S2S Landscape approach for the benefit of key stakeholders. Result evaluation is directed towards documenting and analyzing the required behavioral changes, which are categorized as changes in the behavior of target user groups, changes in the behavior of major institutions, and changes in how and where financial investments are made. This leads to the emergence of new forms of collaborative actions among institutions, partnerships between the government and civil society, and changes in user behavior. This may involve evaluating the effectiveness of educational workshops or assessing the impact of new regulations on the development of the S2S Landscape approach. Second-order results are focused on behavioral changes rather than changes in the state of the ecosystem. These behavioral changes are necessary to achieve third-order results, which involve improvements in quality of life, income, or engagement in alternative livelihoods in target communities.

The focus of third-order results is on implementing intervention strategies that encompass process monitoring and evaluation, stress reduction, environmental and socioeconomic status indicators, and capturing learning for dissemination and adaptive management. The goal is to achieve improvements in the ecosystem and the quality of life for people living in communities along the whole area under the S2S Landscape approach, by establishing valid

cause-and-effect relationships between program activities and positive changes in the ecosystem and quality of life for people. These results represent the reward for appropriate and sustained achievements in institutional and behavioral change.

The fourth-order results are the Long-Term Impact. The objective is to establish a balance between social and environmental conditions, recognizing assumptions and uncertainties, along with a table of intervention strategies involving the relevant stakeholders who need to be engaged and the linkages between strategies and established results. The ToC, at this step, becomes the foundation for monitoring and adaptive management in Step 4. The developed strategies will be implemented in the next step.

3.4.7 Step 4 - Act, Methods of implementation, Transform and Adapt (Execution & Monitoring)

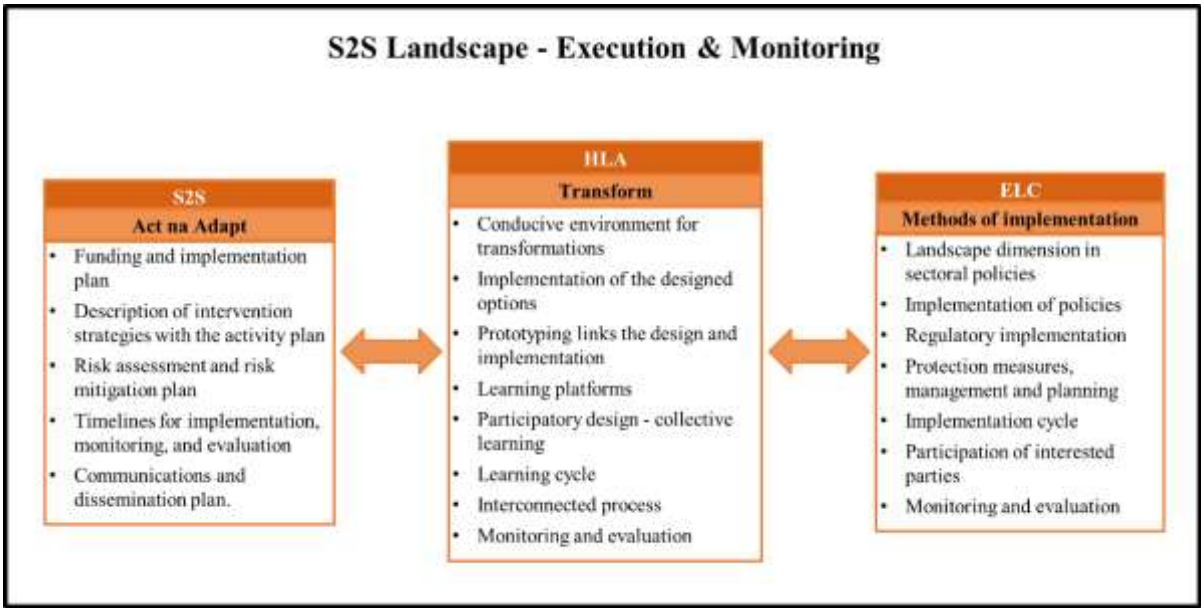


Figure 3-7 Interaction between Act, Methods of implementation, Transform, and Adapt steps that are encompassed by the Execution and monitoring step in the S2S Landscape approach.

The financing strategy and implementation plan will be developed in this step (Figure 6). A Source-to-sea Landscape program or project can follow traditional financing approaches. However, due to its systemic nature, this approach may give rise to new stakeholders in the outcomes, including beneficiaries located upstream or downstream of the program's activities, interest groups from various segments, and development partners with cross-sectoral interests or broader geographic scopes. These dynamics often result in innovative financing strategies. Consequently, funding sources diversify and encompass the public sector, do-

nors, and the private sector through various mechanisms, such as the blended finance resulting from the combination of public sector and private donors funding with innovative economic instruments, such as payment for ecosystem services (PES), facility and value chain certification according to corporate social responsibility goals, investments in green infrastructure, public-private partnerships (PPPs), internalized water pricing, green bonds, among others (Granit et al., 2017b; Money, 2018a, 2018b; Qadir, 2018; WWC and OECD, 2015):

It is essential to ensure continuous investments in freshwater and marine water resources and the landscape to secure sustainable financing. In this context, governance is central as the foundation for any Source-to-Sea Landscape programs and projects. Monitoring discussions and enhancing understanding of funding mechanisms and the value of water and landscape are paramount (Griesinger and Michels-Brito, 2022; GWP, 2023; Money, 2018b, 2018a; OCDE, 2018; Rees et al., 2008; van Hofwegen, 2006; WHO, 2016; WWC and OECD 2015).

The implementation plan is developed based on the Theory of Change (ToC), defining activities for each intervention strategy and establishing a timeline for implementation, monitoring, and evaluation. The participatory approach is present throughout the project or program cycle and serves as the basis for the implementation plan as well. Selecting indicators is crucial to confirm the assumptions underlying the ToC and provide information to stakeholders about the project or program's impact. Engaging them in the process of selecting goals and indicators helps ensure their commitment and capture their individual interests. These indicators should monitor progress in the implementation of the plan and measure the expected outcomes. They need to monitor progress towards first to fourth-order outcomes, covering different areas such as enabling conditions, changes in behavior and practice, shifts in the state of the system and priority flows, and progress towards the desired long-term impact, for example (Bertule et al., 2017; Mathews et al., 2019): process indicators, stress reduction indicators, environmental state indicators, and impact indicators.

The monitoring system must be designed to provide feedback on the effectiveness of the S2S Landscape approach and identify areas for improvement. By using these indicators, the results of the prototypes are confirmed, and the assumptions of the theory of change can be tested and adjusted if necessary. Additionally, they can assess the level of adoption of the S2S Landscape approach management by stakeholders and its formalization in governance mechanisms. It is essential to promote open dissemination of information, technology, and processes within the Source-to-Sea Landscape approach to make information, knowledge, and learning more accessible. Regardless of the strategy used, it is important to actually implement some form of information repository to coordinate, track, monitor, and evaluate the program

and project. It is crucial to have the support of stakeholders and external parties as they play a significant role in transferring lessons learned and communicating results, both locally and globally.

3.5 The overall spiral of continuous improvement and re-planning

The continuous monitoring and evaluation enabled the verification of the anticipated advancements outlined in the ToC, allowing for revisions and adjustments to the implemented strategies and actions, resulting in new planning within the S2S Landscape approach. This process facilitated the understanding of how governance and management of the S2S Landscape approach were adopted and formalized within governance mechanisms such as laws, policies, regulations, funding, partnerships, and procedures, among others. The conception of the S2S Landscape is based on systems thinking, practical learning, participation, and adaptive governance and management. The continuous spiral of steps for the improvement of the S2S Landscape is similar to the Lewinian spiral for action-research (a spiral of planning, action, and fact-finding about the result of the action, according to Lewin (1946)). The process contributes to generating knowledge and interactive management of the governance, management, and learning cycles, allowing an in-depth analysis of how intervention strategies responded to the established objectives. In this way, it becomes possible to evaluate both the unexpected results and interactions among different segments of the S2S Landscape, including the positive and negative impacts that reverberated throughout the entire system.

A comprehensive understanding of the system in focus, the stakeholders involved, governance, management, and adopted practices is paramount, as it can lead to adjustments in the implemented strategies. These adaptations can provide insights that broaden the understanding of connections along the S2S Landscape *continuum*. As learning about the system and its outcomes advances, the S2S Landscape approach gains renewed momentum and becomes applicable on broader scales. It is important to highlight that systematic learning has been and is facilitated by established learning and information platforms, which overcome critical obstacles to transformative research, such as diverse objectives, needs, priorities, divergent values, and power imbalances.

The S2S Landscape approach brings a spiral that highlights how the process is continuous and interconnected. The incorporation of scenarios emerges as a valuable strategy for adapting and expanding the scope of the S2S Landscape approach. Scenarios allow for exploring different possible futures and their implications, providing crucial information for decision-making and preparing for uncertainty. They assist in evaluating emerging trends, anticipating future changes, assessing risks and opportunities, testing varied approaches, and guiding project or program scope expansion. It is essential to emphasize that it must be conducted collaboratively, involving different stakeholders to ensure the consideration of diverse perspectives and knowledge in constructing scenarios and formulating new adaptive strategies. It is a moment that showcases and validates the outcomes while also laying the groundwork for future endeavors. Figure 7 provides a visual overview of how the S2S Landscape spiral corresponds to a continuous cycle of Comprehension-Involvement-Planning-Execution & Monitoring, resulting in what we call the S2S Landscape approach.

It considers water as a guiding thread connecting a diverse tapestry of environments. Each environment plays a unique role, but they are all pieces of a larger, interconnected landscape. Actions in a single location reverberate throughout the landscape, creating a web of complex connections.

This holistic view of the Source-to-sea Landscape approach helps us understand the complex relationship between water and ecosystems and how our actions regarding water affect the landscape and vice versa. Considering the landscape is essential in the water sector; it is like examining the body (the landscape) and its venous system (the water), comprehending its internal connections within that body, and its external interactions with the universe. As the interaction between water and landscape changes, the physical, biological, and cultural context also transforms. Therefore, this approach can be the key to addressing the challenges of governance and sustainable resource management in an interconnected and constantly evolving world.

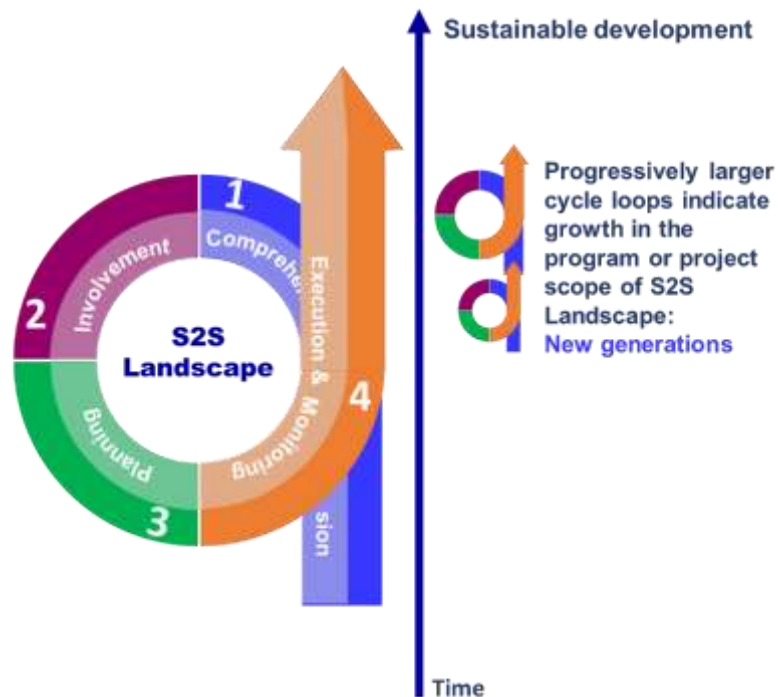


Figure 3-8 Source-to-sea Landscape approach - Step 1: Comprehension; Step 2: Involvement; Step 3: Planning; and Step 4: Execution & Monitoring.

3.6 Conclusion

This research analyzed the interactions and connections between the S2S approach, landscape concepts, and the European Landscape Convention (ELC) guidelines. The analysis and theoretical integration of landscape concepts resulted in the conception of a hybrid landscape vision, which we named and adopted as the Hybrid Landscape Approach (HLA). HLA embraces and encompasses both aspects related to human and cultural relationships and the inherent benefits of technologies. This hybrid perspective aligns with the S2S approach and the ELC guidelines. By analyzing the principles of these approaches, we confirmed their adherence, allowing us to consider these principles as symbiotic and validate integration. The integration of the steps of each approach resulted in a new governance and management approach, which we named the S2S Landscape approach.

The S2S Landscape approach encompasses four essential steps (Comprehension, Involvement, Planning, and Execution & Monitoring) to understand, innovate, learn, design, implement, and assess projects and programs related to water in the landscape. It addresses the complex connections that water holds within the landscape, considering physical, biological, socio-environmental, and economic aspects across all segments, from land to the open ocean.

Additionally, it promotes a transdisciplinary process that goes from problem identification to solution design and practical implementation. This approach can be the path to addressing the challenges of sustainable resource governance and management in an interconnected and ever-changing world in a systemic view.

BUILDING BRIDGES OVER FRAGMENTED WATERS: THE SOURCE-TO-SEA LANDSCAPE APPROACH AS A CATALYST FOR POLITICAL COHESION IN EU WATER MANAGEMENT

Abstract

This study investigates the coherence and integration of the European water and marine Directives (Water Framework Directive, Groundwater Directive, Marine Strategy Framework Directive, and Maritime Spatial Planning Directive) through the lens of the Source-to-Sea Landscape approach. Based on systems thinking, the approach framework integrates terrestrial, freshwater, and marine environments by addressing interconnected ecological, cultural, and governance processes. Using a qualitative, analytical-deductive method, the study employs content analysis and a matrix-based evaluation to assess normative alignment across twelve subcriteria organized into two main axes: Systemic Vision of Territorial Processes (Diagnosis) and Governance and Management (Action). The results reveal a persistent fragmentation in policy coordination, a lack of binding mechanisms to address emerging challenges (such as climate impacts and emerging pollutants), and limited incorporation of the landscape concept as a unifying link for the land–freshwater–marine *continuum*. Atmospheric processes and land-sea connectivity remain underrepresented, weakening policy responsiveness to hydrological and climate variability. The findings highlight the importance of strengthening multilevel governance, harmonizing monitoring systems, and promoting integrated planning instruments. The Source-to-Sea Landscape is proposed as a complementary strategic framework to existing

European Union instruments, enabling coherent actions across scales and sectors. Practical implementation pathways include integrating water and marine planning instruments, developing regional pilot projects (co-pilots), and aligning with EU climate adaptation and funding strategies. The Institutionalization of the Source-to-Sea Landscape could place the European Union at the forefront of integrated territorial governance, ensuring the sustainability of water resources and the protection of ecosystems from source to sea.

Keywords

S2S Landscape, European Union Directives, Policy integration, Water Resources, Environmental governance, Land–sea connectivity, Sustainability

4.1 Introduction

Policy instruments and legal frameworks play an important role in supporting the objectives, processes, and structures of water resources and landscape governance, thereby creating an enabling environment for planning and decision-making (Bouwma et al., 2015; Pahl-Wostl et al., 2012). However, when these instruments are not coordinated, their effectiveness is compromised. The fragmentation of governance approaches reflects this disarticulation among policy instruments, legal frameworks, and regulations, which often overlap and lack clear definitions of roles and jurisdictions (Ahonen et al., 2022; Granit et al., 2017).

In this context, the challenges for policymaking are significant, encompassing conceptual, institutional, and power issues, especially in terms of identity issues, which hinder overcoming fragmentation and directly impact the effective governance of water resources and the landscape. These challenges highlight the need for approaches that recognize the systemic and interdependent nature of natural resources. Understanding the Earth as a system (Steffen et al., 2004) and recognizing that water (hydrosphere) connects the lithosphere, atmosphere, and biosphere reinforces the need to view water as an integrated system that transcends political and sectoral boundaries. Therefore, policy instruments and legal frameworks need to be integrated both vertically and horizontally, and knowledge (technical, scientific, and traditional) must be shared across sectors, institutions, and governance scales. This continuous flow of information is essential to ensure balanced governance arrangements, strengthen the adaptive

capacity of systems, and thus create the necessary conditions for sustainable management of water resources and landscapes. (Armitage et al., 2012; Granit et al., 2017; OECD, 2023).

The source-to-sea landscape (S2S Landscape) approach (Michels-Brito et al., 2024) capitalizes on this vision and proposes a framework that integrates all levels to achieve sustainable governance of water resources and landscapes. It emphasizes that the landscape can serve as a unifying factor by integrating the drainage basin, land use, and sociocultural aspects within a holistic view from the source to the sea. This includes groundwater and atmospheric water, encompassing various ecosystems and communities along the watercourse to the open ocean. From this synthesis emerges an innovative conceptual proposal, in which the landscape is understood as a dynamic and integrative process—ecological, spatial, and cultural—that structures the governance of socioecological systems along the source-to-sea *continuum*. Water is thus recognized as a structuring element of the landscape, not only for its physical and biological aspects, but also for its centrality in socio-environmental links, acting as an integrator that operates across space and time (Michels-Brito et al., 2024). This perspective aligns with Wiens's (2002) view that the conventional distinction between land and water does not play a significant role in landscape ecology. What matters are the patterns, interactions, and spatial processes, not the substrate or the physical setting. In this way, the approach overcomes the spatial and scale limitations of existing approaches by encompassing socio-environmental processes beyond the watershed, integrating the continuity of vegetation patterns and cultural organizations.

The approach is based on systems thinking (Koskinen, 2013; Folledo, 2000), which recognizes the interdependence among ecological, social, and institutional systems, allowing for the effective management of the complexity inherent in environmental governance. This perspective also supports an integrated reading of dynamics over time, considering the past, present, and future, as a basis for more informed and sustainable decisions. It starts with the need to establish an institutional and normative baseline, identifying conflicting policies, regulations, and practices that hinder coordinated action. Understanding how governance systems have responded — or not — to ecosystem changes at different scales is essential for developing programs and projects that are consistent with sustainability objectives. This aligns with previous research on governance coherence and policy integration (Armitage et al., 2012; Granit et al., 2017; OECD, 2023).

Therefore, convergence between legal frameworks, regulations, and policy instruments is essential to support planning, implementation, evaluation, and monitoring. These alignments strengthen confidence in the participatory process and attract financial resources for investment (Jägerskog et al., 2013; Mathews et al., 2019).

In the pursuit of creating an enabling environment for water resources and landscape governance and management, Europe has innovated over the past two decades, adopting new legislation, policy instruments, and measures. The goal is to achieve Good Ecological Status (GES) and Good Chemical Status (GCS) in freshwater ecosystems and Good Environmental Status (GES) in marine ecosystems. Although both statuses are officially abbreviated as GES, this article adopts "Eco-GES" for the freshwater context and "Env-GES" for the marine context for clarity. Among the main regulatory instruments, the European Union directives stand out, such as the Water Framework Directive (WFD - 2000/60/EC), the Groundwater Directive (GWD - 2006/118/EC), the Marine Strategy Framework Directive (MSFD - 2008/56/EC) and the Maritime Spatial Planning Directive (MSPD - 2014/89/EU). In addition to these directives, within the framework of the Council of Europe, the following stand out: the European Landscape Convention (2000), the first international treaty dedicated exclusively to landscape, and the Recommendation CM/Rec(2008)3, which provides methodological guidance for implementing the Convention. Based on this set of legal and policy instruments, it becomes essential to understand the theoretical framework and regulatory design that support them, in order to assess their contribution to sustainability in the water resources and landscape governance. European directives implicitly or explicitly adopt the ecosystem approach, which requires adaptive management models capable of responding to continuous transformations and uncertainties. The pragmatic approach is another characteristic, in which cyclical plans and programs are used to achieve environmental goals (Soininen & Platjouw, 2018).

However, the very characteristics that give flexibility and adaptability to directives can, paradoxically, hinder the consolidation of stable, long-term management and planning practices. In light of this, it is necessary to investigate the extent to which these instruments contribute to institutional fragmentation or, conversely, promote the creation of an enabling environment for the integration and effective application of systemic approaches to water resources and landscape governance and management.

Therefore, this research aims to analyze and assess the extent to which this main set of directives related to the governance and management of freshwater and marine water resources (Directives: 2000/60/EC; 2006/118/EC; 2008/56/EC; 2014/89/EU) create the normative and institutional conditions necessary for the implementation of an integrated approach such as S2S Landscape. Using this framework as a reference, the study aims to identify the degree of conceptual and practical adherence of these directives to the principles and structuring elements of the approach, highlighting any possible synergies, gaps, or contradictions that may impact planning, implementation, and monitoring efforts. At the same time, the analysis contributes to the discussion of the potential of the S2S Landscape approach itself as a guiding framework for strengthening environmental governance and the sustainability of water resources and landscapes in Europe.

4.2 Method

This study employed qualitative, analytical-deductive research methods, as described by Ritchie and Spencer (1994), Lacey and Luff (2007), Richardson (2012), and Teixeira et al. (2014). Content analysis (Bardin, 1979) was used at two analytical levels. First, to critically interpret the normative content of Directives 2000/60/EC, 2006/118/EC, 2008/56/EC, and 2014/89/EU, in order to identify the intentions and perceptions underlying their concepts, principles, and political dimensions. Second, to define and operationalize the analysis criteria. These criteria were developed based on the concepts, principles, and key elements of the S2S Landscape approach. In this analytical-deductive process, content analysis facilitated the clarification, classification, and categorization of key elements (Richardson, 2012).

According to Bardin (1979), content analysis is a set of communication analysis techniques that aim to obtain, through systematic and objective procedures, quantitative or qualitative indicators that allow the inference of knowledge related to the conditions of production and reception of these messages. This method is recognized for its versatility in revealing what is implicit or explicit in texts, organizing them in ways that generate analytical categories.

The methodological phases proposed by Bardin (1979, pp. 95–101), including pre-analysis, exploration of the material (with coding and categorization), and processing of the results, were essential for organizing the principles of the S2S Landscape approach into analytical criteria and subcriteria. This structuring allowed the normative content of the directives to be analyzed systematically and in line with the deductive logic of the study.

The use of the concepts and principles of the S2S Landscape as an analytical foundation was a central element of this methodology, providing a structured set of normative and operational guidelines for assessing the coherence of public policies with the objectives of this new approach to governance and management. Principle-oriented analysis allows us to capture not only the presence or absence of specific normative contents, but also the degree to which these contents reflect fundamental values such as integration, equity, adaptability, sustainability, among others. In addition, principles act as ethical and operational standards that shape the legitimacy of governance and management practices, functioning as criteria for interpreting intentions and guiding institutional transformations (OECD, 2015; Rosso, 2025; Vayena & Blasimme, 2020).

The systematization of the approach's core principles led to the definition of two main analytical criteria: (1) Systemic Vision of Territorial Processes (Diagnosis) and (2) Governance and Management (Action). Each of these criteria was broken down into six sub-criteria, totaling twelve analytical dimensions. The first criterion enables us to evaluate the extent to which normative instruments acknowledge and incorporate a systemic and integrated understanding of territorial processes, particularly in relation to water and the flows that structure socio-ecological systems. The second criterion focuses on institutional action and examines the presence of mechanisms and conditions that enable the coordination of policies and the effective implementation of the S2S Landscape approach. This organization between diagnosis and action aims to reflect the operational logic of the approach, which requires both a systemic reading of the territory and the institutional capacity to act in an integrated, adaptive, and sustainable manner.

To operationalize the analysis, an analytical matrix was developed, inspired by the proposal of Leopold et al. (1971), which enables the structuring of the relationship between the criteria and the normative content of the directives. The matrix was filled with graphic symbols that could express how each category was considered in relation to the directives. The discussion session presents the analysis of the results of the Matrix. This tool enabled a transversal and comparative reading, allowing for the identification of not only the normative support points for implementing the approach but also the gaps and overlaps that could compromise its effectiveness.

In addition, the research included a cross-sectional analysis of the degree of integration between the directives themselves, through the construction of a comparative matrix (see Table SM1, supplementary material). This matrix sought to highlight synergies, overlaps, and gaps between the instruments. Although this second analytical tool does not form the main body of the criterion-based analysis, it provides an additional basis for interpreting the level of regulatory and institutional fragmentation among European water governance instruments.

4.3 Results

This section presents the results of the categorization process. The process led to the development of two main analytical criteria, built based on the core principles of the approach: (1) Systemic Vision of Territorial Processes (Diagnosis) and (2) Governance and Management (Action). To facilitate a more precise and comprehensive analysis, each criterion was broken down into 6 subcriteria, totaling 12 analytical dimensions. The definitions of each subcriterion are detailed in Tables 1 and 2. Next, the results of the normative analysis are summarized through the Analytical Matrix (Figure 1), which relates each subcriterion to the selected European guidelines.

4.3.1 Systemic View of Territorial Processes (Diagnosis) – Criteria 1

The S2S Landscape approach adopts a holistic and integrated perspective on the flows and processes of the source-to-sea system, acknowledging that changes in one component impact the entire system. This criterion recognizes the complexity and interconnection between the natural, social, economic, and cultural components, from the perspective of the hydrological cycle. It is based on the understanding that fresh and marine water are the same *continuum*, in which nature and culture are integrated, extending beyond the river basin and visible geographic limits, thereby integrating land and water within the landscape. Therefore, to enable a more precise and structured analysis, this criterion was subdivided into six subcriteria (Table 1), allowing us to specifically explore the different aspects of the hydrological cycle and the socioecological interactions that comprise it.

Table 4-1- Subcriteria of the Criterion Systemic View of Territorial Processes

SUBCRITERIA	DEFINITION
Flows	It refers to the visible water flows across the landscape in the upstream-downstream direction. This includes surface runoff and associated processes that connect subsystems at different scales. In this subcriterion, the main flows include water, biota, sediments, pollutants, and materials, which interact and influence the ecosystem services provided by the drainage system
Cycle	It relates to the understanding and appreciation of the processes that return water from downstream to upstream, from the oceans to the springs, through atmospheric processes that are an important part of the hydrological cycle. These processes are essential for the system's feedback, providing knowledge of precipitation and humidity patterns, and supporting planning.
Nature-culture integration	This criterion considers the interrelation between natural and cultural systems, as well as socio-ecological issues, addressing the hydrosocial concept (Linton, 2014). The S2S Landscape expands this concept by recognizing that human, social, and cultural activities alter the water cycle. In diagnostics, it is crucial to analyze the socio-ecological dimension and nature-culture integration to identify system impacts and changes.
Land-water integration in the landscape	This criterion focuses on the biophysical interaction between land and water within the landscape. It examines how alterations in the landscape, such as changes in land use and infrastructure, affect water flows and associated ecosystem services. It includes the continuity of vegetation patterns that affect water flows within and beyond the watershed.
Freshwater-marine water integration	This criterion recognizes that freshwater and marine systems are part of the same hydrological <i>continuum</i> . It examines how activities and changes in freshwater environments (rivers, lakes, and estuaries) impact marine ecosystems and vice versa. This is crucial for understanding how upstream activities can have a significant impact on downstream marine ecosystems. Additionally, marine processes such as tidal actions and storms can influence estuarine and fluvial dynamics.
Integration of surface and sub-surface processes	This criterion focuses on the interaction between surface waters (rivers, lakes, and runoff) and groundwater (aquifers and groundwater flows). It examines how these interactions influence water availability and quality, as well as associated ecosystem services.

4.3.2 Governance and Management (Action) - Criteria 2

Governance and Management (Action) is the criterion that encompasses the essential principles and practices for effectively coordinating and implementing policies and actions at different levels and sectors. Based on systems thinking, the approach emphasizes the need to ensure that governance and management policies and practices are effective and sustainable, providing a solid foundation for decision-making and coordinated action. This means that processes must be adaptive and resilient, and active participation is essential to ensure the long-term sustainability of natural resources and ecosystems. At this point, it is important to distinguish between governance and management, as each plays a distinct yet complementary role in the policy and implementation cycle. Governance provides the institutional framework and objectives that guide planning and decision-making, while management mobilizes the necessary resources to implement actions within that framework (Olsen et al., 2009). To enable a more precise and structured analysis, this criterion was also subdivided into six subcriteria (Table 2) to reflect the main operational attributes required for effective governance and management within the S2S Landscape context.

Table 4-2 Subcriteria of the Criterion Governance and Management (Action).

SUBCRITERIA	DEFINITION
Multilevel	Multilevel governance and management refer to the coordination and collaboration of different levels of government and other stakeholders in formulating and implementing public policies.
Intersectoral	It refers to the coordination and collaboration between different sectors or areas of activity to achieve common goals. Intersectoral management integrates knowledge, resources, and actions from multiple economic and social sectors (such as agriculture, industry, conservation, tourism, etc.) in formulating and implementing management policies, promoting synergies, and avoiding use conflicts.

Adaptive and Resilient	Adaptive governance refers to the capacity of institutional structures and political processes to adjust flexibly and effectively to changes and uncertainties. Resilience in governance relates to the ability of these systems to recover and maintain their essential functions after disruptions or adverse events. Adaptive management continuously adjusts implementation policies and operational practices based on new knowledge and conditions, ensuring the efficient use of human and material resources.
Participatory	This criterion refers to the active and continuous involvement of internal and external stakeholders in the delimited system in the decision-making process. It is understood as a systemic and cross-cutting element that underpins adaptive governance and enhances the co-creation of knowledge, conflict resolution, and legitimacy in environmental management. It is not treated as a standalone phase but as an ongoing principle embedded throughout all stages of governance.
Includes internal and external factors of conservation (persistence) and change	This subcriterion considers a system's internal and external influences when formulating and implementing policies. This means taking into account the forces that maintain the system's stability and continuity (conservation), as well as the forces that drive innovation and transformation (change), including the issue of persistence. It is important to consider internal (biological, physical) and external (social, economic) factors that influence persistence and change in management.
Long-term sustainability	This subcriterion refers to the ability of governance and management systems to ensure the conservation and sustainable use of natural resources and ecosystems over the long term. It focuses on balancing current needs with the ability of future generations to meet theirs, considering cumulative environmental, social, and economic impacts.

4.3.3 Result Matrix

After defining and operationalizing the analytical criteria and sub-criteria, a qualitative analysis of the normative content of the four selected European directives was conducted. Figure X presents the summarized results of this analysis, indicating the degree of adherence of each directive to each subcriterion.

The matrix provides a comparative view of the correspondence between the normative contents of the directives and the elements considered fundamental by the S2S Landscape

approach, highlighting areas of convergence, gaps, or partial alignment. To facilitate interpretation, three visual symbols are used, the legend for which is incorporated into the figure

Criteria (Level 1)	Criteria (Level 2)	Directive 2000/60/EC (WFD) Updated	Directive 2006/118/CE Groundwater Directive (GWD) Update	Directive 2008/56/EC (MSFD) Updated	Directive 2014/89/UE (Maritime Spatial Planning (MSPD)
Systemic View of Territorial Processes (Diagnosis)	Flows	■	□	▨	▨
	Cycle	□	□	□	□
	Nature-culture integration	▨	▨	▨	▨
	Land-water integration in the landscape	▨	▨	▨	▨
	Freshwater-marine water integration	▨	□	▨	▨
	Integration of surface and subsurface processes	▨	▨	□	□
Governance and Management (Action)	Multilevel	■	■	▨	▨
	Intersectoral	■	■	■	■
	Adaptive and Resilient	▨	▨	▨	▨
	Participatory	■	▨	■	■
	Includes internal and external factors of conservation (persistence) and change	■	▨	▨	■
	Long-term sustainability	▨	▨	▨	▨

Figure 4-1 - Result Matrix – Summary of the analysis of the criteria and subcriteria against the normative content of the EU directives. The black square indicates that the directive meets the subcriterion, the square with diagonal stripes signifies that the directive.

4.4 Discussion

The analyzed directives present their own principles, guidelines, goals, and objectives, which guide their implementation by the European Union and its Member States. This section analyzes how these guidelines align with the criteria and subcriteria of the S2S Landscape approach, assessing whether they fully meet, partially meet, or fail to meet these subcriteria. Additionally, the analysis aimed to understand to what extent these standards create an enabling

environment for implementing the Source-to-Sea approach, or whether the S2S Landscape logic itself can be used as a tool to enhance the integration and sustainability of policies.

4.4.1 Systemic View of Territorial Processes (Diagnosis)

4.4.1.1 Flow

The WFD meets the Flow subcriterion, especially by adopting a river basin-based approach, which integrates the management of inland, coastal, and transitional waters, supporting a longitudinal (upstream-downstream) and connected view of flows across subsystems. Its main objective is to prevent the degradation of aquatic ecosystems, improve water quality, and promote the sustainable use of water resources by ensuring pollution reduction and the protection of water-dependent ecosystems. It recognizes the importance of water flows along the *continuum*, particularly in the definitions of transitional and coastal waters and their interactions with inland waters (Arts. 1 and 2). Recital 17 highlights the vulnerability and the need to manage water quality in coastal and estuarine ecosystems. Article 3 reinforces the need for coordination between river basin districts, including coastal waters, suggesting integrated management of flows from upstream to downstream. Article 8 addresses the monitoring water flows and volumes to assess ecological and chemical status, and Annex V complements this by stressing the need to monitor pollutants that may be transferred from river basins to the marine environment.

Despite these advances, the WFD primarily focuses on pollutant flows management, emphasizing pollution control and the protection of ecological and hydromorphological status, which involves elements such as sediments and biota. Although these elements are indirectly considered under the ecological and hydromorphological status (particularly through environmental quality standards and biological indicators), it does not explicitly promote the integrated and continuous management of the processes and interactions involving these flows, nor does it ensure their longitudinal (upstream-downstream) or lateral (the exchanges between the river's main channel and adjacent zones connectivity). While there is concern for elements such as the fragmentation of aquatic habitats (e.g., barriers to fish movement), the management of flows remains fragmented. The directive presents limitations on the holistic integration of natural flows and their connections throughout the entire hydrological system. It is more focused on water quality and quantity, but it lacks a systemic vision that integrates the dynamics of flows throughout the entire hydrological *continuum*.

GWD does not meet the Flows subcriterion because its approach is limited to ground-water quality and does not explicitly address the flows of water, sediments, biota, and other materials that connect subsystems along the *continuum* in the landscape. Although it contributes indirectly, in conjunction with the WFD, to the preservation of broader flows (such as the connection between groundwater and surface water), surface runoff and the interactions of flows across different scales are not directly addressed, as required by the subcriterion.

The WFD and the MSFD address coastal and transitional waters with distinct approaches, resulting in overlaps and potential conflicts. The WFD adopts a river basin-based approach, integrating the management of inland, coastal, and transitional waters. Meanwhile, the MSFD focuses on the protection of the marine environment, emphasizing an ecosystem-based approach, incorporating coastal waters when not fully covered by the WFD. Despite this observation in the MSFD, a duplication of approaches may occur, leading to confusion over the responsibilities of each directive and conflicting objectives, particularly in monitoring and achieving Good Environmental Status (GES), since the MSFD also relies on the WFD to provide data on coastal waters. Not forgetting that this concept of GES is influenced by human values and parameters that meet our needs without fully considering the complex interactions between ecological, socioeconomic, and cultural factors. Mee et al. (2008) highlighted that the MSFD faces difficulties in harmonizing the definition of 'Good Environmental Status' among Member States due to the concept's different cultural and scientific interpretations. This subjectivity, also influenced by the principle of subsidiarity, contributes to a practical challenge in implementing a well-integrated ecosystem-based approach.

The Directive 2014/89/EU partially addresses the Flows subcriterion. Recognizing the importance of considering land-sea interactions is widely emphasized by the directive in both recitals and articles (e.g., arts. 1, 4, 5, 6, and 7). It mentions environmental aspects that can be inferred as referring to the flows of materials, water, sediments, and pollutants between terrestrial and marine systems. However, despite the directive's guidance to consider environmental aspects in planning, applying an ecosystem-based approach, there is no systematic and detailed approach to water and biological flows, particularly regarding freshwater and marine flows along the entire hydrological *continuum*, i.e., flows between terrestrial and marine ecosystems. The management of these flows is only partially addressed, leaving gaps in the deeper integration of riverine and marine systems.

The main gap in the interaction between the directives lies in the absence of a clear and cohesive mechanism to integrate the continuous management of water, sediment, biota, and pollutant flows, along with their ecosystem services, from headwaters to the marine environ-

ment. The discretion granted to Member States also hinders this integration, as each country can interpret and implement the directives differently, undermining uniformity in actions. The concept of landscape could provide a more integrative vision, but the directives do not even mention the landscape in the context. This separation between inland and marine water management has been highlighted in both literature and policy analyses (e.g. Howarth, 2018), particularly regarding the need for better alignment between directives to avoid gaps or overlaps in actions.

4.4.1.2 Cycle

None of the directives address atmospheric processes, such as atmospheric rivers and marine aerosols, nor oceanic processes, such as ocean currents, upwelling, and gas exchange between the ocean and the atmosphere. Although distinct, systems thinking helps us understand that all these phenomena are interconnected within the Earth system, affecting the hydrological cycle and, consequently, the climate and the transport of water. They impact water quantity and quality, coastal ecology, and are amplified by climate change, making it essential to consider them for sustainable and integrated water resource management. At this point, we will focus only on atmospheric processes as per the subcriterion.

Atmospheric rivers (ARs) are long, narrow corridors with a large amount of water vapor that transport moisture and heat from lower latitudes (originating from tropical and/or extra-tropical sources) and are driven by convection and convergence processes toward mid and high latitudes (Gimeno et al., 2014; Zhu & Newell, 1998). In Europe, ARs are responsible for a significant part of the annual precipitation, especially along the Atlantic coast, and can cause intense rainfall when the moisture they carry encounters topographical barriers, such as mountain ranges. Thus, they play a critical role in the hydrological cycle as they directly affect water availability, the formation of heavy rains, and water resource management (Gimeno-Sotelo et al., 2024). Recently, the study by Francis et al. (2022) identified a new AR path towards Europe, crossing the Sahara Desert during the winter months, something previously considered unusual. This phenomenon had a significant impact on snow cover, with the albedo reduced by up to 40% in the Alps. The Pyrenees, located in the northeastern part of the Iberian Peninsula, between Spain and France, were also affected by the phenomenon. This example also highlights the complexity of these processes, showing that not only moisture but also materials such as dust can be transported, impacting both the hydrological cycle and the water quality and local ecosystems.

Atmospheric processes, such as evaporation and precipitation dynamics, play a crucial role in the hydrological cycle, including aquifer recharge. Evapotranspiration and seasonal variations are equally important for monitoring and projecting the amount of water that infiltrates the soil and reaches groundwater. Riedel and Waber (2020) explored how these processes influence groundwater recharge in Central Europe. Another example is the influence of the El Niño phenomenon (an atmospheric process), which can directly affect recharge levels. In regions where recharge is limited to certain times of the year, an inadequate understanding of these cycles can lead to overexploitation of aquifers (Moeck et al., 2024). King and Sillmann (2020) show the complexity of El Niño in European hydroclimate, where it is generally associated with wet conditions in western and southern Europe and dry conditions in northern Europe. Extreme El Niño events can lead to dry conditions over a broader area, including Western Europe. Bringing these issues to light is important for water resource management, effective planning, and mitigating extreme events such as droughts and floods.

Tropical cyclones (TCs) can significantly affect mid-latitudes, such as the Iberian Peninsula and Western Europe. The formation of these cyclones is influenced by large-scale atmospheric and oceanic processes, such as sea surface temperature and ocean heat content. During the positive phase of the North Atlantic Oscillation (NAO), the frequency of TC formation in the North Atlantic is suppressed due to increased wind shear (Pérez-Alarcón et al., 2023). Despite the extratropical transition of TCs, which weakens their tropical characteristics, they continue to bring strong winds and heavy rains, which require greater integration of these climatic variabilities into water resource management and mitigation strategies. Pérez-Alarcón et al. (2023) conducted a study that showed that about 4.2% of the annual precipitation between August and November in Galicia and Northern Portugal can be attributed to TCs, affecting the hydrological cycle of these areas. This contribution can temporarily increase the amount of available water, but it also raises the risks of flooding and degradation of water quality due to pollutant runoff. However, the directives analyzed do not address this dynamic, pointing to a gap in integrating large-scale atmospheric processes into water management frameworks.

Another important aspect is the relationship with atmospheric pollution and acid deposition, which can alter groundwater quality by infiltrating dissolved pollutants. The atmospheric cycle of elements such as carbon and nitrogen can influence soil chemistry and, consequently, groundwater quality, potentially increasing nitrate concentrations in aquifers.

The consideration of atmospheric processes also promotes preparation for climate change adaptation and helps create strategies that strengthen ecosystem resilience and sustainable water resource management. The integration of these processes into water resource

governance is essential to ensure proper allocation, protection against extreme events, and the preservation of aquatic ecosystems. Failure to observe atmospheric processes can increase vulnerability, compromise the effectiveness of management policies, and foster the overexploitation of water resources.

Although the WFD considers anthropogenic pressures and addresses public participation, the integration of cultural and social aspects occurs in a limited and implicit manner. It does not explicitly address the interrelationship between nature and culture or the hydrosocial concept, tending to focus more on technical and ecological aspects.

For example, Article 1 establishes the general objective of protecting and improving the status of water bodies, and Article 4 mentions the need to achieve Good Ecological and Chemical Status (GES and GCS). Article 5 and Annex II require an analysis of river basin characteristics, including anthropogenic pressures and impacts, which can be interpreted as an indirect acknowledgment of the importance of interactions between natural and human systems. However, does not explicitly recognize the cultural and social dynamics in modifying natural processes, nor does it clearly integrate these elements into environmental objectives.

Even when analyzing biological, physicochemical, and hydromorphological parameters (Annex V), which partly reflect the effects of human activities on aquatic ecosystems, the WFD is limited to a technical-ecological approach. The integration between natural and cultural aspects (as required by socioecological approaches) goes beyond merely assessing human impact or environmental conditions. In this way, the WFD partially meets the subcriterion.

GWD implicitly acknowledges the interactions between human activities and groundwater, primarily regarding pollution and chemical protection, but it does not address the interrelation between culture and nature in a structured manner, nor does it explicitly incorporate the sociological dimension.

Human activities, such as agriculture, land use, and urbanization, directly impact the water cycle, affecting the quantity and quality of groundwater. For example, it is crucial to understand the feedback effects between human activities and ecological processes. Intensive agricultural practices can compromise aquifer recharge and contaminate groundwater, consequently impacting future agricultural practices (Foster & Custodio, 2019; Malki et al., 2017). Integrating cultural aspects into management requires the involvement of local communities in governance, which can enhance the effectiveness of policies and the perception of impacts. This is particularly relevant in the case of groundwater, where impacts tend to be less visible, making it difficult to recognize the severity of changes caused by human activities. The MSFD aims to achieve or maintain the GES of marine waters, considering the impacts of human ac-

tivities on marine ecosystems. Its articles and annexes address pollution, habitat integrity, biodiversity, and anthropogenic pressure, with a focus on sustainability. However, its approach remains fragmented and does not fully integrate cultural and social dimensions, overlooking how human and natural systems mutually influence each other over time. This gap is compounded by the fact that the definition of GES depends on human values and social perceptions, which vary significantly across regions (Mee et al., 2008). To overcome this fragmentation, it would be necessary to broaden the scope of the directive and more explicitly integrate the socio-ecological dimension, recognizing that human activities shape ecosystems and vice versa. This would include, for example, mapping cultural practices that affect marine resources. Adopting the “hydrosocial” concept (Linton, 2014; Linton & Budds, 2014) could contribute to a better understanding of the impact of climate change and water resource management policies, and the processes that extend along the *continuum* to the marine environment. Thus, the Directive partially meets the Nature-culture integration subcriterion.

MSPD also partially addresses the Nature-Culture Integration subcriterion. Although it recognizes the importance of considering the impacts of human activities, such as fishing, transportation, and tourism, on the sustainable management of maritime space and the preservation of ecosystems, it does not systematically and explicitly address the concept of nature-culture integration or the hydrosocial dimension.

For example, Articles 1, 5, 6, and 7 establish a framework for maritime spatial planning focused on sustainable growth and ecosystem preservation, taking into account economic, social, and environmental aspects. The directive emphasizes the importance of an ecosystem-based approach and land-sea interactions for sustainable management, but does not explicitly address nature-culture integration. Although it mentions the need to balance human activities and environmental impacts, it lacks a specific approach that integrates ecological processes and cultural and social dynamics, remaining primarily focused on organizing the use of maritime space for economic and environmental purposes. As previously noted in the case of the MSFD, the concept of GES is also referenced in the MSPD through its strong alignment with the MSFD’s ecosystem-based approach. Although GES is not directly defined in the MSPD’s legal provisions, its objective of contributing to GES, as emphasized in Recitals 2, 14, and 22, reflects the Directive’s environmental pillar. However, varying scientific and cultural interpretations across Member States may still hinder the consistent implementation of an integrated, ecosystem-based maritime spatial planning framework. This is also particularly evident in the definition of “Good Ecological Status” and “Good Chemical Status” in the WFD and GWD Directives. While they set out priority parameters and substances, the non-exhaustive nature of

these lists and the discretion granted to Member States in identifying relevant pollutants and setting national limit values may lead to situations where certain types of pollution or levels of contamination not explicitly regulated are tacitly considered “acceptable” in certain jurisdictions. This inherent flexibility of the Directives, on the one hand, allows adaptation to local realities, but on the other hand, may compromise harmonization and environmental ambition across the Union.

Tett et al. (2007) also highlight this subjectivity by demonstrating that the definition of 'Good Status' is intrinsically linked to human values and how we perceive ecosystem services. Suppose the condition of a water system deteriorates to the point of negatively affecting fish populations valued by humans. In that case, this condition can be considered "bad" because it compromises the ecosystem services we appreciate, such as fishing or the biodiversity we seek to preserve. However, if the level of disturbance caused by human activities, such as the introduction of pollutants or habitat modification, still allows for the maintenance of these services, it may be seen as acceptable.

4.4.1.3 Land-water integration in the landscape

The directive includes elements that can be interpreted as an indirect consideration of the interaction between land and water, such as the analysis of anthropogenic pressures, which involves identifying points and diffuse sources of pollution resulting from activities like agriculture, industry, and urban land use. The hydromorphological status of water bodies also addresses significant physical modifications of water bodies and the regulation of watercourses, requiring the assessment of land use patterns, including urban, industrial, and agricultural areas, fishing zones, and forests. However, it does not explicitly and comprehensively address landscape changes, their impacts on water flows and associated ecosystem services, or the continuity of vegetation patterns within and beyond the watersheds.

The groundwater directive acknowledges that human activities, such as agriculture and urbanization, can introduce pollutants that affect the quality of groundwater (Arts. 1, 2, and 3). However, the integration of the relationship between land use and water flows in the landscape, as required by the Land-Water Integration in the Landscape criterion, is not explicitly addressed. For example, the conversion of forests into agricultural areas can reduce water infiltration into the soil, thereby decreasing aquifer recharge and increasing surface runoff. This leads to the degradation of groundwater quality due to a higher load of sediments and pollutants.

Although Articles 4 and 6 of the directive mention measures to prevent or limit the introduction of pollutants into groundwater, particularly in the context of diffuse pollution resulting from agricultural practices and other land uses, the focus is more restricted to water quality than to the biophysical integration in the landscape.

Therefore, an integrated and detailed analysis of the biophysical interaction between land and water in the landscape remains absent in both directives.

This gap becomes even more evident when we observe the tangible effects of land use changes on water flows. Deforestation, for instance, directly impacts aquatic ecosystems by intensifying soil erosion and degrading water quality. Although the WFD implicitly covers these effects through the requirement to analyze pressures on river basins, the Programs of Measures (PoMs) often fail to incorporate specific actions to mitigate deforestation. This shortcoming weakens the systemic response to impacts on the health of water bodies and associated aquifers, revealing a fragile integration between water management and vegetation cover. Apostolaki et al. (2019) demonstrate how such impacts and morphological changes affect hydrological flows. Another example is the study by Teuling et al. (2019) on changes in water flows and evapotranspiration due to reforestation, deforestation, and urbanization, and how such changes directly affected the interaction between surface and groundwater. The authors observed that land-use changes between 1960 and 2010 (deforestation, reforestation, and urbanization) and climate change directly impacted the interaction between surface and groundwater differently in various regions of Europe.

While acknowledging the progress achieved by the WFD and GWD, it still lacks a holistic approach that adequately integrates the concept of landscape and the cumulative impacts of land use changes and climate change. The directives could go further by incorporating vegetation continuity and green infrastructure into an effective water management strategy. Therefore, it can be concluded that the WFD and GWD only partially meet the subcriterion.

The MSFD requires Member States to conduct an initial assessment of their marine waters, considering the physicochemical and biological characteristics, as well as the pressures and impacts of human activities (Art. 8). This assessment includes elements that may be influenced by changes in land use and water flows from the land, such as pollution and sedimentation. Still, it does not explicitly address how changes in the landscape influence these flows. The programs of measures to achieve GES may include actions to mitigate the impacts of land-based activities affecting the marine environment, such as reducing pollution from terrestrial sources and restoring ecosystems. There is a mention of the need to consider impacts on coastal waters and suggests that the impacts of changes in land use and infrastructure should

be considered, but this is not done systematically to address the biophysical integration between land and water (Art. 13). Although the directive mentions cooperation between Member States, considering transboundary impacts and coordination with river basins, it does not specifically address changes in land use and infrastructure as factors directly affecting water flows.

The S2S Landscape concept highlights the interconnection and continuity between terrestrial and aquatic landscapes. It treats them as integrated parts of a cohesive system, where changes in one area can directly affect other parts of the system. Incorporating this concept would help fill gaps in the MSFD, which currently addresses land and aquatic impacts in a fragmented manner. With this integration, the MSFD could provide a more effective approach to the sustainable management of ecosystems, improving the protection of ecosystem services along the entire environmental *continuum*.

The MSPD addresses land-sea interactions in several sections (e.g., Recital 16 and Arts. 1, 4, and 7), emphasizing the importance of managing terrestrial and marine activities in an integrated manner. When Member States apply processes such as integrated coastal management, the outcomes must be incorporated into maritime spatial planning, considering the impacts of terrestrial activities, such as urbanization, tourism, and agriculture, on the marine environment. However, although the directive acknowledges this need, it does not directly address the biophysical interaction between land and water within the landscape. There is a lack of specific guidance on how land-use changes, such as deforestation, urbanization, or agricultural practices, may affect water flows in watersheds and subsequently impact the marine environment. The directive focuses on the direct impacts of terrestrial activities on the sea but does not deeply analyze how land-use changes influence ecological connectivity and ecosystem services. Additionally, it does not establish a clear mechanism for integrating with the WFD and the MSFD, only recommending that these directives be considered.

Another important issue to be considered, aligned with the S2S Landscape principles, is the understanding that the seabed is part of the terrestrial system. The seabed, particularly in coastal and estuarine regions, is intrinsically connected to terrestrial systems in terms of sediment, nutrient flows, and biogeochemical processes, which eventually accumulate in the marine environment, affecting ocean ecology, coastal erosion, and regulatory ecosystem services (Burdige, 2012; Hairsine, 2017). The MSFD addresses the state of the marine environment, including seabed ecosystems, and requires Member States to assess and monitor environmental impacts, especially pollutants, in marine waters, including the seabed (Art. 8). However, the MSPD does not explicitly address this connection, leaving a gap in the complete integration of

land-water interactions without offering coordinated mechanisms with the MSFD in these aspects.

For example, Guérin and Lizińska (2022), in their analysis of the main elements of the GES concept, focusing on Descriptor 6 (seabed integrity - Annex I), identified several significant gaps in the implementation of the MSFD among Member States, such as: variability in the application of criteria, due to the lack of clear standards and thresholds to identify acceptable impacts on the seabed, which undermines regional comparisons; although the directive mentions the importance of regional conventions, such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), not all countries consistently use its tools, highlighting the absence of effective alignment mechanisms; they also pointed out the lack of specific guidelines on how to manage human activities in the long term and the absence of unified methodologies to assess seabed impacts, resulting in discrepancies in data collection and analysis; and the interaction between land-use changes (such as urbanization) and seabed impacts, which has been neglected. The seabed plays a critical role in the environmental *continuum*, connecting terrestrial and aquatic ecosystems and directly influencing ecology and ecosystem services.

These gaps highlight the need for a systematic integration between land and marine policies, as the lack of harmonized criteria and consistent reporting undermines not only the protection of benthic ecosystems but also broader objectives, such as the integration of freshwater and marine systems and the connectivity between surface and subsurface processes. These issues also reflect weaknesses in governance and management, such as multilevel coordination, intersectoral integration, and the need for adaptive and resilient structures, which will be discussed later in the specific sub-criteria of the Governance and Management (Action) criterion.

Finally, human activities occur across all dimensions of the sea (surface, water column, seabed, and seafloor), which increases the complexity of managing ecological impacts. Subsea infrastructure, such as submarine cables, pipelines, and resource extraction, interacts with ecological processes like sediment transport and biogeochemical flows. The inclusion of coordinated guidelines between the MSPD and the MSFD could improve the management of these infrastructures on the seabed, as well as the flows of sediments and nutrients originating from land-based activities. Some works address these interactions, such as those by Asprogerakas et al. (2020) and Vince and Day (2020).

Therefore, the MSPD partially meets the subcriterion, as many of the issues are implied. It does not thoroughly explore the physical and ecological effects of landscape changes, and it lacks clear guidelines and integration mechanisms.

4.4.1.4 Freshwater-marine water integration

The WFD recognizes the connection between freshwater and marine systems in some aspects. The inclusion of transitional ecosystems (coastal waters and estuaries) in its scope of protection (Art. 1), the establishment of environmental objectives (Art. 4), along with the requirement to identify anthropogenic pressures (Annex II) and monitor physicochemical and biological parameters of these water bodies to assess the quality of waters flowing into the sea, demonstrates that there is concern in addressing the connection and impacts between freshwater and marine waters.

However, the main focus remains on freshwater, without detailing the continuous effects of freshwater flows on marine ecosystems. This manifests itself in the absence of an explicit understanding and integration of the bidirectional dynamics between the two systems as a single *continuum*. Details are lacking in how upstream processes (in river and lake systems) affect marine ecosystems and how marine dynamics can influence freshwater systems.

Saltwater intrusion serves as a clear example of this limitation. While the WFD (and the GWD) address its prevention to ensure the GCS of the groundwater, the focus is on groundwater quality itself. A detailed analysis of how the intrusion itself, by reducing freshwater discharge to the sea or altering coastal groundwater flows, impacts adjacent marine ecosystems and the wider hydrological *continuum* (from land to ocean) is lacking. Thus, the WFD only partially addresses the subcriterion.

In relation to GWD, the issue of interactions between groundwater and coastal zones is also neglected. Coastal aquifers that extend beneath the seabed can be influenced by tidal movements, leading to saltwater intrusion, which compromises the quality of freshwater in these systems. This intrusion is particularly critical in regions where freshwater resources are already limited, such as the Po Delta (Italy) and Andalusia (Spain), as pointed out by Bellafiore et al. (2021) and Duque et al. (2019). Furthermore, the directive fails to recognize how broader marine processes, such as tides and storms, can influence not only aquifers but also river and estuarine flows, affecting recharge and quality of associated groundwater. Nor does it consider the indirect impacts of pollutants transported by groundwater, such as nutrients from agriculture, that end up reaching marine environments, contributing to eutrophication. Thus, the GWD also does not meet the subcriterion. The MSFD partially meets the Freshwater-Marine

Water Integration subcriterion. Like the WFD, it aims to achieve GES, requiring Member States to conduct an initial assessment of their marine waters, considering the physicochemical and biological characteristics and taking into account the pressures and impacts of human activities (Art. 8). This assessment includes external pressures from inland waters, such as the runoff of nutrients, pollutants, and sediments from rivers and lakes. Therefore, it recognizes that land-based activities create flows directly affecting marine ecosystems.

Article 13, which addresses programs of measures, suggests a connection between freshwater and marine waters, especially when dealing with land-based pollution sources and the need to coordinate actions with the WFD. Member States can include actions to mitigate the impacts of land-based activities on marine ecosystems, but the way these measures are implemented is left to each State's discretion, resulting in uneven application and a lack of uniformity. There is a gap in how programs should be structured to monitor and mitigate the impacts of freshwater flows on marine ecosystems. The hydrological connection between rivers and seas is acknowledged, but no clear guidance or effective mechanisms exist to integrate the flow dynamics along the hydrological *continuum*.

The MSPD also acknowledges the interdependence between marine and terrestrial environments by requiring that maritime spatial plans explicitly consider land–sea interactions (Arts. 4, 6, and 7). However, the directive remains focused on spatially organizing maritime uses to support sustainable economic activities. While it proposes coherence with other instruments such as the WFD and the MSFD, the MSPD does not delve into the functional hydrological links between freshwater and marine systems. Thus, it only partially meets the subcriterion by recognizing the spatial connection but not the functional hydrological *continuum*.

A cross-cutting issue that highlights the fragmentation between directives is the lack of a coordinated approach to submarine groundwater discharge (SGD). Although SGD represents a critical pathway for the transfer of freshwater, nutrients, and pollutants from the terrestrial to the marine system, it is largely neglected by the WFD, GWD, and MSFD. SGD refers to any flow of water across the sediment–water interface in coastal environments, including discharge from aquifers (which can be visible, as Saito (2017) identified in low-tide zones on Rapa Nui Island) and recirculation of seawater through sediments. Despite its importance for biogeochemical cycles, the maintenance of coastal ecosystems, and interaction between freshwater and marine water, the detailed analysis of this process, as a connection between surface and structural domains, is developed in the section dedicated to the subcriterion "Integration of surface and subsurface processes". In summary, the MSFD complements the WFD with respect to marine environments, but the goals and coordination between these directives are not always aligned.

The MSPD should be more integrated with the MSFD, especially in dealing with the impacts of freshwater flows on marine ecosystems. Neither of them provides an explicit integration mechanism. The fact that they mention the need to observe each other's guidelines does not ensure sufficient coordination in terms of governance. For example, economic activities such as agriculture and fishing may be treated differently between the two environments, making it difficult to implement an integrated approach, as observed by Wang et al. (2021).

4.4.1.5 Integration of surface and subsurface processes

The WFD demonstrates an understanding of the interconnection between surface and groundwater resources, as evidenced by recitals 20, 33, and 34, which emphasize that the quantitative state of groundwater can influence the ecological quality of surface waters and terrestrial ecosystems. These recitals highlight the importance of coordinating and integrating surface and subsurface processes for effective water management. Articles like 4 and 17 reinforce the need to protect, improve, and restore both surface and groundwater bodies, addressing pollution and the balance between abstraction and recharge, critical aspects for integrating these processes. The WFD's annexes, especially II and V, complement this approach by providing guidelines for the characterization and monitoring of surface and groundwater, considering their interaction with ecosystems and human impacts. This includes the identification of significant anthropogenic and hydromorphological pressures, such as diffuse and point-source pollution, as provided in Annex II and Articles 5 and 8.

However, it is important to note that despite acknowledging this interconnection, the WFD does not provide sufficient mechanisms or strategies for fully integrating these processes. In practice, these two systems are often treated separately despite the directive's guidelines. Additionally, the discretion granted to Member States in implementing the rules can result in uneven application, undermining a more unified approach. The WFD's predominant focus on pollution prevention and control and impact assessment also limits the adoption of a holistic approach needed to integrate surface and subsurface processes fully. It does not comprehensively address other critical aspects of the long-term dynamics of the hydrological cycle, particularly considering the cumulative impacts of land use changes and climate change.

The WFD does not explicitly discuss the ecosystem services provided by this interaction. Ecosystem services such as water purification, habitat provision, and nutrient cycling are crucial for maintaining the health of both aquatic and terrestrial ecosystems. The absence of this discussion limits the directive's ability to address the full range of benefits offered by integrated water systems.

GWD, primarily focused on the protection of groundwater from pollution and deterioration, establishes strict criteria for the assessment and monitoring of its quality, marking a significant advancement in groundwater management in Europe. Although it implicitly acknowledges the interaction between groundwater and surface ecosystems, the directive does not significantly extend beyond what the WFD already establishes in terms of integrating these processes. As a complementary directive to the WFD, it has the potential to expand and improve legislation, addressing existing gaps and emerging challenges.

For example, clearer guidelines could be introduced regarding how Member States should monitor and manage the interactions between surface and groundwater, considering bidirectional flows, aquifer recharge, and the impact of agricultural and urban practices on these processes. The introduction of requirements for integrated hydrological modeling would help create a more holistic view of the water system, enabling better planning and risk mitigation, such as the overexploitation of aquifers or cross-contamination. Clear limits on the amount of water that can be extracted from aquifers, particularly in areas vulnerable to overexploitation, could also be established.

Regarding the MSFD, although it includes coastal waters in marine waters (Art. 3), this inclusion is limited to aspects not covered by the WFD or other Community legislation. By seeking to avoid regulatory overlaps, the directive ends up creating an artificial separation between water domains that are ecologically and hydrologically interconnected. This fragmentation compromises the operationalization of the directive, as phenomena such as discharge from coastal aquifers, the transfer of nutrients between groundwater and coastal areas, or recharge by inland water bodies are not taken into account in the action plans, monitoring programs, or environmental targets (Arts. 8 and 13). Furthermore, coordination with the WFD, although foreseen (Art. 6), is limited to generic guidelines, without establishing binding legal mechanisms or technical frameworks for interoperability. Therefore, the implementation of this coordination depends on the political will and administrative capacity of each Member State, leaving room for uneven approaches and gaps in implementation. This omission compromises the ecosystem-based approach and the coherence of integrated environmental management that the directive claims to adopt (Art. 1). Therefore, the MSFD does not meet the subcriterion.

Concerning MSPD, while acknowledging the importance of land-sea interactions, this integration is addressed in the context of maritime spatial planning. The directive mentions instruments such as integrated coastal management to be implemented by Member States, but with a focus on coordinating human activities to support blue growth and environmental protection. In other words, although the planning considers the location and impact of differ-

ent uses, it does not delve into the hydrological dynamics of water systems, such as the interaction between surface and groundwater. The directive essentially outlines a functional map of maritime uses, but does not incorporate the natural processes that underpin the ecological functioning of coastal areas. This gap reveals that, within the scope of the MSPD, groundwater–surface flows remain outside the regulatory scope, requiring complementary coordination with other policies to ensure integrated water cycle management. With regard to coordination with the MSFD, the MSPD recognizes the need to consider the environmental objectives of the MSFD when developing national maritime plans. However, this consideration remains advisory and non-binding, reproducing the same problem already identified in the relationship between the MSFD and the WFD. Thus, the MSPD also does not meet the subcriterion.

As anticipated in the “Freshwater-marine water integration” subcriterion, SGD illustrates in an exemplary way the limitations of the directives analyzed about the integration between water compartments. SGD constitutes a key hydrological process in which groundwater flows into the ocean through the sediment-water interface, transporting nutrients, pollutants, and altering the salinity and biogeochemistry of coastal environments. This discharge originates from subsurface processes involving continental recharge, pressure gradients, interaction between saturated and unsaturated zones, and aquifer dynamics (Taniguchi et al., 2002; Burnett et al., 2006; Taniguchi et al., 2019), which reinforces its intrinsically linked nature to surface–subsoil integration.

This process is influenced by factors such as tides, precipitation, and land use. It plays a crucial role in biogeochemical cycles, in the maintenance of coastal ecosystems, and in the provision of freshwater for human consumption, agriculture, and cultural activities (Moosdorf & Oehler, 2017; Taniguchi et al., 2002). On the other hand, SGD can also facilitate negative impacts, such as the occurrence of harmful algal blooms (HABs), which compromise fisheries and the well-being of coastal communities. According to Alorda-Kleinglass et al. (2021), SGD can transport large amounts of nutrients, often contaminants of natural or anthropogenic origin (such as metals and agricultural contaminants), which pass through coastal sediments and directly influence water quality, primary productivity, and biogeochemical cycles in marine environments. When nutrients such as nitrogen and phosphorus are introduced in excess, they act as fertilizers that promote accelerated algae growth, overloading the coastal system. In regions with aquifer overexploitation or intensive land use, SGD can act as a vector of eutrophication, changes in salinity, or even transport of persistent contaminants (Alorda-Kleinglass et al., 2021; Burnett et al., 2006; Taniguchi et al., 2019).

Sustainable management of coastal aquifers is an essential component of the vertical integration of water systems, especially in the context of increased extraction, diffuse pollution, and climate change (Moosdorf & Oehler, 2017; Taniguchi et al., 2019). Additionally, land management practices and green infrastructure (Monteiro et al., 2020), such as infiltration basins and controlled recharge zones, can improve aquifer recharge in regions where groundwater is extensively used. Promoting a circular economy that closes the water cycle, together with public awareness mechanisms focused on conservation and responsible water use, would also bring significant benefits.

The absence of specific mechanisms to deal with groundwater-sea flows, such as the SGD, highlights a persistent mismatch between scientific knowledge and regulatory instruments, not only in the European context but also at a global level. For groundwater-surface water integration to be effective, it is necessary to move beyond conceptual recognition and create regulatory, operational, and monitoring frameworks that incorporate the hydrological complexity of coastal areas.

4.4.2 Governance and management (Action)

4.4.2.1 Multilevel

The WFD recitals play a critical role in establishing the logical foundation for implementing multilevel governance. They emphasize the need to adapt environmental policies to regional conditions (Recital 11), promote cooperation and public participation across all governance levels (Recitals 14 and 46), integrate water management with other EU policies (Recital 16), and ensure coordination in cross-border river basins (Recital 35). Aligning with these principles, the WFD incorporates key concepts for coordination across governance levels (local, regional, national, and international), ensuring collaboration among Member States and stakeholders and promoting international cooperation in cross-border basins (e.g., Arts. 3, 4, 13, 14, and 15).

However, the directive lacks explicit mechanisms to reinforce coordination among regions and Member States, often resulting in variable implementations. While stakeholder collaboration is emphasized, operational flexibility for Member States may lead to fragmented outcomes. These gaps hinder the harmonization of management practices, impacting shared objectives. For instance, Marthe Indset (2023) highlights that differences in organizational structures, administrative capacities, and subnational coordination mechanisms—alongside the discretionary power granted to Member States—result in variations in coordination and

implementation practices. This flexibility leads to distinct approaches depending on local and regional contexts. The study highlighted that institutional differences in Norway and Sweden, such as the allocation of responsibilities and bureaucratic autonomy, affected the directive's implementation and contributed to uneven outcomes. Domerenok (2017) notes that implementing the WFD in Italy was marked by institutional conflicts, regional resistance to accepting new district authorities, and a fragmented process that failed to effectively coordinate the various jurisdictions involved. The author argues that the lack of robust accountability mechanisms for ensuring cooperation between jurisdictions leaves implementation vulnerable to local political dynamics. Thus, while the WFD incorporates multilevel governance principles and meets the criterion in its foundational design, an update is necessary to address the absence of mechanisms to ensure effective and consistent coordination across governance levels and jurisdictions.

In GWD, there is no explicit focus on multi-level governance in the same way as in the WFD. However, it provides for coordination among Member States in specific areas related to groundwater protection, as seen in Article 3, which mentions the need for coordination to establish thresholds and ensure water quality protection in transboundary groundwater bodies. The directive emphasizes the role of Member States in implementation and monitoring but does not define a detailed multi-level structure, leaving each country to organize competent authorities and local responsibilities. Therefore, in relation to the multi-level governance sub-criterion, GWD complements the WFD by addressing coordination between countries, although it leaves the structure and operational responsibilities vague and broad, which may lead to inconsistencies in application. Thus, while the GWD addresses the criterion by supporting inter-state coordination, it requires further development to clarify multilevel governance structures and responsibilities, to ensure more consistent implementation across Member States.

The MSFD requires Member States sharing a marine region or sub-region to coordinate their strategies (Art. 6), using available regional cooperation structures whenever feasible and appropriate. Article 7 establishes that each Member State must designate authorities responsible for its implementation, promoting the principle of multilevel governance.

Complementing other EU legislation, such as the WFD, the MSFD aims to integrate environmental protection objectives and coordinate monitoring programs and marine water management measures. Article 13, for instance, requires Member States to identify and implement specific measures for each marine region or sub-region to achieve and maintain a GES. Article 19 requires public consultation and stakeholder involvement during the development and implementation of strategies.

Despite these provisions, the Directive lacks specificity on how this multilevel coordination should be structured, which can lead to varying interpretations and uneven implementation across Member States. The absence of an explicit structure of responsibilities in the Directive leaves gaps in practical integration, hindering effective coordination between the various levels and governance entities involved.

For example, elements of multilevel governance and Marine Protected Areas (MPAs) are addressed in a dispersed manner across articles dealing with the implementation of measures, cooperation among Member States, and the creation of monitoring and protection programs (Arts. 5 and 13). However, the directive does not provide clear guidelines on how coordination between management levels should occur, which creates interpretative challenges and compromises the effectiveness and uniformity of implementation. Muccitelli et al. (2023) highlight that many MPAs in Europe lack adequate management plans, which weakens their protection capacity. The absence of these plans implies uncertainty regarding conservation actions and the authorities responsible for their implementation, leading many MPAs to be regarded as mere "paper parks" (areas protected only formally). The European Committee of the Regions, in its "Opinion of the European Committee of the Regions — Local and regional authorities protecting the marine environment" (2021/C 300/08), also highlighting coordination failures among local, regional, and national authorities as an obstacle achieving GES. It was also observed that many subnational authorities are unaware of their rights and duties, and it is suggested that clearer integration mechanisms be created to increase the effectiveness of the MSFD.

Like other directives, the MSPD partially meets the subcriterion of multilevel governance. It recognizes the importance of coordination between different levels of governance and establishes a general framework for cross-border cooperation and stakeholder inclusion. However, there are significant gaps regarding coordination mechanisms, integration with local governance, addressing land-sea interactions, and applying adaptive governance. The lack of binding requirements and clear guidelines on how different levels of governance should coordinate limits the effectiveness of the directive.

For example, Gomez-Ballesteros et al. (2021) and Ansong et al. (2021) recognize that while the MSPD represents progress, differences in governance structures hinder cross-border coordination and the adoption of a harmonized approach. Key challenges include institutional disparities between countries, a lack of clear criteria for geographic planning scales, mismatches between ecological and administrative boundaries, Inconsistencies in data quality and format, and a lack of clear mechanisms for stakeholder engagement at different scales. Addi-

tionally, there is a lack of technical training, transdisciplinary approaches, and adequate human and financial resources. These limitations restrict the MSPD's ability to achieve effective governance of marine spaces in Europe by compromising integrated implementation and hindering the adoption of a coordinated ecosystem approach.

4.4.2.2 Intersectoral

The WFD emphasizes the importance of integrating water protection and sustainable management with other community policies, including energy, transportation, agriculture, fisheries, and tourism (Recitals 16 and 17), as well as coordination within river basins, promoting coordination between different basins, and ensuring, in particular, cooperation in transboundary areas. Articles 4, 11, and 13 emphasize the importance of coordinated measures and require that basin plans outline sectoral interactions and their management. Annexes II and III complement this by requiring assessment of sectoral pressures on water resources and economic analyses that consider impacts and interactions between different sectors.

Nevertheless, while the WFD meets the subcriterion by promoting sectoral integration and encouraging collaboration, it does not establish specific guidelines to structure formalized coordination and cooperation between sectors. This is because the responsibility for coordination lies with the Member States, which can result in fragmented or poorly coordinated approaches. Zingraff-Hamed et al. (2020) illustrate this limitation by pointing out failures in communication and intersectoral integration due to the lack of coordination between the Common Agricultural Policy (CAP) and the WFD in the Netherlands and Ireland, which led to suboptimal decisions, such as the disproportionate emphasis on reducing phosphorus in urban wastewater, without adequately considering the role of agriculture as a significant source of diffuse pollution.

In relation to GWD, it meets the Intersectoral criterion, as it includes provisions that imply the need for coordination between different sectors to protect groundwater from pollution (Recital 9 and Art. 6), it does not establish explicit mechanisms for integrated intersectoral management. The directive relies on the WFD to provide the general framework for this coordination. However, it misses the opportunity to expand on these provisions and thus avoid gaps in policy implementation. It could have been strengthened by introducing intersectoral governance mechanisms, such as advisory committees with representation from different sectors or clear guidelines for aligning sectoral policies within river basin management plans. This gap can lead to practical challenges, particularly in areas where groundwater protection depends on coordination with sectors like agriculture and industry.

The MSFD meets the intersectoral criterion, as it recognizes the need for policy coherence (Art. 1), integration and cooperation between sectors (Art. 6), and considers the social and economic impacts of the measures (Art. 13 and Annex VI). However, it does not establish institutional processes or clear guidelines on how to operationalize intersectoral coordination, leaving it up to Member States to define the mechanisms and structures to ensure this integration. As a result, collaboration between sectors, even when foreseen in programs of measures involving human activities of different origins, lacks practical guidance, which can hinder effective intersectoral management and coherent governance of the marine environment.

Similar to multilevel governance, this flexibility leads to non-uniformity and different levels of directive implementation across countries. Even considering Commission Directive (EU) 2017/845 (2017), which amends and complements Annex III of the MSFD, improvements in the intersectoral aspect occur indirectly. It more clearly addresses anthropogenic pressures and the impacts that different sectors may have on the marine environment, including sectors such as agriculture, fisheries, tourism, transport, and other types of activities. The inclusion of an indicative list of human activities and pressures facilitates the identification of contact points between different economic and social sectors that affect the marine environment. However, even with these elements that facilitate intersectoral integration, there is no direct progress in creating coordination mechanisms or institutional structures for intersectoral governance and management, leaving gaps in the practical implementation of coordination and collaboration among multiple sectors.

The MSPD also meets the intersectoral criterion, as it promotes the integration of multiple economic and social sectors (Arts. 1, 5, and 6), establishes the basis for intersectoral planning and decision-making, and encourages public participation, cross-border collaboration, and policy coherence (Arts. 4, 8, 9, and 11). However, as with other directives, it lacks clear institutional coordination structures between sectors and mechanisms that can harmonize different interests and stimulate collaboration. Implementation depends on the national context, and may be more integrated in countries with a tradition of intersectoral governance, but fragmented where such a culture is limited. Thus, the directive meets the proposed criterion, but with limitations in terms of institutional operationalization of intersectoral coordination.

Paramana et al. (2023) criticize the lack of effective integration between the MSFD and MSPD, highlighting challenges related to intersectoral and multilevel governance, especially due to differences in the competencies of competent authorities and the absence of adequate coordination mechanisms. The fragmented implementation of these directives often leads to overlapping competencies and conflicting policies, hindering the integrated approach needed

for the sustainability of marine resources. The study analyzed Mediterranean countries of the EU, such as Spain, Italy, Greece, Slovenia, Malta, Cyprus, and Croatia, and identified that, in many cases, the lack of integration contributes to governance failures. The article suggests that integration under a single competent authority or the creation of Interministerial Committees could strengthen intersectoral and multilevel coordination. Furthermore, it recommends implementing the Directives within ecosystem boundaries, ensuring a coherent and adaptive approach.

4.4.2.3 Adaptive and Resilient

The WFD partially meets the Adaptive and Resilient criterion. The directive adopts an integrated approach by establishing a framework for water basin management based on geographic and hydrological criteria, considering the functioning of ecosystems rather than administrative or political boundaries. The combined pursuit of good ecological and chemical status (GES and GCS), along with robust basin characterization and iterative monitoring, forms the foundation for enhancing the ecological resilience of European water bodies. As noted by Soininen and Platjouw (2018), these elements are central to the adaptive and ecosystem-based design of directives like the WFD and MSFD. However, successful implementation hinges on overcoming governance bottlenecks (Zingraff-Hamed et al., 2020) and ensuring that ecological goals are not divorced from their social context (Langlet & Westholm, 2021). The iterative planning cycle, with periodic reviews (Arts. 11 and 13), supports the adaptability of management by allowing measures to be adjusted based on new scientific knowledge and evolving environmental conditions.

Thus, the WFD contains various provisions that enable flexibility, continuous adjustments, and responses to changes, demonstrating adaptability and resilience. However, these concepts are not explicitly addressed as guiding principles of governance and management. Instead, they are embedded in operational practices and processes (e.g., Arts. 4, 11, 13, and 20). Resilience, understood as the ability of a system to absorb disturbances while maintaining essential functions (Holling, 1973), is implicit in the directive's emphasis on safeguarding water quality and meeting long-term objectives. However, the flexibility allowed by the exception system for non-compliance with GES and GCS objectives, as described in Article 4, may weaken the directive's effectiveness if these exceptions are interpreted broadly. This could allow environmental objectives to be overlooked in favor of economic or social interests. There are also limitations in the application of economic instruments (Art. 9) and in the mandatory fulfillment

of objectives, making it difficult to ensure that the recovery of water costs is effective and that environmental goals are consistently achieved.

The GWD contains provisions for updating based on scientific and technical progress (Art. 10), and requires the identification of significant and persistent trends in pollutant increases, along with the definition of a starting point for reversal (Art. 5 and annexes). This is an important aspect of adaptive governance, as it allows policies to be adjusted in response to continuous monitoring data. It connects to the WFD by requiring that this information be integrated into river basin management plans (Art. 13). It also provides for exemptions in special circumstances (Art. 6), indicating regulatory flexibility. The articulation between monitoring, implementation of measures, and plan review contributes to the system's ability to adapt to changing conditions.

However, the discretionary power granted to Member States in setting thresholds (Arts. 3 and 6) can lead to inconsistencies in protection, particularly when the adopted criteria are not sufficiently stringent or scientifically grounded. This undermines the effectiveness of measures and adaptive governance, especially in countries with limited resources or weaker institutions. The absence of mandatory standards and effective coordination mechanisms hinders the system's resilience and recovery, particularly in transboundary contexts. It also weakens integration with the WFD, compromising the uniform management of groundwater.

The MSFD plays an essential role in promoting ecosystem resilience by defining GES. It incorporates key elements of adaptive and resilient governance, such as periodic review and adjustment cycles (Art.17), integration of scientific knowledge (Arts. 8, 10, and 11), implementation flexibility (Art. 13 and 14), and regional cooperation (Art. 06). However, it also faces challenges related to resilience. Excessive flexibility and gaps in legal enforceability can weaken the resilience of marine ecosystems and may result in inadequate adaptation. Thus, the Directive partially meets the subcriterion.

The MSPD establishes a framework for maritime spatial planning and adopts a programmatic approach involving the development of cyclical and evolving plans to achieve environmental objectives (Art. 4), thereby contributing to the reduction of sectoral fragmentation in marine environmental governance. In this regard, it aligns with adaptive management, one of the key mechanisms for implementing an ecosystem-based approach. However, the broad definition of objectives in the MSPD may result in a lack of binding requirements and challenges in reconciling environmental, social, and economic priorities.

Another critical issue, also found in other directives, is the considerable margin of discretion granted under Article 6 regarding whether or not to implement certain measures. Articles

7 and 8 also highlight the importance of land–sea integration, and Article 11 promotes cooperation between Member States, all relevant to building institutional resilience.

However, the lack of clarity regarding the binding nature of specific targets, combined with broad allowances for exceptions, reduces the predictability and continuity of implementation. As Soininen and Platjouw (2018) argue, regulatory resilience depends on flexibility, adaptive planning, and binding mechanisms that ensure compliance and continuity. When legal frameworks rely too heavily on soft coordination without enforceable obligations, they risk failing to guide timely responses to environmental changes and systemic pressures.

The discretionary space, which we have observed and discussed in this and previous sub-criteria, is a common feature of EU environmental directives. It is shaped and ideally limited by the principle of subsidiarity (TFEU, 2012; European Union, 2012). While this principle allows for necessary flexibility to accommodate national contexts, it also opens the door to divergent interpretations and practices.

In practice, this flexibility has led to divergent national approaches, undermining the uniform application of directives. Kaavi (2024) shows that the interpretative margin of the WFD resulted in significant variations in its transposition and implementation. For instance, Austria broadly applied Article 4 exemptions to approve hydropower projects in the name of public interest, often without a rigorous assessment of environmental impacts. Germany also used the exemption, although with stricter judicial oversight, but weakened the effectiveness of cost recovery by favoring voluntary economic instruments. Finland, initially treating cost recovery as merely optional, began reforms only after pressure from the European Commission. These examples illustrate how excessive discretion can compromise the achievement of environmental objectives and delay alignment with EU standards. Similar findings are presented in Puharinen's (2024) study on the implementation of the WFD and MSFD across the EU.

4.4.2.4 Participatory

The WFD promotes public participation by requiring Member States to involve the public and other stakeholders in the development, review, and updating of river basin management plans (Art. 14). To facilitate this, relevant information is made available in advance, allowing everyone to comment and contribute. This ensures that the public has a voice in water planning and management, with opportunities for participation guaranteed both in the creation and updates of these plans.

Another important aspect of the WFD is the communication between countries and the European Commission (Art. 15). This communication ensures access to information about man-

agement plans and their implementation progress, facilitating effective cooperation and monitoring. Therefore, it can be concluded that the WFD meets the participatory criterion from a legal and procedural standpoint, as it guarantees public access to information and formal consultation opportunities.

Nonetheless, while the WFD ensures information accessibility and establishes periods for public consultation, its primary focus is on the formal structure of the process, without extensively detailing the depth or quality of participation in terms of inclusion and representation.

Regarding the GWD, although it does not directly mention public participation, it is closely linked to the WFD, which clearly requires Member States to ensure stakeholder participation in water management processes. This implicitly applies to the protection of groundwater, reinforced by transparency requirements such as the publication of information in river basin management plans and criteria for exemptions. However, the directive could have been more proactive by including more explicit provisions or by expanding participation mechanisms within the specific context of groundwater protection, thereby reinforcing inclusion. Therefore, by not expanding these provisions, the directive meets the Participatory criterion only partially.

In contrast, the MSFD explicitly promotes stakeholder participation and transparency throughout its implementation. Article 19 ensures public involvement by requiring the publication of key elements of marine strategies, such as the initial assessment, environmental targets, and monitoring programs, and enabling public input. Notably, the MSFD is the only directive among those analyzed to explicitly reference Directive 2003/4/EC, which guarantees public access to environmental information and represents a significant step forward in institutionalizing transparency and participation.

This contributes to greater public awareness, inclusion, and participation in environmental decision-making, aligning with the European Union's international commitments, such as the Aarhus Convention. Annex VI of the directive explicitly mentions "Communication, stakeholder participation, and public awareness" among the measures to be implemented by Member States. This highlights the importance of promoting awareness and active stakeholder involvement as a key component of efforts to achieve Good Environmental Status (GES) in the marine environment.

Therefore, the MSFD meets the participatory criterion from a legal and procedural standpoint, particularly by incorporating Directive 2003/4/EC, and reinforcing transparency and stakeholder involvement. However, as with the WFD, it lacks concrete mechanisms to ensure

inclusive, continuous, and representative participation. The absence of guidelines to identify and engage stakeholders may lead to the exclusion of relevant groups. Moreover, there are no mandatory requirements for how Member States should ensure that stakeholders' contributions are integrated into final decisions, nor robust methods to assess the quality of participation. Instead, these aspects are largely left to national discretion. Like other directives, the MSPD requires that stakeholders and the public are informed and consulted early in the planning process, and reinforces that Member States ensure access to the finalized plans (Art. 9). However, it does not detail how stakeholder engagement should be carried out, leaving much of the responsibility to Member States. This can result in divergent approaches and, in some cases, limited or merely symbolic participation without guaranteeing that all voices are heard.

The directive also refers to other instruments that address public participation, such as Directive 2003/35/EC (Art. 21), which ensures participation in environmental matters in large projects and environmental licensing, and Directive 2001/42/EC (in Recital 23), which addresses the assessment of environmental impacts during the strategic planning stage. Therefore, the directive meets the participatory criterion from a procedural standpoint.

4.4.2.5 Includes internal and external factors of conservation (persistence) and change

The WFD meets the criterion. It demonstrates a commitment to preserving water quality and protecting aquatic ecosystems, promoting the persistence of certain ecological characteristics while incorporating mechanisms for adapting to changes.

Regarding conservation and persistence, the WFD promotes the maintenance of ecological characteristics by requiring water bodies to achieve and maintain GES, preventing deterioration (Arts. 4 and Annex V). Continuous monitoring and periodic reviews of management plans (Arts. 8 and 13) ensure that changes can be detected and proactively addressed, preserving the essential characteristics of the system.

In terms of change and adaptation, the WFD has the capacity to integrate new scientific information and adjust policies every six years (Arts. 11 and 13), allowing water systems to adapt to new environmental and social realities. The exemptions provided in Article 4 offer flexibility to address significant external pressures, such as climate change or extreme events, ensuring that policies can be adjusted to meet emerging challenges.

When considering internal and external factors, the inclusion of an economic analysis of water use, which evaluates both the supply and demand for water resources (Art. 9 and Annex III), and the promotion of public involvement (Art. 14) are ways to address external pressures that influence water resource management. Additionally, the WFD addresses internal factors

by directly protecting aquatic ecosystems (Art. 6), with Annex IV reinforcing this protection by identifying and classifying various zones that require specific protection to preserve their essential characteristics and ecological integrity.

Nonetheless, limitations remain in how the WFD operationalizes these principles despite recognizing growing pressures. The Directive presents gaps in how it monitors and responds to changes in water systems. The flexibility of exemptions may undermine ecological persistence if interpreted too broadly, and the directive lacks explicit consideration of structural, legal, or social barriers to adaptation. It also provides limited guidance on managing sector-specific demands (agriculture, industry, domestic use) and their interaction with climate change and extreme events. The absence of mechanisms for adaptively monitoring evolving water use further constrains temporal responses to emerging pressures, risking a form of stability that may prove unsustainable in the long term.

The GWD partially meets the criterion. It promotes the conservation of groundwater resources and demonstrates a general commitment to change by allowing for adaptation to scientific and technical progress, as outlined in Article 8, enabling updates to protect water quality.

However, the directive does not directly introduce specific adaptation mechanisms. Instead, it allows only certain annexes to be updated through regulatory procedures, subject to oversight and justified by scientific and technical progress. In other words, the directive acknowledges the need for updates but does not clearly define how these adaptations should be operationalized. This aligns with persistence, aiming to maintain the stability of water resources in the face of known threats but without providing a specific pathway for adaptation.

The directive also presents important gaps by not adequately addressing external pressures such as climate change and sector-specific demands. Although it acknowledges pollution from industrial and agricultural sources, it lacks guidance on managing competing uses, prioritizing sectors, or responding to climate-induced challenges like droughts and recharge variability. This weakens the directive's capacity to support adaptive and integrated responses, as it over-relies on technical updates without offering robust strategies to ensure groundwater resilience and ecological persistence.

The MSFD aims to protect and preserve marine ecosystems and apply an ecosystem-based approach, which demonstrates a certain focus on internal conservation factors, ensuring that the pressures from human activities are kept at levels compatible with good environmental status. The requirement to implement continuous monitoring programs and establish spatial

protection measures (Art. 13) is an important element to ensure the maintenance of ecological integrity, a key aspect for persistence.

The MSFD also acknowledges change factors, including anthropogenic impacts that can influence ecosystem transformation. The initial assessment required under Article 8 includes an analysis of the main impacts and pressures on the marine environment and the establishment of environmental targets, and programs of measures (Arts. 10 and 13) to mitigate the impacts of human activities. Furthermore, Article 17 provides for the periodic review and adaptation of marine strategies, demonstrating the necessary flexibility to address emerging challenges and external pressures, which is relevant for managing changes and innovations, ensuring that strategies can evolve to meet new contexts.

The directive recommends that Member States include management instruments, such as economic and mitigation measures, to influence human activities and encourage actions that promote sustainability in the programs of measures (Annex IV), reflecting an attempt to balance maintaining what works well (persistence) with adapting to new challenges (change). However, Article 14 allows exceptions for certain human activities that may hinder the achievement of good environmental status, potentially prioritizing economic and social interests over ecological integrity. It also lacks clear guidance on integrating climate change impacts into their programs of measures and mechanisms for resolving conflicts between competing marine uses and conservation goals. Moreover, it lacks clarity on how to integrate broader socio-economic drivers and assess the effectiveness of measures that support resilience and transformation. Thus, the directive partially meets the subcriterion.

The MSPD addresses the conservation of marine and coastal ecosystems by applying an ecosystem-based approach. It identifies environmental protection and climate change resilience as the main objectives of marine spatial planning (Art. 5). The directive also considers the factors that drive change, particularly regarding resource development and sustainable use. It highlights land-sea interactions, indicating that external factors, such as human activities on land, influence the marine environment and affect coastal and marine dynamics, driving both change and persistence.

The directive meets the subcriterion by seeking to promote the coexistence of relevant activities and uses. It demonstrates an attempt to balance ecosystem conservation (preserving what works well) with the need for adaptation and the development of new uses, supported by a knowledge-based approach (Art. 10). However, it lacks clear guidance on how to systematically integrate conservation and change-related factors into decision-making. This may lead to inconsistent implementation and limit managers' ability to identify concrete actions for re-

silience and sustainability. While flexibility can support local adaptation, the absence of clear criteria risks uneven application across Member States.

4.4.2.6 Long-term sustainability

The WFD partially meets the subcriterion of long-term sustainability by incorporating important elements, such as the Principle of Cost Recovery for Water Services (Art. 9 and Annex III), which promotes the internalization of environmental and resource costs (water use) to ensure economic sustainability. However, its practical implementation is uneven among Member States, particularly in defining clear parameters for indirect costs.

Article 20 (Technical adaptations of the directive), Article 11 (programs of measures), and Article 9 (cost recovery) recognize the principles of precaution, preventive action, source control, and the polluter-pays principle. They are also referenced in recitals 11 and 44. These principles emphasize that, even in the face of scientific uncertainties, anticipatory actions are necessary to prevent potential environmental damage, as the lack of certainty should not justify inaction. Furthermore, damages must be addressed at their source, and the costs of their repair or mitigation should be attributed to the responsible party. While the recent proposal for a revised WFD (2022/0344(COD)) makes significant progress by including emerging substances, such as pharmaceuticals, PFAS, and microplastics, through watch lists and dynamic update mechanisms, implementation gaps remain. The directive still lacks clear operational mechanisms for cross-sectoral integration, especially among sectors competing for water resources, which hinders the systemic management needed to address resource nexuses.

The GWD contributes to long-term sustainability in some aspects by protecting groundwater through pollution prevention (Art. 1), continuous monitoring (Art. 5 and Annex IV), and periodic reviews (Art. 10). The Directive complements the WFD and other environmental regulations but lacks clear mechanisms for implementing this coordination in practice. This gap can lead to fragmented governance, inconsistent management actions, inefficient resource allocation, and reduced policy effectiveness, undermining the integrated approach needed to address complex challenges and promote long-term sustainability.

Moreover, the Directive does not explicitly address sustainable and regenerative practices, such as rainwater reuse or the promotion of nature-based solutions, which are key elements for long-term sustainability, as increasingly recognized in the scientific literature (Gebreslassie et al., 2025; Kebede et al., 2024; Wartalska et al., 2024). Social and economic impacts of related activities are also not considered in an integrated manner, limiting the Directive's ability to balance development and conservation, as highlighted by the subcriterion.

Furthermore, the Directive does not explicitly recognize the role of climate change in groundwater protection, nor does it establish clear links with the emerging challenges already addressed in its proposed revision. These issues may compromise the Directive's ability to ensure resilience, long-term conservation, and suitability for future generations. It stands in contrast to the principles of sustainability and precaution. Therefore, the Directive partially meets the subcriterion.

The MSFD recognizes the need for a balance between development and conservation, aligning its objectives with the principle of intergenerational sustainability and applying the ecosystem-based approach to managing human activities (Art. 1), which is essential for ensuring long-term sustainability. Including environmental indicators (Art. 10), it establishes a mechanism for continuous monitoring of environmental impacts, ensuring that current actions do not compromise future sustainability. However, there is a lack of methodologies to assess cumulative impacts and specific mechanisms for socioeconomic monitoring, despite the directive mentioning both the need to evaluate cumulative and synergistic pressures and social and economic analyses (Art. 8).

There are also limitations in addressing the interconnections between freshwater and marine systems; the lack of clear mechanisms to integrate with terrestrial policies hinders the ability to manage resources holistically and sustainably in the long term, leading to fragmentation, implementation inequality among Member States, and reduced policy effectiveness. The absence of long-term goals represents a critical challenges that need to be addressed to ensure that future generations can meet their needs.

In the issue of emerging pollutants, the Directive represented an initial step forward by including microplastics in Descriptor 10 (Marine Litter). However, regulatory coverage has remained limited, as Annex V and the PoMs do not include standardized methodologies for monitoring other relevant emerging pollutants, such as pharmaceuticals, nanoparticles, and persistent chemicals. This technical gap compromises the Directive's ability to anticipate risks and respond in a preventive and adaptive manner, which are key elements for long-term sustainability.

This limitation is compounded by the lack of a clear approach to addressing the long-term and cumulative impacts of climate change on marine ecosystems, such as ocean warming and acidification, sea level rise, and biodiversity loss. The MSFD does not set specific climate resilience targets or robust adaptive guidelines, and it lacks multilevel coordination, especially when it comes to linking it to global agreements such as the Paris Agreement. When considering the intersection between emerging pollutants and climate change, the gap becomes even

more critical: global warming can intensify the toxic effects of these pollutants, while ocean acidification can alter their mobility and bioavailability. Thus, the directive only partially meets the subcriterion, as it fails to provide integrated and effective responses to complex and inter-connected environmental threats.

The MSPD contributes to long-term sustainability by establishing a framework for coordinated maritime spatial planning based on the ecosystem approach (Art. 1), including the explicit consideration of land-sea interactions (Art. 7), periodic reviews (Art. 6) and evidence-based decision-making through the use of the best available data (Art. 10). These provisions aim to prevent the unsustainable exploitation of marine spaces, recognizing the impacts of climate change and the need for intergenerational resilience (Art. 5; Recitals 13 and 14).

As with other directives, the MSPD grants Member States significant flexibility to define their economic, social, and environmental priorities according to national contexts (Arts. 4 and 5). While this flexibility allows for contextual adaptations, it can also generate asymmetries in implementation, especially in the absence of binding coordination mechanisms or common sustainability targets. The Directive provides for transnational cooperation and reporting to the European Commission (Arts. 11 to 14), but it does not impose effective enforcement instruments to ensure convergence among Member States.

Furthermore, the directive does not define long-term quantitative ecological limits, nor does it establish specific obligations to address emerging pollutants or operationalize climate targets. While it recognizes the impacts of climate change, it lacks a regulatory framework that directly integrates mitigation or adaptation measures into maritime spatial planning. These elements are crucial for anticipating environmental and socio-economic risks and ensuring the long-term resilience of marine systems.

An interesting observation when analyzing the Directive is that, although it integrates sustainability as a guiding principle, its focus on strategic economic sectors may, in practice, lead to an instrumentalization of maritime spatial planning as a tool for economic development, relegating environmental objectives to a secondary role if there is no effective integration between sectoral and environmental instruments. Thus, the MSPD partially meets the Long-Term Sustainability subcriterion.

4.5 Key Findings from the Directive-S2S Landscape Analysis

In the analysis of the criteria and their respective subcriteria, common issues were identified between the Directives, including convergences and gaps concerning the S2S Landscape

approach. The findings presented not only highlight the key points for implementing the approach but also provide relevant insights for any integrated water and landscape management model. These points reflect how regulatory frameworks address aspects such as the integration of natural and cultural systems, the coordination of policies across different levels and sectors, and the challenges associated with fragmented approaches, which directly influence the implementation of integrated strategies. The following are the main insights drawn from this analysis:

- The definition of "Good Status" (ecological, chemical, or environmental), explicitly or implicitly in the Directives, is not purely technical or ecological but rather a normative construction influenced by human values, political interests, and socioeconomic needs. This subjectivity becomes particularly evident in implementing the directives, especially during their transposition into national legislation, where the lack of a binding parameter for what constitutes "Good Status" allows for broad discretion among Member States. As a result, interpretations may vary significantly, affecting the harmonization of environmental policies, monitoring, and results, compromising the effectiveness of water governance .
- The transposition and implementation of Directives by Member States involve a high degree of discretion (based on the principle of subsidiarity) in interpreting, adapting, and applying regulations, leading to uneven and fragmented implementations. While this granted flexibility is important for accommodating different local and national realities, the absence of clear and uniform guidelines on its application results in divergent interpretations, gaps in implementation, and difficulties in coordination and alignment among countries, particularly in cross-border and cross-sectoral issues, especially when not accompanied by effective accountability and enforcement mechanisms.
- The directives do not adequately consider atmospheric processes in water management, such as atmospheric rivers, evaporation and precipitation cycles, and gas exchanges between the ocean and the atmosphere. This gap reflects a fragmentation in the regulatory approach and the absence of integrated guidelines in environmental governance, leading to policies that overlook the interdependence within the hydrological cycle. As a result, ecosystem vulnerability increases as atmospheric processes play a fundamental role in the hydrological cycle, directly influencing climate, water quantity and quality, and the ecology of aquatic systems. This compromises the resilience of these ecosystems to extreme climatic events, such as droughts and floods, while also limiting their capacity to adapt to climate change.

- **Absence of the Landscape Concept** - The concept of landscape as an integrated system connecting upstream and downstream flows within the geographic and cultural space is not fully explored. Although the interaction between aquatic and terrestrial subsystems is recognized, the integration of processes that sustain ecosystem and cultural services remains limited. The directives do not use the landscape as an integrating element of environmental, social, and economic processes within the territory, nor do they recognize that the landscape reflects the dynamic interactions between biophysical factors (soil, water, vegetation, and climate) and human factors (land use, culture, infrastructure, and perception). Incorporating this perspective could improve the alignment between directives, preventing the disconnection in the management of land, inland waters, and marine areas.
- **Emerging pollutants and regulatory fragmentation** - The management of emerging pollutants critically illustrates the limitations of the current fragmented regulatory model. Although the WFD, GWD, and Environmental Quality Standards Directive (EQSD) are under joint review (legislative process 2022/0344/COD), with advances such as the expansion of the priority substance lists and the introduction of dynamic monitoring mechanisms (including microplastics, PFAS, and pharmaceuticals), structural gaps persist. Regulation remains divided between sectoral instruments, with poorly operational cross-references, without regulatory consolidation or effective integration of the different compartments of the water cycle. Furthermore, the exclusion of the MSFD and MSPD directives from this review highlights the persistence of a compartmentalized approach, which overlooks the interconnectedness between rivers, aquifers, coastal zones, and oceans. This disarticulation compromises systemic governance and the capacity for preventive response to emerging chemical threats in interconnected aquatic ecosystems, contradicting the principles of integrated landscape and water resources management.
- **Climate change impacts are poorly addressed.** The directives address Climate change only in a limited manner, without robust strategies to manage cumulative impacts such as sea level rise, changes in precipitation patterns, and extreme weather events. The absence of specific guidelines and the lack of concrete operationalization of climate targets outlined in broader EU strategies weakens the ability of water management policies to ensure ecosystem resilience and the sustainability of water resources in the face of future climate scenarios. This undermines the coordination between mitigation, adaptation, and integrated territorial management. **Limited Focus on Cultural and Social Dimensions.** The directives address human pressures and impacts on ecosystems, but fail to integrate the interrelationships between nature and culture. Recognizing these pressures does not equate to fully integrating the cultural and so-

cial dynamics that both influence and are influenced by natural processes. Additionally, the concept of "hydrosocial," which would allow for a broader understanding of socio-ecological dynamics by connecting climate change, water management policies, and cultural practices along the land-sea *continuum*, has also not been adopted.

- **Weak Multilevel and Cross-Sectoral Governance.** The absence of effective mechanisms to coordinate different levels of governance (local, regional, national, and international) and economic sectors undermines the integrated implementation of the directives. Although the need for coordination is recognized, there are no clear instruments to align policies and actions in cross-border and cross-sectoral contexts. This can result in priority conflicts between sectors and make the efficient management of water resources and landscapes more challenging.
- **Fragmented and Inconsistent Monitoring and Evaluation.** Although the directives require national environmental monitoring systems, the lack of harmonized criteria and an integrated evaluation framework across the different parts of the hydrological cycle compromises data comparability and hinders coordination among Member States. Significant gaps remain in spatial coverage, definition of indicators, and methodological coherence between directives, especially between inland and marine waters. The absence of clear and binding mechanisms for tracking and enforcing environmental targets allows some countries to downscale commitments due to economic or political pressures, reducing the effectiveness of the directives in protecting aquatic ecosystems.
- **Limited and Unequal Public Participation.** The directives require public consultation and participation in water and maritime space management processes, but they do not establish robust guidelines to ensure that this participation is inclusive, representative, and effective at all stages of planning and implementation. The lack of clear criteria for operationalizing public involvement undermines the ability of various stakeholders to influence decision-making processes meaningfully. Additionally, implementing public participation varies widely among Member States, as the directives grant flexibility in how each country conducts consultations and stakeholder engagement. This results in practical inequalities, where some nations adopt more transparent and interactive approaches while others limit participation to formal, less accessible mechanisms.

In addition to the findings based on the analytical criteria, it is also relevant to consider the degree of integration among the Directives themselves. Although they share general water protection and sustainable management objectives, the Directives were designed to operate within distinct domains - groundwater, inland waters, coastal and marine systems, and maritime spatial planning - without a unified institutional or legal coordination framework. This

results in regulatory fragmentation, particularly in transitional zones and across shared responsibilities. A comparative matrix of these instruments (Table 4-3) reveals that while there are points of complementarity and cooperation, there are also overlaps and significant gaps, especially in governance, monitoring, and implementation timelines. These inconsistencies hinder the coherent application of integrated approaches such as the S2S Landscape.

The S2S Landscape expands the foundations of water resources governance and integrated management by explicitly incorporating the concept of landscape and recognizing the connections between terrestrial, freshwater, coastal, and marine systems as interconnected parts of a continuous cycle. It also includes multi-scale components by broadening the focus of watershed management to incorporate coastal and marine processes, connecting upstream-downstream and downstream-upstream flows.

The European Union (EU) has a legislative framework that supports integrated approaches, despite the gaps identified in the analyzed directives, and has made progress toward the sustainability of water resources. Moving forward is a continuous process, where we learn the next steps in practice.

The concept of landscape, recommended by the European Union through the European Landscape Convention (ELC) and its implementation recommendations, innovates by integrating ecological, cultural, social, and economic dimensions. It recognizes the landscape not only as a physical space defined by cities, fields, rivers, and mountains (territory) but also as a reflection of the dynamic relationship between humans and the environment.

The S2S Landscape approach contributes to this progress by broadening the concept of landscape, promoting the inclusion of ecological, cultural, social, and economic variables in planning. It integrates the terrestrial landscape with water bodies, following the principles of landscape approaches, but with a territorial scope broader than the landscape unit, encompassing the entire space from the source to the open ocean.

In this territory, it considers the full set of interactions between environmental processes (water cycle, biodiversity flows, among others) and human processes (land use, cultural, and economic activities), emphasizing that land and water form a single system, not separate parts. Additionally, the S2S Landscape approach introduces mechanisms that facilitate the holistic integration of processes, allowing for adaptive governance and management capable of addressing the identified gaps, harmonizing policies, and aligning definitions with a systemic and standardized model, promoting greater coherence among Member States.

Table 4-3 Comparative Matrix of the WFD, GWD, MSFD, and MSPD: Cooperation, Complementarity, Overlaps, and Gaps.

Aspect	Directive 2008/56/EC (Marine Strategy)	Directive 2000/60/EC (Water Framework)	Directive 2014/89/EU (Maritime Spatial Plan- ning)	Directive 2006/118/EC (Groundwater Protec- tion)	Cooperation/Complementarity/ Overlap/Gaps
General Objective	To protect and preserve the marine environment, prevent its deterioration, and, where practicable, restore marine ecosystems while achieving Good Environmental Status (GES) of marine waters by 2020 (Art. 1).	To establish a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater to achieve good ecological and chemical status by 2027 (Art. 1).	To promote the sustainable growth of maritime economies, the sustainable development of marine areas, and the sustainable use of marine resources through maritime spatial planning (Art. 5).	To prevent and control groundwater pollution, avoid further deterioration, and protect groundwater quality, particularly for human consumption and ecosystem functioning (Art. 1).	Each directive sets a distinct but complementary objective across segments of the water system - from groundwater to inland and marine waters (complementation). However, differences in environmental ambition and framing (protection vs. development) may lead to tension in implementation (gap).
Scope	Applies to marine waters, including seabed, subsoil, and coastal waters as defined in Art. 3(1); excludes territorial waters of overseas countries and territories.	Covers inland surface waters, transitional waters, coastal waters up to one nautical mile, and groundwater, as defined in Art. 2.	Applies to marine waters as defined in Art. 3(1) of the MSFD, excluding coastal waters under national planning when already covered by terrestrial spatial plans.	Applies specifically to groundwater, particularly for human consumption and ecosystem protection, as defined in Art. 2.	Together, the directives span the full water <i>continuum</i> from groundwater to the open sea (complementation). However, coordination mechanisms between the defined water types are limited, and legal definitions may create overlaps or jurisdictional gaps, particularly in coastal and transitional zones (overlap/gap).

Sector Integration	Promotes an ecosystem-based approach and requires integration of environmental concerns into policies affecting the marine environment, including fisheries, shipping, and energy (Arts. 1, 4, 5, 6).	Encourages coordination with other policies (e.g., agriculture, energy, tourism) to achieve river basin management goals (Art. 3, 4, 13).	Defines spatial planning as a cross-sectoral tool to manage competing maritime activities (e.g., energy, transport, conservation) and promote sustainable use (Art. 5, 6, 8)	Focuses on pollution prevention linked to sectoral pressures (e.g., agriculture, industry), but with limited provisions for cross-sector coordination (Art. 6).	All directives promote sector integration (cooperation), but none establish binding or institutionalized mechanisms for intersectoral coordination (gap). This weakens implementation across linked water systems, particularly at the land-sea interface, where overlapping sectoral pressures require integrated action.
Programs of Measures	Requires Member States to develop programs of measures to achieve or maintain Good Environmental Status of the marine environment, including spatial, regulatory, and economic tools (Art. 13).	Requires the establishment of river basin programs of measures to achieve good ecological and chemical status of surface (including rivers, lakes, transitional and coastal waters) and groundwater (Art. 11).	Maritime spatial plans must support the sustainable development and integrated management of marine and coastal activities; while not formally called "programs of measures," they serve a similar planning and implementation function (Art. 8).	Requires specific measures to prevent and limit the input of pollutants into groundwater, particularly from diffuse and point sources (Art. 5).	All directives require programs of measures or equivalent planning instruments aligned with environmental objectives (cooperation), but these operate under different legal frameworks and terminologies (overlap), and lack clear coordination mechanisms between inland and marine domains (gap).

Assessment and Monitoring	Requires initial environmental assessment and continuous (regular) monitoring of marine waters based on indicators, GES (Art. 8 and 11).	Requires assessment of water status and continuous monitoring of surface and groundwater quality, quantity, and ecological parameters (Art. 8).	Requires the use of best available data and tools for maritime spatial planning but does not prescribe formal monitoring schemes (Art. 10).	Requires monitoring of groundwater chemical status and trend analysis for pollutant concentrations (Art. 8).	The WFD, GWD, and MSFD require structured assessment and monitoring systems (cooperation), while the MSPD only mandates the use of existing data without establishing formal monitoring obligations (gap). Monitoring frameworks and indicators vary according to water type and directive (overlap), and there are no mechanisms to ensure methodological alignment or data integration across freshwater and marine domains (gap)."
Anthropogenic Pressures	Requires Member States to identify and assess pressures from human activities on the marine environment, including cumulative and trans-boundary impacts (Arts. 8, 9).	Requires identification of pressures and impacts on the status of surface and groundwater, such as pollution and hydromorphological alterations (Art. 5, Annex II).	Considers land-sea interactions and pressures related to the spatial and temporal distribution of maritime activities (Art. 6).	Requires identification and control of pollutants from anthropogenic sources, such as agriculture and industry (Art. 6).	All directives recognize anthropogenic pressures (cooperation), and together they address pressures across domains (complementation). However, they use different classification systems and lack integrated assessment of cumulative impacts across water types and sectors (overlap/gap).

Regional Coordination	Requires coordination through regional sea conventions (e.g., OSPAR, HELCOM) and cooperation among Member States sharing marine regions (Art. 6).	Requires coordination at the level of river basin districts, including transboundary basins shared by multiple Member States (Art. 3).	Requires cooperation among Member States and with neighboring countries when marine regions or subregions extend beyond national borders (Art. 11).	Encourages cooperation between Member States sharing groundwater bodies, including exchanging information and harmonizing threshold values (Art. 7).	All directives promote regional cooperation within their respective domains (cooperation), but no directive mandates coordination mechanisms across domains (e.g., river–coast–sea–aquifer systems) (gap), limiting integrated governance of transboundary and interconnected waters (gap/complementation).
Spatial Planning	Does not establish spatial planning instruments per se, but considers the spatial distribution of human activities and pressures in marine waters (Art. 8).	Identifies river basin districts as spatial management units and allows for designation of protected areas (Art. 3, Art. 7, Annex IV).	Establishes maritime spatial plans as legal instruments to manage the spatial and temporal distribution of maritime activities and ensure sustainable use (Arts. 5, 6, 8).	Does not address spatial planning directly, but includes the delineation of groundwater bodies and protection zones around abstraction points (Arts. 3, 6).	The MSPD explicitly introduces spatial planning instruments (complementation), while the other directives embed spatial logic within functional units (river basins, aquifers, marine regions) (cooperation). However, there is no mechanism to coordinate spatial planning across terrestrial and marine domains (gap).

Land-Sea Interactions	Recognizes the influence of land-based activities on marine ecosystems and focuses on the final part of the water cycle, but does not provide detailed provisions for land-sea integration (Art. 8).	Considers interactions between surface and groundwater, including pressures affecting transitional and coastal waters (Art. 5, Annex II).	Requires Member States to consider land-sea interactions in maritime spatial plans, aiming at integrated management of coastal and marine activities (Art. 6).	Addresses interactions between surface water and groundwater but does not extend its scope to downstream coastal or marine areas (Art. 3).	Cooperation/Complementation/Gap: All directives acknowledge some dimension of land-sea interaction (cooperation), and together they form a partial <i>continuum</i> from source to sea (complementation). However, integration remains fragmented, with no common framework to manage cross-domain impacts and feedback (gap), particularly due to the lack of detailed linkage between groundwater, inland, and marine waters in a coherent and continuous manner (gap).
Timelines and Coherence	Establishes 6-year implementation cycles (Arts. 3, 5, 17). The third cycle (2024–2030) requires Member States to update their initial assessments, Good Environmental Status determinations, and targets by October 15, 2024.	Defines 6-year river basin management cycles (Arts. 4, 13). The third cycle (2022–2027) requires updated River Basin Management Plans by December 22, 2021, and implementation of measures by December 22, 2024.	Requires Member States to establish maritime spatial plans by March 31, 2021 (Art. 4). No mandatory revision cycle is specified, but updates are expected as necessary to reflect evolving conditions.	No unified timeline. Implementation depends on national threshold values and reporting schedules (Arts. 3, 5), although aligned with WFD cycles.	Each directive defines its own implementation cycle (complementation), but these timelines are not harmonized across instruments. The lack of alignment between planning and implementation cycles reduces opportunities for coherent and synchronized management across groundwater, inland, coastal, and marine systems (gap).

Governance and Institutional Coordination	Encourages coordination with relevant international organizations and regional conventions (Arts. 5, 6), and promotes cooperation through Common Implementation Strategy (CIS) working groups. However, institutional mechanisms for cross-directive governance are not clearly defined.	Requires governance at the level of River Basin Districts, including coordination across national borders and sectors (Art. 3). Implementation is supported by the CIS and various EU-wide working groups.	Delegates planning responsibilities to Member States (Art. 4), allowing flexible institutional arrangements. Coordination between sectors is encouraged but not formally structured at the EU level.	Relies on national authorities to set threshold values and monitor implementation (Arts. 3, 5). No explicit provisions for institutional coordination across directives or with marine/coastal frameworks.	All directives encourage cooperation through international or intersectoral mechanisms (cooperation), but they do not establish formal or binding frameworks for cross-directive institutional coordination. This weakens the implementation of integrated water and marine policy across governance levels (gap).
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4.6 Practical Application and Institutional Implementation of the S2S Landscape

The S2S Landscape approach not only identifies and fills gaps in directives but also offers a practical and institutional structure to align existing policies and strategies, promoting integrated management of terrestrial, freshwater, and marine systems. This integration can be achieved through legal mechanisms, multi-level governance tools, and strategic funding, ensuring effective and sustainable implementation:

- **Integration into Existing Planning Instruments** - The S2S Landscape can be directly incorporated into River Basin Management Plans (WFD), in the marine strategy (MSFD), Programs of Measures (PoMs) derived from both the WFD and the MSFD, and Maritime Spatial Planning (MSPD), promoting an integrated vision of the impacts between rivers, coastal, and marine zones. This ensures that local and trans-boundary actions are coordinated, contributing to policy coherence and the reduction of cross-sectoral conflicts.
- **Overcoming Fragmentation in Governance** - Since the transposition of directives varies across Member States, the S2S Landscape approach can serve as an integrative reference to align national policies. It facilitates cooperation across different governance scales (local, national, and regional) and economic sectors, such as water, energy, agriculture, and transport, promoting greater efficiency in policy coordination and integration.
- **Promoting Connectivity between Terrestrial and Marine Environments** - Current directives fragment the management of water resources and aquatic ecosystems, lacking an efficient integration mechanism. The S2S Landscape highlights the need for joint actions between inland and marine water management, promoting the continuity of water, sediment, nutrient, and pollutant flows along the hydrological cycle. This reduces fragmentation and enhances the resilience of ecosystems to extreme climatic events.
- **Enhancing Ecosystem-Based Management** - The S2S Landscape can act as a link between existing directive strategies and emerging environmental challenges, such as climate change and emerging pollutants. This focus enables a more dynamic and resilient approach for adaptation and mitigation of environmental impacts, promoting nature-based solutions.
- **Harmonization and Integrated Monitoring** - The development of common criteria for monitoring and evaluation is essential to facilitate comparability of environmen-

tal data among Member States and ensure a rapid response to new environmental threats. Advanced technologies, such as geographic information systems (GIS) and open data portals, can support this integration, promoting greater transparency and efficiency.

The S2S Landscape approach can be formally introduced in the European Union gradually as a complementary strategic framework, similar to the current environmental and biodiversity strategies. This can be achieved through:

- Revision of Existing Directives, especially the WFD and MSFD, to explicitly include the source-to-sea perspective;
- Creation of a Multi-level Governance Platform, promoting cooperation between river basin committees and maritime regions;
- Inclusion in EU Climate Adaptation and Action Plans, highlighting the importance of integrated management of connected systems for climate resilience;
- Exploration of thematic funding mechanisms, with criteria-oriented land-sea integration, climate resilience, and ecological restoration, capable of supporting pilot projects aligned with the principles of the Source-to-Sea Landscape approach;
- Utilizing European frameworks to support research, innovation, and territorial cooperation, which promote integrated actions across multiple scales and sectors, facilitating the practical and collaborative implementation of the S2S Landscape approach in strategic territories.

The creation of Pilot Projects (Co-Pilots) for testing and demonstration in strategic regions, such as the Atlantic Region, which includes countries like Portugal, Spain, France, and Ireland, becomes essential. These areas, characterized by complex estuaries, coastal zones vulnerable to extreme climate events (flooding, sea-level rise), and diverse economic activities (fishing, tourism, maritime transport), offer ideal conditions for testing, demonstrating, and assessing the feasibility of the S2S Landscape approach. These projects would function as innovation labs, enabling:

- The joint implementation of land–sea management strategies;
- Practical application of integrated strategies, including joint monitoring of freshwater and marine systems;
- Testing of nature-based solutions for mitigating emerging pollutants and adapting to climate change;
- Engage multiple stakeholders, promote co-creation of local solutions, and disseminate best practices among Member States.

The S2S Landscape framework is flexible enough to be adapted to local specificities while maintaining a systemic, integrated, and coordinated vision. This helps mitigate the negative effects of discretion in the transposition of directives, ensuring greater policy coherence and sustainability in the management of water resources and landscapes.

Continuous and inclusive public participation is one of the fundamental pillars of this approach's success. Regular and structured participatory processes, including co-creation of local solutions and community monitoring, ensure greater policy legitimacy and community engagement, aligning solutions with local needs and realities.

4.7 Conclusion

The analysis identified how the principles (criteria and sub-criteria) of the S2S Landscape approach align with the WFD, GWD, MSFD, and MSPD directives, highlighting convergences, gaps, and opportunities to strengthen water and landscape governance and integrated management. The methodology was based on applying evaluative criteria, the Leopold matrix, and analytical-deductive analysis to assess the interrelationships between the criteria and the directives.

Two main criteria were defined for the analysis: Systemic Vision of Territorial Processes (Diagnosis) and Governance and Management (Action), subdivided into 12 sub-criteria, which revealed the challenges faced by the directives. These challenges include fragmentation in the coordination of cross-border and cross-sectoral policies, the absence of clear guidelines, clear operational targets, and binding coordination mechanisms for emerging issues (such as emerging pollutants and cumulative climate impacts), and the lack of full integration of the landscape concept as a key element to connect biophysical and human processes.

The analysis also revealed that gaps in addressing atmospheric processes and land-sea connectivity weaken policies' ability to respond effectively to climate change and extreme weather events, compromising ecosystem resilience. Additionally, discrepancies in directive transposition among Member States and unequal public participation directly affect the effectiveness of environmental policies.

In this context, the S2S Landscape approach emerges as an opportunity to fill these gaps and strengthen the European regulatory framework. Its incorporation can promote a more integrated and adaptive management, improving coordination between policies and sectors and facilitating the harmonization of definitions and practices among Member States.

By adopting the landscape concept as a central element, the S2S Landscape integrates ecological, cultural, and social variables into planning, going beyond conventional watershed boundaries to connect terrestrial and marine areas into a single continuous system. The inclusion of integrated monitoring mechanisms, nature-based solutions, and regional pilot projects (co-pilots) offers a practical foundation to test the feasibility of this approach, enabling more resilient and sustainable management.

Finally, the success of this approach depends on effective multi-level governance, continuous public participation, and adequate funding. With the advancement of the European Union's institutional framework, the integration of the S2S Landscape could place the EU at the forefront of integrated source-to-sea territorial governance, ensuring the sustainability of water resources and the long-term protection of ecosystems.

SOURCE-TO-SEA LANDSCAPE: A CONCEPTUAL FRAMEWORK FOR THE INTEGRATED GOVERN- ANCE OF FRESHWATER, COASTAL, AND MARINE SYSTEMS³

5.1 Introduction

This chapter begins with a central question: to what extent does the Source-to-Sea (S2S) approach offer a substantive innovation for overcoming fragmentation in the governance of interconnected socio-ecological systems, rather than simply reorganizing principles already present in previous integrative approaches?

Addressing this question requires a progressive and cumulative analytical exploration, with adjustments in which conceptual gaps and emerging insights help refine the understanding of integrative water governance. This process led to the development of three interrelated studies, structured as scientific articles, which together provided empirical, conceptual, and normative foundations for a new proposal for territorial and environmental integration.

The first study compares Integrated Water Resources Management (IWRM), Integrated Coastal Management (ICM), and the S2S approach, identifying their convergences, complementarities, and gaps. The second study highlights a central limitation in the S2S approach: the absence of an explicit territorial dimension grounded in the landscape. Based on this finding, a conceptual framework was developed, and the S2S Landscape was proposed. The third study applied this framework to normative analysis. It examines the coherence among four key European directives for governing freshwater and marine systems (the Water Framework Directive -WFD, the Groundwater Directive - GWD, the Marine Strategy Framework Directive -

³ Michels-Brito, A., Ferreira, J.C.R., & Saito, C.H. (2026, in preparation). Source-to-Sea Landscape: A Conceptual Framework for the Integrated Governance of Freshwater, Coastal, and Marine Systems. In: G. Nhamo (Ed.), *Perspectives in Ocean, Marine and Coastal Governance Vol. 1: Transitions, Dynamics, and Institutional Innovations*. [Publisher]. (Abstract accepted; full chapter due January 2026).

MSFD, and the Maritime Spatial Planning Directive - MSPD) in light of the principles and elements of the S2S Landscape approach. Based on this set of studies, this chapter aims to establish a common analytical field, capable of articulating dimensions that were previously addressed in a fragmented manner: hydrological flows (and their impacts), interconnected territories (land–freshwater–sea), and the normative and institutional systems that regulate them.

Rather than offering a purely descriptive synthesis, the chapter advances towards formulating a governance framework grounded in coherence across scales, policies, and territories. It provides a space for conceptual integration and strategic application, articulating the different levels of analysis to illuminate the factors that perpetuate governance fragmentation and to identify pathways to overcome it through the S2S Landscape approach.

5.2 Fundamentals of Integrative Approaches: IWRM, ICM, and S2S

In recent decades, fragmentation in the management of water resources and coastal and marine environments has led to the development of different integrative strategies. Among them, IWRM, ICM, and, more recently, the S2S approach stand out. Although developed in distinct contexts, these frameworks share the objective of improving water governance and management by promoting human well-being and ecological sustainability through coordinated action across sectors and scales.

IWRM, widely promoted by the Global Water Partnership (GWP, 2000), aims to coordinate the development and management of water, land, and related resources to maximize economic and social well-being equitably, without compromising the sustainability of vital ecosystems. It is a river basin-oriented approach based on the four Dublin principles (ICWE, 1992): (i) water as a finite and vulnerable resource; (ii) water development and management should be participatory; (iii) women play a central role in the provision, management, and safeguarding of water; and (iv) water has an economic value.

Integrated Coastal Management (ICM) emerged to coordinate the planning and sustainable use of coastal zones, which are dynamic and highly vulnerable socioecological systems. ICM may be understood as a continuous decision-making process aimed at maintaining or restoring the ecological integrity of coastal zones while improving the quality of life of local populations through sustainable development (Cicin-Sain et al., 1998; Eger et al., 2021). Although both approaches recognize upstream-downstream linkages and connections between

terrestrial and aquatic systems, their practical articulation has often been limited by fragmented legal and institutional frameworks, as well as by a lack of mechanisms to integrate freshwater and marine waters.

In this context, the S2S approach emerges as an alternative for overcoming the spatial and institutional limitations of previous approaches by proposing a vision of the water system as a *continuum* that connects the river basin to the ocean (Granit et al., 2017b; Mathews et al., 2019). It presents a framework that considers the hydrological system as a whole, analyzing water resources through the lens of the water cycle, in which freshwater and marine waters are part of a continuous and interdependent process. Structured on the identification of key flows (water, biota, sediments, pollutants, materials, and ecosystem services), the approach bases its analysis on the connections between the various segments of this *continuum*, from source to sea, expanding the scope of integration and supporting a systemic and transboundary governance model.

While promising, this perspective also raised questions regarding the real capacity of this approach to innovate compared to already established integrative frameworks. Given this, it became necessary to analyze its innovative potential and determine to what extent it represents a break from approaches such as IWRM and ICM. To do this, we sought to understand their foundations and identify points of convergence and articulation between the three, in order to assess whether they are integrative, complementary, or competing.

The analysis revealed that the S2S approach not only reorganizes existing elements but also introduces significant advances by proposing a vision of the water system as a hydrosocial *continuum*, characterized by the identification of key flows and their connections and interactions. It also explicitly incorporates the principles of the blue and green economy, directing its strategies towards forms of sustainable development that integrate environmental conservation and social justice. On the other hand, because it is still relatively new, the approach presents an incipient treatment of dimensions such as gender and the value of water.

The analysis also showed that the S2S approach integrates and complements IWRM and ICM. This complementarity occurs at this common point: water, the central element that, through its flows, connects different geographic segments, offering promising ways to overcome the fragmented logic of sectoral management. However, the approach does not explicitly address the territorial patterns, land uses, and sociocultural contexts that shape and are shaped by these systems. In other words, there is a lack of an integrated view of the landscape. This gap limits the holistic understanding of the interconnections between natural and social systems. In light of this, it becomes essential to deepen the understanding of the interaction be-

tween human dynamics, spatial organization, and hydrosocial functioning, extending the analysis to identify potential relationships and connections with landscape-based approaches.

5.3 Beyond Hydrological Integration: Incorporating the Landscape Dimension

The recognition that the S2S approach does not fully address the spatial and sociocultural dimensions of hydrosocial systems raises a new question in this research: Is it possible to enhance this approach by introducing a perspective that articulates water flows to the territories and contexts that sustain them? This concern leads to considering landscape as an interpretive lens, capable of revealing potential pathways to overcome the identified limitations.

To develop this hypothesis, it became important to distinguish between two ways of reading space. A territorial perspective focuses on how land is used, occupied, and organized (e.g., the location of cities, forests, agricultural areas, and infrastructure). A landscape perspective, on the other hand, expands this view by understanding territory as a living system in which biophysical, ecological, and sociocultural elements interact dynamically.

The analysis began with a theoretical review of the landscape concept, covering its geographical, ecological, and epistemological roots. It was observed that, although landscape studies originally emerged from a holistic and integrative perspective, as in the contributions of Humboldt (Zonneveld, 1995), Vidal de La Blache (Antrop, 2000), and Bertrand (Bertrand & Tricart, 1968), over the twentieth century, a separation was consolidated between two predominant approaches: the geographical approach, focused on the sociocultural and territorial dimensions of spatial patterns; and the ecological approach, centered on natural processes and the conservation of biodiversity (Antrop, 2000; Wiens, 2008).

This division, however, has proven insufficient to address the complexity of contemporary socioecological systems, particularly in the context of integrated water governance. Therefore, It adopted a more integrative framework, drawing from formulation of the Hybrid Landscape Approach (HLA) concept, to overcome disciplinary fragmentation by understanding landscape as a hybrid system, simultaneously natural and cultural, ecological and symbolic, procedural and territorial, based on dynamic relationships between what circulates and what is structured (flows and forms), and between the meanings we attribute to and the uses we make of the territory (values and functions) (Bertrand, 2004; Naveh & Lieberman, 1994; Antrop, 2005). This

conception converged with the values and concepts of the European Landscape Convention (ELC), which resumes this integrative tradition.

Based on this conceptual framework, it became possible to identify points of convergence between the core principles of the S2S, HLA, and ELC. Both the S2S and HLA frameworks are multilevel, adaptive, and resilient, aiming at the integrated and participatory management of water resources and territories. While the S2S focuses on adaptation and resilience to face water governance challenges, the HLA views the landscape as an interconnected and cohesive system, uniting natural and cultural, terrestrial and aquatic elements. Both approaches align with the ELC principles, revealing strong complementarity and potential for integration.

This convergence enabled the formulation of an integrative proposal, which incorporates the landscape as a structuring element of water governance along the source-to-sea *continuum*: the S2S Landscape approach.

5.4 The S2S Landscape approach

The S2S Landscape approach proposes a holistic and transdisciplinary strategy to fill gaps and address fragmentation in the governance and management of landscape and water resources. It does so through an integrative approach that considers natural and social processes across multiple territorial dimensions and levels of organization. Structured in four steps — Comprehension, Involvement, Planning, and Execution & Monitoring — it offers a methodological pathway to understand, design, implement, and adapt interventions in complex systems, articulating physical, ecological, sociocultural, and institutional dimensions.

More than a linear sequence, it is a dynamic and continuous cycle of improvement and learning, capable of dealing with different contexts and scales along the source to sea *continuum*. The following analysis presents each of the four steps of the approach, highlighting their objectives, processes, and expected outcomes within a systemic and adaptive framework.

5.4.1 Step 1 - Comprehension

This step aims to develop a holistic understanding of the S2S Landscape system by identifying and characterizing the main flows (water, biota, sediments, pollutants, materials, and ecosystem services) that connect the different subsystems along the source-to-sea *continuum*. This involved delimiting the study area, analyzing the ecological and social

processes mediated by water as a structuring element of the landscape, and assessing how changes in these flows impact ecosystems, biodiversity, and human well-being. The approach recognizes the multidirectionality of flows, considering not only longitudinal movements (upstream–downstream), but also lateral flows (between the channel and riparian zones) and reverse or atmospheric flows (such as flying rivers and species migration). This expanded view enhances the understanding of the hydrosocial system and reinforces the need for an integrated analysis of impacts and connections across the entire *continuum*. This step results in a diagnosis that describes the priority flows, their alterations and consequences, encompassing their characteristics and interdependencies within the landscape, serving as a basis for the following steps. It is also important to note that stakeholder mapping commences at this stage, enabling the diagnosis to be subsequently discussed, adapted, and validated collectively.

5.4.2 Step 2 - Involvement

This step aims to understand how the different actors are organized in relation to the resource use and management in the S2S Landscape system. This involves mapping and engaging affected, causative, facilitating, supporting, and external stakeholders. Following the participatory validation of the diagnosis, the demand for ecosystem services, sociocultural dynamics, and associated conflicts are analyzed, as well as governance gaps and overlaps. A central outcome of this step is the stakeholder map, which identifies their roles, interests, influences, and connections with the prioritized flows, serving as a basis for engagement strategies. The differential of this step lies in the incorporation of interactive scenario analysis, which enables continuous stakeholder participation in exploring how the system may respond to current conditions and how it could evolve in light of the problems already identified. Ultimately, this step provides a baseline of existing governance, highlights the institutional forces that support or hinder change, identifies normative conflicts, overlaps, and coordination failures, and establishes the conditions for the transition to the next step. This includes the pre-definition of quality objectives and preparation for participatory planning of the Theory of Change (ToC).

5.4.3 Step 3 - Planning

This step marks the planning phase of the program or project, involving the definition of landscape and water resources quality objectives, the participatory formulation of the ToC, and the detailing of the strategies and activities required to achieve the desired outcomes. The ToC establishes clear connections between actions, expected results and long-term impacts, and is structured based on the Orders of Outcomes framework: (1) creation of enabling conditions, (2) behavior change, (3) implementation of interventions, and (4) long-term impacts. This step also incorporates the previously developed scenarios to test the robustness of the strategies in the face of uncertainty and prepare the system for future changes. Targets, indicators, support policies, and territorial planning instruments are defined to integrate the S2S dimension across relevant sectors. Ultimately, the step consolidates a coherent, measurable, and adaptable action plan that will serve as a basis for implementation, monitoring, and adaptive management in subsequent steps.

5.4.4 Step 4 - Execution & Monitoring

This step defines the implementation plan and financing strategy for the project or program, based on the previously developed Theory of Change. Given the systemic nature of the S2S Landscape approach, new actors may become involved, and innovative financial arrangements may emerge. These could include public-private partnerships, payment for ecosystem services, certifications, and green bonds. The plan details the activities, timelines, and responsibilities, adopting participatively defined indicators to monitor the expected outcomes at the four levels (enabling conditions, behavioral changes, implementation of interventions, and long-term impacts). The monitoring system tracks progress, tests the assumptions of the ToC, identifies areas for improvement, and promotes continuous adaptation of the program. It also reinforces the importance of transparency, knowledge dissemination, and maintaining an information repository to ensure coordination, evaluation, and continuous learning, with stakeholder involvement at all levels.

Taken together, these steps consolidate the S2S Landscape approach as a continuous spiral of learning, action, and replanning, allowing strategies and interventions to be revised and adapted based on evidence and observed outcomes. More than a technical model, it constitutes an adaptive governance framework that articulates diverse practices, institutions, and knowledge, promoting an integrated understanding of the landscape and water as interdependent systems. The continuous use of participatory scenarios strengthens the capacity for anticipation and supports effective response in contexts marked by uncertainty and environmental change.

The main innovation of the approach lies in its ability to overcome traditional compartmentalizations, such as those between inland and marine waters (IWRM vs. ICM) or between natural space and inhabited territory, by proposing an expanded territorial vision that encompasses the entire *continuum* from source to ocean. By incorporating the hydrosocial cycle, ecological interactions, biophysical flows, and human and cultural processes, S2S Landscape offers a cohesive and holistic framework for understanding and governing complex socioecological systems. This integration enables the recognition of landscape as a structuring element of the relationship between water and society, reinforcing that the fragmentation of these connections compromises the sustainability of ecosystems and human wellbeing. Water shapes the landscape, and it is through the landscape that the relationships between water and society are constructed.

In this sense, S2S Landscape not only fills gaps in previous approaches but also moves towards a truly systemic, transdisciplinary, and future-oriented governance. Table 5-1 summarizes the identified limitations and illustrates how the S2S Landscape approach addresses and transcends these constraints.

Table 5-1 Limitations of Traditional Approaches Overcome by the S2S Landscape Approach

Approach	Identified Limitation	How the S2S Landscape Overcomes It
S2S	Focus on source-to-sea flows without adequately incorporating socio-environmental processes that extend beyond the drainage area.	Overcomes the spatial limitations by encompassing socio-environmental processes beyond the drainage area from source to sea (including the continuity of vegetation patterns beyond the watershed and cultural organizations extending to the other side of the relief's summit).
ICM	It recognizes the mutual influence between environmental processes and social processes, but the view is limited to coastal zones and the sea.	It encompasses the entire river basin and the freshwater flows that reach the coastal zone and the sea
IWRM	Limitation to the basin territory, without integration with the sea and coastal areas	Encompassing the coastal area and the open sea, going beyond the water basin borders
HLA and ELC	Scale limitation to the landscape unit, which is generally smaller than the water basin	Encompassing the water basin as a socioecological <i>continuum</i> from the source to the sea

5.5 Normative applicability of the S2S Landscape in the European context: an analysis in light of EU directives

The S2S Landscape approach, by integrating ecological, sociocultural, and institutional dimensions across the entire source-to-sea *continuum*, brings relevant implications for environmental governance. Its implementation, however, demands more than conceptual or methodological advances: it requires an institutional and normative environment capable of supporting coherent, multiscale, and intersectoral actions.

In this context, this section examines the extent to which the main regulatory frameworks of the European Union related to water and marine governance (WFD, GWD, MSFD, and MSPD) provide the institutional and legal conditions necessary for the implementation of an integrated approach such as the S2S Landscape.

The analysis adopts the S2S Landscape as both a conceptual and operational framework, and assesses the degree of practical and conceptual alignment of these directives with its principles and core elements. Particular attention is given to the potential synergies, gaps, and contradictions that emerge when these directives are examined from a systemic territorial perspective. In doing so, it sought to contribute not only to the understanding of the limitations and potential of the European regulatory framework but also to the broader debate on whether the S2S Landscape can function as a catalyst for normative and territorial integration.

The evaluation was conducted using an analytical matrix inspired by Leopold's matrix model. Two main analytical criteria were defined, reflecting the internal logic of the approach itself:

1. Systemic Vision of Territorial Processes (Diagnosis)
2. Governance and Management (Action)

These criteria reflect, respectively, the need for an integrated reading of the territory and the institutional capacity to act on it. Each criterion was divided into six sub-criteria, resulting in twelve analytical dimensions that serve as lenses for examining the normative contents of the directives in light of the principles of the approach.

The first criterion covers aspects such as upstream-downstream hydrological flows, atmospheric processes within the water cycle, integration between natural and cultural systems, land-water articulation in the landscape, connectivity between fresh and marine water, and interactions between surface and groundwater.

The second criterion assesses the conditions for coordinated and adaptive action, including multilevel coordination, intersectoral integration, adaptive and resilient capacity, continuous social participation, consideration of internal and external factors of persistence and change, and the promotion of long-term sustainability.

Together, these twelve dimensions structured the analytical matrix that guided the normative evaluation of the directives, allowing a transversal and comparative assessment of their points of alignment, gaps, and inconsistencies in relation to the S2S Landscape approach.

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In addition to this criterion-based assessment, a complementary comparative matrix was used to examine the degree of integration among the directives themselves. This matrix identified areas of cooperation, complementarity, overlap, and regulatory gaps across the WFD, GWD, MSFD, and MSPD, providing an additional basis for interpreting regulatory and institutional fragmentation within the European water governance framework.

5.6 The Key Findings

The analysis of the criteria and their sub-criteria revealed common issues across the directives, including convergences and gaps related to the S2S Landscape approach. The findings presented here highlight not only the key points for the implementation of the approach but also provide relevant insights for any integrated water and landscape management model. These points reflect how the regulatory frameworks address aspects such as the integration between natural and cultural systems, the policy coordination across different levels and sectors, and the challenges posed by fragmented approaches, which directly influence the effectiveness of integrated strategies. The following are the main highlights of this analysis:

- The definition of “Good Status” in the directives is normative and open to national interpretation, which compromises the harmonization and comparability of environmental targets. The broad discretionary power granted to Member States hinders coherent and coordinated implementation, especially in cross-border and intersectoral contexts.
- The transposition of the directives by Member States involves broad discretion, resulting in uneven and fragmented implementations. While this flexibility allows for local adaptations, the lack of clear guidelines and effective accountability mechanisms undermines coordination, especially in cross-border and intersectoral contexts.
- The directives neglect atmospheric processes within the hydrological cycle, such as evaporation, precipitation, and ocean-atmosphere exchange, reflecting regulatory fragmentation and the absence of integrated guidelines. This omission compromises the resilience of aquatic ecosystems to extreme events and climate change by ignoring the interdependence between climate, water, and ecology.

- The directives do not incorporate the concept of landscape as an integrated system that connects biophysical and human processes in the territory. Although they recognize the interaction between aquatic and terrestrial subsystems, they lack an approach that integrates ecosystem and cultural services. This omission limits the articulation between land management, inland waters, and marine areas, compromising coherence between the directives.
- Even with the ongoing review of the WFD and the GWD under the 2022/0344/COD legislative process, the regulation of these pollutants remains characterized by normative and institutional fragmentation. The exclusion of the marine directives (MSFD and MSPD) from this process reinforces a compartmentalized approach that disregards the continuity between the compartments of the hydrological cycle.
- Climate change is addressed in a limited way, without robust strategies to deal with cumulative impacts such as sea level rise, altered precipitation patterns, and extreme events. The absence of specific guidelines and operational mechanisms weakens the capacity of water management policies to ensure ecosystem resilience and water sustainability, compromising the articulation between mitigation, adaptation, and integrated territorial management.
- The directives recognize human pressures on ecosystems but fail to adequately integrate cultural and social dynamics in the relationships between nature and society. A hydrosocial perspective that connects climate change, water management, and cultural practices across the land-sea *continuum* is lacking, limiting the understanding of socioecological dynamics.
- The lack of effective mechanisms to coordinate governance levels and economic sectors compromises the integrated implementation of the directives. Although the need for coordination is acknowledged, clear instruments to align policies in transboundary and intersectoral contexts are missing, leading to conflicting priorities and hindering the efficient management of water and landscapes.
- Despite the requirements of directives for national monitoring systems, the absence of harmonized criteria and an integrated assessment framework compromises the comparability of data and coordination between Member States. Gaps persist in spatial coverage, indicator definition, and methodological coherence, especially between inland and marine waters. The lack of binding mechanisms for tracking and enforcing

environmental targets allows for the relaxation of commitments, reducing the effectiveness of the protection of aquatic ecosystems.

- Although the directives provide for public participation, they lack robust guidelines to ensure inclusion, representativeness, and effectiveness in decision-making processes. The absence of clear operational criteria and the flexibility granted to Member States result in uneven practices: while some adopt broad participatory mechanisms, others maintain formal and restrictive approaches, weakening social influence on the management of water and maritime space.

Additionally, a comparative assessment was carried out between the directives themselves (WFD, GWD, MSFD, and MSPD), considering their objectives, scopes, planning instruments, governance mechanisms, monitoring, and sectoral integration. This analysis revealed a framework of formal complementarity, with each directive covering different compartments of the water cycle (from aquifers to the sea) but with limited practical integration. Conceptual overlaps and regulatory gaps persist, particularly in coastal and transition zones, where coordination between instruments is most critical. The lack of coordinated planning, monitoring, and evaluation mechanisms across terrestrial, subsurface, and marine domains limits the production of interoperable data, hinders synergistic management, and weakens temporal and spatial alignment between instruments.

Despite the common discourse on integration and coordination, there is a lack of binding provisions that ensure an intersectoral and cross-scale approach in practice. The directives largely operate in a compartmentalized manner, with weak institutional coordination and misaligned timelines, which compromise integrated responses to complex challenges such as emerging pollutants, climate change, and landscape governance at land-sea interfaces. These findings reinforce the results of the previous analysis based on the relationship between directives and the principles of the S2S Landscape and highlight the urgency of an integrative model capable of overcoming regulatory and institutional fragmentation through a systemic, territorial, and adaptive logic, a role for which the S2S Landscape approach is particularly well-suited.

In summary, the S2S Landscape approach expands the scope of river basin management by connecting upstream-downstream-upstream flows and promoting an integrated reading of the territory based on the concept of landscape. It articulates environmental processes (such as the water cycle and biodiversity) with human processes (land use, culture, and economy), reaffirming that land and water are parts of a single, interconnected system.

5.7 From Vision to Action: Pathways for Implementing the S2S Landscape Approach

The S2S Landscape approach goes beyond identifying regulatory gaps by offering a practical and institutional framework capable of aligning existing policies and strategies. Its implementation can be facilitated by legal mechanisms, multi-level governance tools, and strategic financing instruments, such as:

- Integration with existing planning instruments, such as River Basin Management Plans (WFD), Programs of Measures (PoMs) derived from both the WFD and the MSFD, marine strategies (MSFD), and Marine Spatial Planning (MSPD), promotes a coordinated vision across rivers, coastal, and marine zones.
- Reducing governance fragmentation: By serving as a common reference, the S2S Landscape can align national interpretations of EU directives and foster intersectoral cooperation (e.g., water, agriculture, transport), enhancing institutional coordination across governance levels.
- Ensuring Land–Sea Connectivity: The approach emphasizes hydrological and ecological continuity, addressing water, sediment, biota, pollutants, and material flows to reduce fragmentation and strengthen resilience to climate-related impacts.
- Advancing Ecosystem-Based Management supports a dynamic and adaptive response to challenges such as climate change and emerging pollutants by connecting regulatory tools with nature-based solutions.
- Harmonizing monitoring systems: Common criteria and interoperable data platforms (e.g., GIS, open data) improve environmental data comparability and responsiveness across Member States.

The S2S Landscape approach can be progressively adopted as a complementary strategic framework within the EU, in alignment with current environmental and biodiversity strategies that are in force at the time, through:

- Revision of key directives (WFD, MSFD) to explicitly include the source-to-sea perspective;
- Creation of a multi-level governance platform linking inland and coastal-marine institutions;

- Integration into EU climate plans to support ecological and social resilience;
- Thematic funding mechanisms supporting cross-sectoral pilot projects aligned with S2S principles;
- Leveraging EU frameworks for research, innovation, and territorial cooperation.

Pilot projects in strategic regions, such as the Atlantic Region (Portugal, Spain, France, Ireland), can serve as innovation labs to test the feasibility and added value of the approach. These Initiatives would enable the joint implementation of land–sea strategies, integrated monitoring of freshwater and marine systems, the application of nature-based solutions for pollution mitigation and climate adaptation, and stakeholder engagement in co-creation and knowledge exchange.

5.8 Conclusion - From Conceptual Integration to Paradigm Shift

This chapter began with a critical question: whether the Source-to-Sea (S2S) approach represents a substantive innovation capable of overcoming fragmentation in the governance of interconnected socio-ecological systems, or whether it merely reorganizes principles already present in previous integrative approaches.

The analysis developed in this chapter shows that, although the traditional S2S approach is broader than IWRM and ICM, it remains limited in its capacity to integrate territorial, socio-cultural, and institutional dimensions. While it advances the recognition of the hydrological *continuum* and key flows across the source-to-sea system, it still does not fully overcome the conceptual and operational compartmentalization that characterizes environmental governance today.

In contrast, the S2S Landscape approach represents an advance in the conceptualization and governance of interconnected systems. It is not a mere combination of existing frameworks, but rather a reconfiguration of their foundational premises. By incorporating the landscape as an analytical and operational structuring element, the approach promotes a systemic, transdisciplinary, and adaptive model that connects ecological flows with spatial forms, values with functions, and water with society.

The S2S Landscape approach introduces four key contributions:

- A hybrid territorial perspective, grounded in the landscape, that articulates physical, ecological, social, and cultural dimensions across the land–freshwater–marine *continuum*.

- A methodological framework structured in four iterative steps (Comprehension, Involvement, Planning, Execution & Monitoring) that enables adaptive, participatory, and multilevel governance.
- A normative applicability, tested through the critical analysis of European directives, demonstrating its capacity to identify gaps, synergies, and integration pathways that the traditional S2S approach does not address.
- A practical orientation, offering concrete strategies for implementation across sectors, levels of governance, and spatial domains, from local pilot projects to EU policy integration.

These elements position S2S Landscape not only as an expansion of the S2S approach, but also as a conceptual turning point in the governance of water and landscape systems, one that recognizes fragmentation not only as a technical challenge, but also as a territorial, institutional, and epistemological problem.

At the same time, its implementation poses significant challenges. Translating its integrative logic into concrete policies and practices will require institutional commitment, intersectoral cooperation, meaningful social participation, and investment in knowledge systems that can bridge different disciplines and worldviews. These challenges, however, do not diminish its value. On the contrary, they underscore the urgency of an integrated, flexible, and forward-looking governance model, such as the one proposed by S2S Landscape.

In a context marked by accelerated transformations, climate uncertainties, pressures, and socio-environmental inequalities, the S2S Landscape emerges as a strategic contribution to the integrated governance of water, landscapes, and territories. By reconnecting source and sea, nature and society, vision and action, the approach paves outline pathway towards more coherent and systemic governance models, based on systemic thinking, territorial cohesion, and normative coherence, essential pillars for achieving global sustainability goals such as the 2030 Agenda and the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), ensuring the resilience of interdependent ecosystems and societies.

CONCLUSIONS AND RECOMMENDATIONS

Water is a vital and transversal element of the biosphere, flowing across ecological, territorial, and political boundaries. However, despite its interconnected nature, the governance and management of water resources remain fragmented. In recent decades, various integrative strategies and approaches have sought to promote greater coordination across systems and scales, achieving important advances. Nevertheless, environmental degradation continues to intensify, and the implementation of these initiatives remains constrained by rigid institutional structures, sectoral compartmentalization, and spatial discontinuities along the land–water *continuum*. Merely recognizing the connections is not enough — concrete mechanisms are needed to ensure integration and enable a systemic vision grounded in the hydrosocial cycle.

In this context of increasing anthropogenic pressures and accelerating climate change, the urgency for governance models capable of addressing the complexity and interdependence of socio-ecological systems becomes ever more apparent. Overcoming fragmentation requires more than incremental reforms: it demands structural transformations that align institutions, scales, and sectors, fostering coherence between regulatory frameworks and the dynamics of interconnected territories.

The Source-to-Sea (S2S) approach has emerged as a promising strategy to overcome fragmentation by integrating flows, systems, and stakeholders along the entire *continuum* from headwaters to the ocean. Against this backdrop, this thesis was guided by a central question: Does the S2S approach represent a substantive innovation capable of overcoming fragmentation in the governance of interconnected socio-ecological systems, or does it merely repackage, under a new formulation, principles already present in previous integrative approaches?

To answer this question, the study adopted a qualitative, analytical-deductive methodology, structured around three main articles that provided: (1) a conceptual diagnosis of the S2S, IWRM, and ICM approaches, which revealed that S2S contributes to a new systemic vision of the land-sea *continuum*, encompassing interdependence and ecological and human influ-

ences, but lacking an explicit territorial framework; (2) the theoretical formulation of the S2S Landscape approach, integrating landscape-based concepts with the aim of overcoming the identified limitation; and (3) the testing the normative applicability of the new approach, through a critical evaluation of European directives related to freshwater and marine governance.

In addition, the findings were synthesized, integrated, and analyzed in an articulated manner in this final chapter, which goes beyond a simple recapitulation and proposes a governance framework guided by coherence across scales, policies, and territories. This phase represented a strategic exercise in conceptual integration and practical application of the S2S Landscape approach, concluding that it constitutes a new paradigm of integrated governance, capable of aligning ecological, territorial, and institutional dimensions along the land-sea *continuum*. This final chapter summarizes the main findings, identifies the study's limitations, and outlines future research directions.

6.1 Main Research Findings

In response to the overall research question, this study found that the S2S approach revitalizes methods, introduces new conceptual and operational elements, and strengthens the governance and management structure of freshwater and marine resources, providing a new vision of continuous governance from land to sea. However, perhaps because it is more recent, the S2S approach still presents an incipient treatment of gender issues and the value of water. In these areas, IWRM is more mature and can contribute to their further development. The analysis also revealed that the approach requires a deeper understanding of the interdependence between natural and human systems. This interdependence connects territory, society, and water, demanding a broader spatial unit than the water body itself, where the flows connect processes and segments from source to sea.

In this sense, this research went beyond a critical analysis of existing approaches by proposing and formulating the S2S Landscape approach, specifically designed to address the spatial gap identified. The S2S Landscape integrates the principles of the S2S approach with the foundations of landscape-based approaches and the guidelines of the European Landscape Convention (ELC), offering an innovative methodology that articulates territory, society, and water. This approach is structured into four essential steps: Comprehension, Involvement, Planning, and Execution & Monitoring.

The S2S Landscape approach differs by expanding the territorial, ecological, and social scope of previous approaches, innovatively integrating ecological and human processes into a single governance framework:

- Regarding ecological interdependencies and influences, it incorporates an integrated analysis of environmental processes from the source to the open ocean, overcoming the compartmentalization between coastal (ICM) and continental (IWRM) zones. It integrates the terrestrial landscape with water bodies, encompassing a broader territorial scope than traditional landscape units, and recognizes the full range of ecological interactions, such as the water cycle and biodiversity flows, as part of a single, continuous system between land and water.
- Regarding human interdependencies and influences, it expands the analysis of how social processes interact and depend on water bodies from source to sea. It moves beyond direct human interventions on water by also considering the historical transformation of the landscape for social, cultural, and economic purposes, within a broader territorial scope than the landscape unit. It recognizes that human activities affect not only the physical landscape but also biodiversity, ecosystem services, and human communities themselves.
- By integrating human and ecological processes, it adopts the hydrosocial cycle perspective. Grounded in the landscape as a synthesis of natural, social, and cultural dimensions, the approach integrates the biophysical and sociocultural interactions that shape environmental patterns and processes, thus promoting an expanded understanding of the sustainability of both natural and human systems.
- Regarding the integration and complementarity between approaches, S2S Landscape recognizes landscape as a unifying concept for environmental integration. By articulating the S2S approach with the principles of IWRM, ICM, Hybrid Landscape Approach (HLA), and ELC, it proposes a cohesive and innovative methodological structure capable of understanding water flows and the interactions between natural and human systems across the entire territory, from source to sea. This holistic perspective transcends sectoral analyses focused solely on water, promoting a governance framework that is sensitive to the dynamic connections that structure the landscape and support socio-ecological sustainability as a whole.

Furthermore, the approach establishes a continuous cycle of learning, action, and re-planning, grounded in systems thinking, adaptive governance, and practical and participatory learning. Its structure allows for constant monitoring and iterative revision of strategies, pro-

moting knowledge generation and the progressive improvement of water governance and management in the landscape. The incorporation of collaboratively developed scenario planning contributes to dealing with uncertainty, assessing risks, testing alternative pathways, and preparing for application at multiple scales. By viewing water as the connecting thread that links ecosystems, territories, and societies, the S2S Landscape enables an integrated understanding of impacts and feedbacks between local actions and systemic effects.

In this sense, the value and relevance of the S2S Landscape approach were recognized by the United Nations Economic Commission for Europe (UNECE), which included it as an example of the integration of systemic approaches in the *Guidance Note for the Implementation of Source-to-Sea Management in Transboundary Basins* (Box 2, p.33; UNECE, 2025). The document highlights that S2S Landscape, by incorporating landscape approaches into source-to-sea management as a structuring element, enabled a territorially based governance and management model in response to fragmentation, reinforcing policy coherence, sustainability and resilience of ecosystems, as well as the need to align local actions with a systemic and transboundary vision, ensuring active participation with scenario analysis and foster a better understanding of interdependencies, patterns and processes over time.

In addition, the research demonstrated that the S2S Landscape approach not only fills conceptual gaps in traditional approaches but also holds practical viability within the European regulatory context. The critical analysis of key European Union directives related to water governance revealed important convergences and gaps, particularly the absence of effective mechanisms for integrating ecological, social, and cultural processes along the source-sea *continuum*. In this context, the S2S Landscape offers an integrative model capable of aligning existing policies and strategies (such as the WFD, MSFD, and MSPD), overcoming institutional fragmentation through cohesive guidelines, multi-scalar coordination, financing instruments, and collaborative platforms. The proposal for the gradual incorporation of the approach through river basin plans, marine strategies, and pilot projects in strategic territories reinforces its applicability and potential for normative innovation. By adopting the landscape concept as an integrating axis and promoting the connection between natural and human systems at all scales, S2S Landscape contributes to strengthening ecosystem resilience, advancing territorial justice, and consolidating a new paradigm of adaptive and systemic environmental governance in Europe and beyond.

Thus, this research demonstrates that the proposed S2S Landscape Approach transcends the role of merely synthesizing previous frameworks, positioning itself as an innovative reference for adaptive environmental governance and management, capable of aligning normative

coherence, territorial integration, and ecological sustainability. Although its normative analysis focused on the European context, its conceptual and operational foundations reveal strong potential for adaptation in other regional and national contexts facing similar challenges of fragmentation, vulnerability, and institutional disarticulation. The next section discusses the study's limitations and future research directions.

6.2 Limitations of the study

This study presents some limitations that must be addressed. The conceptual development of the S2S Landscape approach was conducted through a theoretical-methodological synthesis, grounded in a critical analysis of existing approaches. This development happened within a broader context marked by persistent fragmentation of governance and the ongoing degradation of interconnected socio-ecological systems. The research strategy adopted was exploratory, cumulative, and adaptive, aiming to trace the emergence of conceptual, normative, and operational gaps throughout the analytical process. Thus, the S2S Landscape approach was not predefined, but it emerged organically in response to the findings generated throughout the research. While this process ensured methodological coherence and adaptive capacity, with a comprehensive and innovative framework, it also limited the time available for developing practical applications through pilot projects. Thus, the approach still needs to be tested and validated in concrete territorial contexts.

Nevertheless, the research tested the normative feasibility of the S2S Landscape approach by critically analyzing key European directives related to freshwater and marine systems. This normative analysis demonstrated the approach's potential for integration into existing legal and institutional frameworks, highlighting its applicability in the integration into public policy and regulatory frameworks. However, the analysis was limited to the European Union context, reflecting a specific political and institutional environment. Therefore, the results may not be directly generalizable to other regions with different legal, institutional, or socio-environmental conditions. Still, the principles and structure of the S2S Landscape approach offer conceptual and methodological adaptability that can support future comparative studies or regional adaptations.

Additionally, due to the scope and complexity of the research, some important themes, such as gender equity, water valuation, and Indigenous or traditional knowledge, while recognized, were not fully addressed in the formulation of the S2S Landscape approach. These di-

mensions are essential for inclusive and just governance and should be incorporated into future developments and applications of the framework.

Finally, it is important to note that the research process, conducted over a five-year period, from conceptualization to dissertation writing, coincided with the COVID-19 pandemic, which imposed logistical and temporal challenges, particularly during the initial and intermediate phases. The study was also developed under a cotutelle agreement, which required adherence to the academic and procedural standards of two different universities. This added complexity and coordination of demands influenced the scope and pace of the research.

6.3 Future research needs

This research provides a relevant theoretical and normative contribution by proposing the S2S Landscape approach as a new methodological framework for the integrated governance of socio-ecological systems along the land–sea *continuum*. However, several issues remain open and should guide future investigations.

First, it is necessary to advance the empirical validation of the S2S Landscape approach through its practical application in real territorial contexts. Although its normative feasibility has been tested in the European context through the critical analysis of relevant directives (such as the WFD, GWD, MSFD, and MSPD), further studies are needed to explore its operationalization across different scales and institutional settings. Pilot projects, comparative case studies, and collaborative territorial planning experiences may provide concrete evidence on their effects, implementation challenges, and potential for institutional adaptation.

In this regard, the downscaling implementation should be tested in a European watershed, preferably in a transboundary basin involving Portuguese territory, to assess how the approach performs under real multilevel governance conditions and cross-border coordination needs.

Second, future research should explore the adaptability of the S2S Landscape approach to diverse geopolitical, cultural, and ecological contexts, particularly in regions characterized by high socio-environmental vulnerability, institutional fragmentation, and historical challenges in territorial governance.

Additionally, it is essential to develop further dimensions that were only partially addressed in this research, such as gender equity, the cultural value of water, the role of Indigenous and local knowledge, and the connections between territorial justice and water govern-

ance. The transversal incorporation of these themes may strengthen the approach as a tool for truly inclusive governance, sensitive to the sociocultural specificities of each territory.

To do that, S2S Landscape should be tested outside Europe, for example, in South America or in Canada, where Indigenous peoples are fighting to be included in the decision-making process about water management. In this context, the initial discussions about applying the S2S Landscape approach in the Amazon Basin by the Amazon Cooperation Treaty Organization (ACTO), can lead to an advancement of integrated environmental governance, if they really present continuity in their regional strategy.

Other issues should be explored or considered more deeply in the S2S Landscape approach. One of them is to incorporate soil science, since soils are a critical component of the water cycle and strongly mediate land–water interactions. Another issue is about overcoming trade-offs and geopolitical interests when confronting territorial limits and boundaries by different criteria, such as watershed, landscape, and political-administrative units. It is likewise important to strongly and clearly integrate ecosystem restoration as part of the S2S Landscape, because management should deal not only with the available resources to avoid losing them, but also to get back the necessary conditions to manage the present and future well-being.

Finally, the overall spiral of the Source-to-sea Landscape implementation presented in Chapter 3 (Comprehension; Step 2: Involvement; Step 3: Planning; and Step 4: Execution & Monitoring) should be tested and detailed as a roadmap, so that it can become a robust guideline addressing adaptive and resilient management procedures to face the ever-changing world.

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PUBLICATIONS

A.1 Peer-reviewed journal articles

A.1.1 Published

- Michels-Brito, A., Ferreira, J. C., & Saito, C. H. (2023). Source-to-sea, integrated water resources management, and integrated coastal management approaches: integrative, complementary, or competing? *Journal of Coastal Conservation*, 27(6), 66. <https://doi.org/10.1007/s11852-023-00999-z>
- Michels-Brito, A., Ferreira, J. C. R., & Saito, C. H. (2024). The Source-to-Sea Landscape: A hybrid integrative territory management approach. *Science of The Total Environment*, 931, 172961. <https://doi.org/10.1016/J.SCITOTENV.2024.172961>

A.1.2 Manuscripts in preparation / ready for submission

- Michels-Brito, A., Ferreira, J.C.R., & Saito, C.H. (2025). *Building Bridges over Fragmented Waters: The Source-to-Sea Approach as a Catalyst for Political Cohesion in EU Water Management*.

A.2 Book chapters

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2025

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