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Breaking down scientific silos: towards Source-to-Sea research in Scotland

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Workshop report linked to Case study and Final Report

Contents

Acknowledgements

A big thank you to everyone who participated in and contributed to the workshop. Your ideas, enthusiasm, and insights made it a real success. A special shout-out to Chris Lickie (NatureScot) and Celeste Kellock (SAGES S2S Forum) for their invaluable support in bringing everything together. We're also grateful to our presenters for sharing their knowledge and expertise. A huge thanks to SEFARI Gateway for supporting this initiative through the Open Call for Specialist Advisory Groups. Thanks to MASTS and the Rural Policy Centre (SRUC) for helping to spread the word on social media. Finally, a heartfelt thanks to over 35 online attendees who joined us and shared their perspectives with the SEFARI Gateway Source-to-Sea Specialist Advisory Group.

Social media

The workshop event was announced online through the following channels:

SAGES S2S Forum website : https://sages.ac.uk/research/fora/sourcetosea/

MASTS: https://x.com/mastscot/status/1803455664460583033 (16 reports and 676 Views until March 2025)

Rural Policy Centre: https://x.com/RuralPolicySRUC/status/1803416252133564881 (9 reports and 500 Views until March 2025)

Rural Exchange blog: https://ruralexchange.scot/blog/sefari-workshop-this-friday--38/#

Purpose

Scotland faces pressing environmental challenges, from biodiversity loss to climate change, requiring cross-sector collaboration and integrated solutions. The Source-to-Sea (S2S) approach offers a holistic framework, recognising the interconnectedness of land, freshwater, and marine environments. It focuses on water flows linking river basins, lakes, aquifers, estuaries, coastlines, and open oceans, forming the S2S system.

A key goal of the S2S approach is to bridge divides across ecosystems, economic sectors, and policies, ensuring upstream-downstream trade-offs are addressed. It is particularly relevant for cross-boundary challenges like climate change, biodiversity loss, and pollution, as well as wicked problems—complex issues where causes, impacts, and responsibilities are difficult to define. The S2S approach is increasingly seen as a way to align policies, maximise synergies, and minimise unintended or indirect impacts on ecosystems and communities.

In Scotland, recent policy-driven projects have highlighted the potential of the S2S approach to enable joint working across policy sectors in addressing biodiversity loss and climate impacts, as well as supporting nature restoration financing. Building on this groundwork, we established the SEFARI Gateway Source-to-Sea Specialist Advisory Group to explore the types of research questions, collaborations, and methods that can support the S2S approach, and whether the collaborative, holistic thinking in the S2S approach can drive innovation in research. Here, interdisciplinary work combines knowledge from various fields—such as ecology, hydrology, economics, and social sciences—to create well-rounded solutions. Trans-disciplinary work goes further by integrating scientific knowledge with practical experience, local insights, and indigenous knowledge and it ensures that solutions are relevant, inclusive, and effective in real-world contexts.

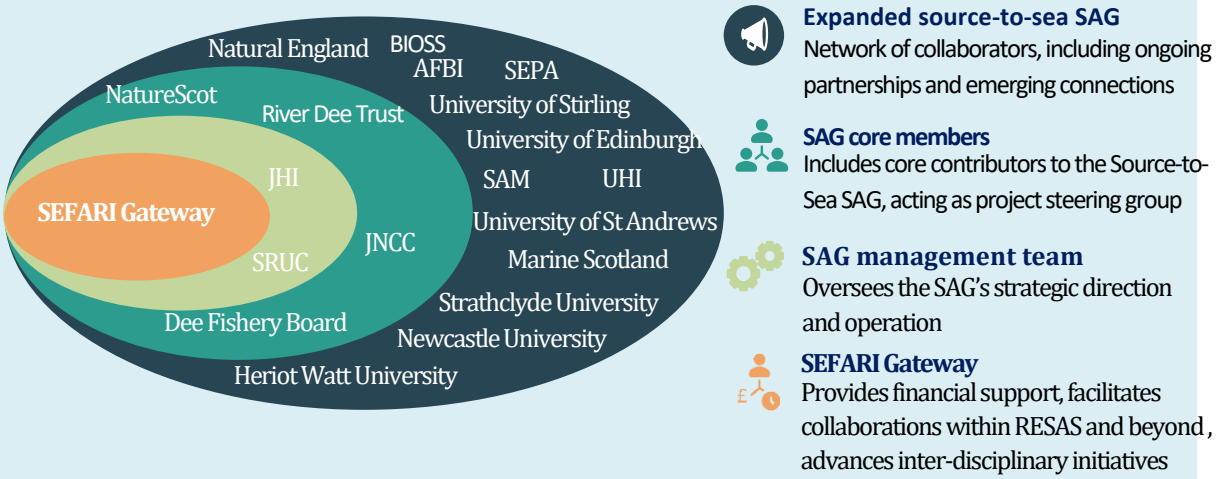
We launched the Source-to-Sea Specialist Advisor Group in August 2023 with a collaborative workshop. We brought together interested stakeholders from NatureScot, JHI, SEPA, JNCC, and the River Dee Trust, who played a key role in steering the next steps of this project (Box 1: Source-to-sea Specialist Advisory Group).

A year later, on 21st June 2024, we hosted an online workshop, bringing together experts from various scientific disciplines, policy advisors and non-governmental organisations (NGOs) from across the UK (Box 1) to discuss our findings, and other source-to-sea projects, research needs and the challenges of applying a source-to-sea lens within current research funding schemes. Here, we summarise the priorities, presentations, roundtable discussions, and key insights captured through our engagement activities during the course of the project.

Box 1. Structure of the Source-to-Sea Specialist Advisory Group (SAG)

Here, we illustrate the structure of the Source-to-Sea Scientific Advisory Group (SAG) as it developed up to the publication of this report. NatureScot, JHI, SEPA, JNCC, and the River Dee Trust, Dee Fishery Board played a steering role in shaping the next steps of the project. This core team engaged with interested experts across the UK, and helped to expand the Specialist Advisory Group.

The Source-to-Sea Specialist Advisory Group



List of organisations contributing to the Source-to-Sea Specialist Advisory Group:

JHI: James Hutton Institute

SRUC: Scottish Rural College

NatureScot

JNCC: Joint Nature Conservation Committee

River Dee Trust

Dee Fishery Board

SEPA: Scottish Environment Protection Agency

Natural England

AFBI: Agri-Food and Biosciences Institute

Scottish Government

University of Stirling

University of Edinburgh

University of St Andrews

University of Aberdeen

Strathclyde University

SAMS: Scottish Association for Marine Science

Scottish Government

Marine Scotland

UHI: University of the Highland and the Islands

Oral presentations

Five speakers presented source-to-sea work, covering both research and policy perspectives with examples from Scotland and the wider UK. Presentations can be made available upon request.

1 James Hutton Institute and Scotland's Rural College

Breaking down scientific silos: towards source-to-sea research in Scotland

By Dr Ioanna Akoumianaki, James Hutton Institute

The presentation focused on the rationale and findings of the literature review conducted for the SEFARI Gateway project. The talk outlined the characteristics of the S2S approach, emphasising its role in managing upstream-downstream interlinkages, identifying cause-and-effect relationships, and addressing 'wicked' environmental issues. A key point highlighted was that, unlike integrated water resource management or integrated coastal management, the S2S approach explicitly integrates land, freshwater, and marine domains, fostering new partnerships and context-specific solutions. The presentation also featured the growing interest in the S2S approach, referencing conferences focused on source-to-sea interdependencies in Scotland and internationally (Figure 1a) as well as ongoing and completed research projects applying a source-to-sea lens (Figure 1b). The talk concluded by inviting discussion on the following questions:

Research needs and approaches:

- ✓ What science do we need to provide evidence at the source-to-sea scale?
- ✓ What indicators, monitoring and modelling are suitable for S2S research?

Technology:

- ✓ What are the priorities for surveillance systems (e.g., real-time monitoring, remote sensing, e-DNA, regulatory etc.)

Funding:

- ✓ How do we finance and stimulate a pipeline of research opportunities?

Actions and progress

- ✓ *What are the next steps to implementing source-to-sea research?*

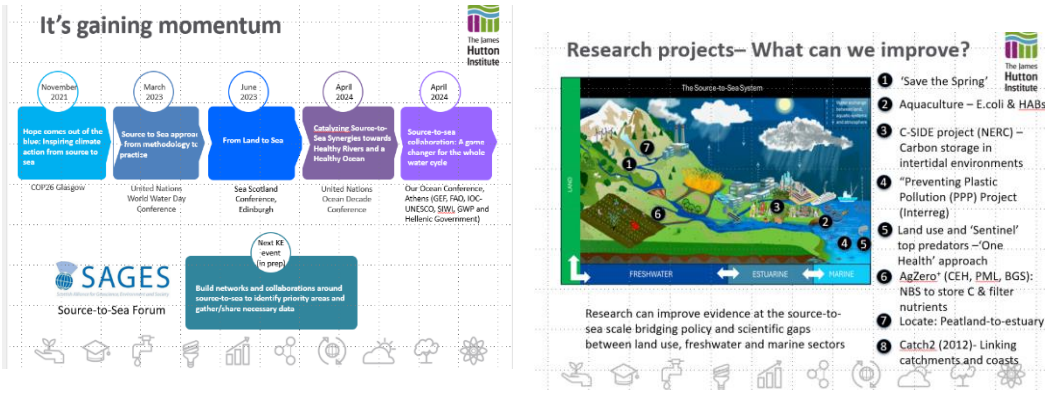


Figure 1. Slides from the presentation by the James Hutton Institute. a. Source-to-Sea events in Scotland and Internationally. b. Map of the research focus of completed and ongoing projects in Scotland and the UK (infographic: modified from a powerpoint presentation led by FAO).

2. NatureScot internship

Source-to-Sea: Enabling Coherent, Efficient, and Synergistic Outcomes

By Dr Celeste Kellock, University of Stirling and Environmental Standards Scotland

The presentation introduced NatureScot's S2S project, which aimed to bring together diverse stakeholders and break down silos in environmental governance in Scotland. The project engaged with a variety of stakeholders through workshops held in-person and online. The presentation summarised key messages (Figure 2) identified during these workshops and detailed in a NatureScot report.

Benefits of the S2S approach

- Strengthening links between policy teams.
- Building a policy baseline for S2S management in Scotland.

Barriers to upstream-downstream policy alignment:

- Limited cross-sector collaboration and siloed monitoring frameworks**.**
- Lack of a shared language for environmental data.
- Traditional engagement strategies, such as formal, policy-led meetings, may not be effective in ensuring involvement by diverse stakeholders.

Opportunities for mainstreaming S2S governance:

- Greater public-private collaboration and funding mechanisms**.**
- Integration of technical solutions across disciplines.
- Using existing policy drivers to implement S2S, rather than reinventing frameworks.
- Applying creative engagement methods, such as interactive workshops and community-based activities.

The talk concluded by emphasising the importance of regional planning, pilot projects, and demonstration cases to drive investment and engagement, illustrating how Scotland can harness cross-sector collaborations to tackle major environmental challenges.

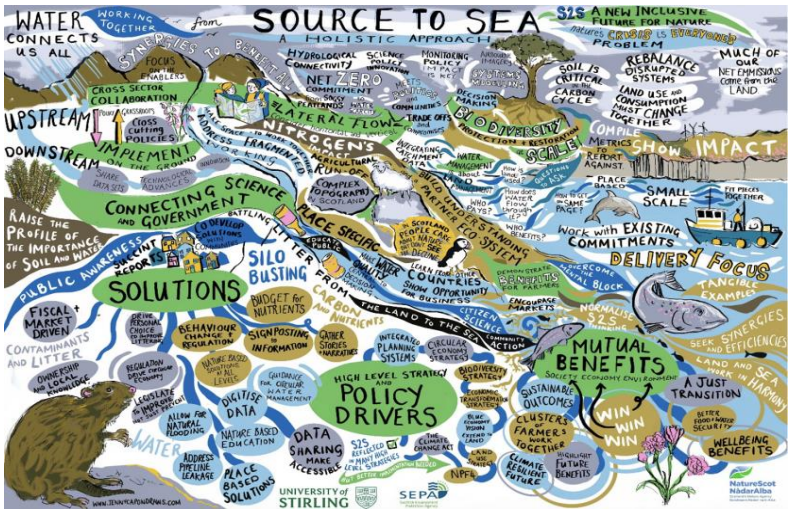


Figure 2. A graphic illustration from the second source-to-sea workshop, displaying key messages on the source-to-sea approach, including solutions, policy drivers and multiple benefits. This image was produced by artist Jenny Capon. Source: NatureScot report.

3. NatureScot

Next Source-to-Sea Steps for NatureScot

By Dr Chris Leakey, Marine Sustainability Manager at NatureScot

The presentation highlighted NatureScot's interest in source-to-sea interlinkages shaped by challenges posed when marine planning objectives and policies lack coherence with land management decisions. The talk outlined NatureScot ongoing source-to-sea work, including joining SIWI's S2S platform; working with colleagues at the Environment Agency in England and the Agrifood Biosciences Institute (AFBI) in Northern Ireland; and linking with the new SAGES Source-to-Sea Forum and the SEFARI Gateway Source-to-Sea Specialist Advisory Group. NatureScot is also planning to be involved in a project funded by the Facility for Investment-Ready Nature in Scotland (FIRNS), which aims to develop a portfolio of river restoration investment packages and delivery support measures for a Source-to-Sea Fund (Figure 3).

The presentation also outlined NatureScot's ambitions for the future:

- Developing and testing S2S-type data plug-ins for a landscape-scale natural capital tool.
- Developing proof-of-concept projects, including involvement in a PhD project on carbon transfers and storage across a source-to-sea transect of freshwater and marine habitats.
- Building Scotland's source-to-sea community to bridge ambition and implementation.

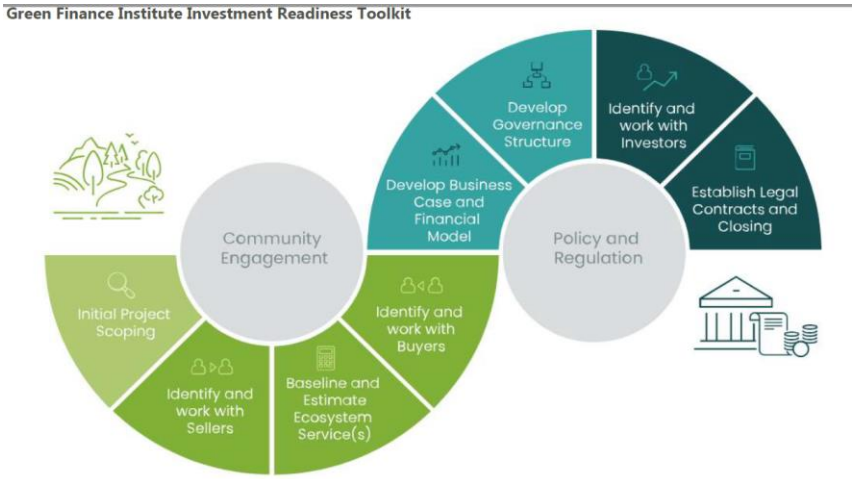


Figure 3. What next for S2S in NatureScot: developing a portfolio of river restoration investment packages and delivery support measures for a Source-to-Sea Fund.

4. Environment Agency

Source-to-Sea Case Study: Blackwater and Colne Catchments

By Jo Bayes & Mike Nelson, Environment Agency

The presentation introduced DEFRA's Natural Capital and Ecosystem Assessment (NCEA), a science innovation and transformation programme that spans across land and water environments. The programme is designed to collect data on the extent, condition and change over time of England's ecosystems and natural capital, along with the benefits these provide to society.

The first part of the talk focused on how the NCEA -now entering its third year- can enhance decision making to achieve better outcomes for nature and the relationship with the S2S

approach. Under the terrestrial natural capital assessment, DEFRA and the Environment Agency are developing monitoring networks for key assets in land-sea interfaces, such as estuaries and coasts (Figure 4). They are also introducing new methods and tools, with plans to scale up efforts over the next few years. They are also working to enhance models, adapt them for source-to-sea applications, mobilise social capital, and strengthen connections with researchers.

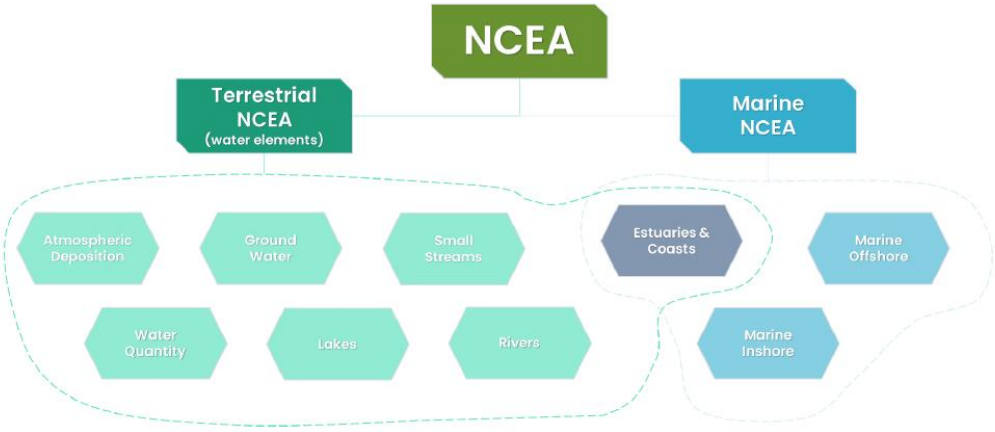


Figure 4. The Natural Capital and Ecosystem Assessment (NCEA), a Defra science innovation and transformation programme, spanning land and water environments. Estuaries and Coasts are studied as part of Natural Capital Approaches at the land-sea Interface. (Copyright: Mike Nelson).

The second part of the talk introduced a specific case study – the Natural Capital Approaches at the Land-Sea Interface Project, Part II - as part of the NCEA in partnership with the University of Essex. This case study examines the Blackwater and Colne catchments in Essex as a source-to-sea system. The project team includes local farm clusters, the Rivers Trust, the Wildlife Trust, and the County Council, all working towards Net Zero, primarily through nature based solutions (NBS).

Th Blackwater and Colne case study (Figure 5) involves trialling an integrated appraisal to identify opportunities for improving water management from source to sea. This involves a cost-benefit analysis of various management scenarios, including nature-first, climate-first, water-first, and social justice approaches. A key aim of the project is to produce a repeatable framework for baseline assessments, using data, evidence, and tools developed through the NCEA. This will allow other regions to replicate the framework and enable land managers across different areas to collaborate and develop source-to-sea strategic plans, demonstrating the value of complementary interventions that can be funded collaboratively to maximise multiple benefits.

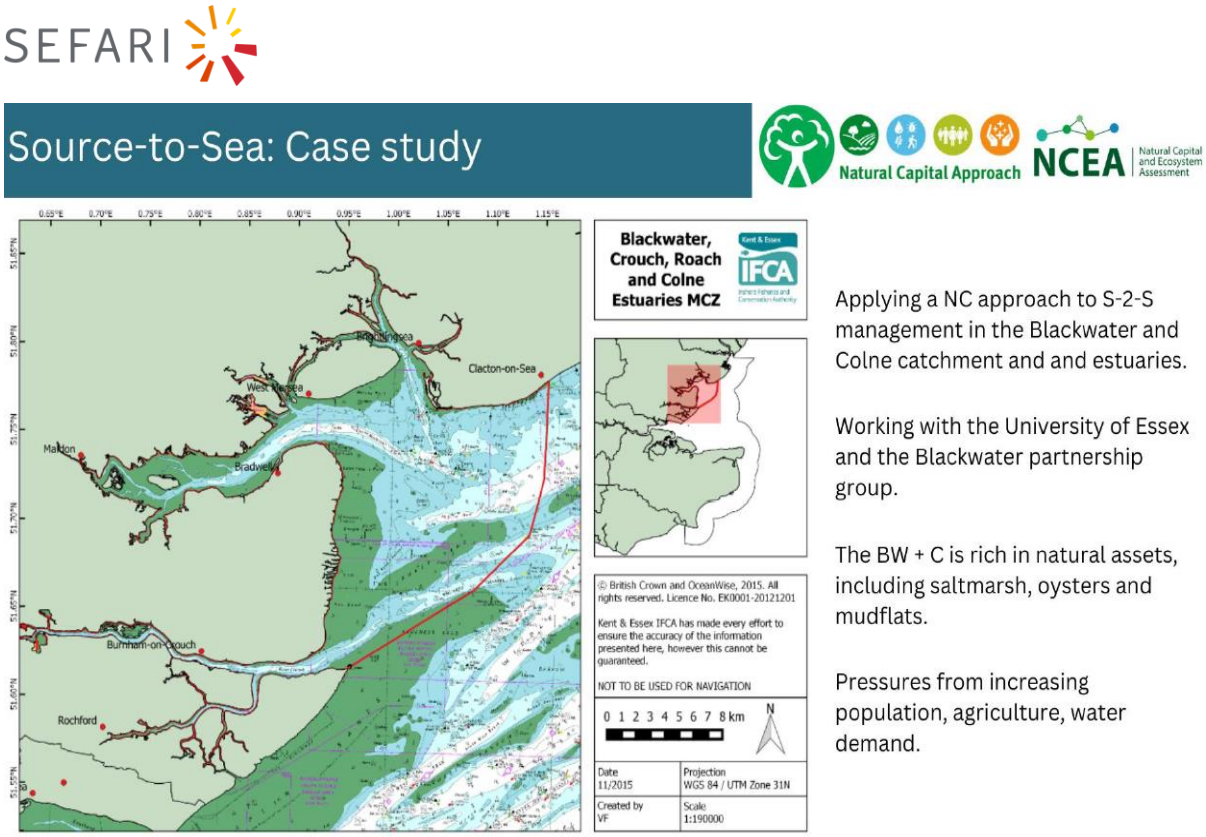


Figure 5. The Blackwater (BW) and Colne (C) catchments in Essex as a source-to-sea system.

5. Agrifood Biosciences Institute (AFBI)

Source-to-Sea Indicators and Evidence

By Dr Matt Service, AFBI, Belfast

The presentation introduced AFBI's evolving work on source-to-sea research in Northern Ireland. The relatively small sizeof the region has enabled the development of a detailed transboundary systems understanding of several catchments and their linked downstream environments.

One example shared was Lough Neagh, where warming summers have led to intense algal blooms that have been monitored as they move downstream to coastal bathing waters. These blooms have been monitored under the Water Framework Directive as they move downstream to coastal bathing waters, illustrating the urban impacts on marine environments driven by nutrient flows..

The presentation also highlighted the management of water quality in shellfish waters, using existing monitoring and analysis programmes within Dundrum Bay. Researchers, jointly working with policy and the water industry, developed a framework that integrates catchment (SWAT), circulation (Delft3D), individual bivalve (AquaShell) and Ecosystem (EcoWin) models with wastewater (microbial) and agricultural (nutrient) partitioning of loads to the bay and shellfish response to nutrient loads. This integration allows for a relatively high degree of confidence in evaluating the impacts of various land management practices. The approach demonstrates a possible balance between reducing nutrients and maintaining shellfish production, with the regulator and water industry investing in NBS for nutrient management to meet the requirements of different policies related to EU directives, such as UWWTD, WFD including protected areas, Habitats Directive, and Marine Strategy Framework Directive).

The talk concluded with two case studies that examined the potential impact of the interaction between agricultural nutrient and sediment runoff under different agricultural land management and climate change (rainfall) scenarios using Dundrum Bay and Lough Foyle as test sites. By using catchment-to-sea models, the researchers were able to explore the intertwined land use -climate change impacts on the downstream environments. Factoring in the climatic impacts changed the water quality outcomes, illustrating that setting targets for reduction in phosphorus, nitrogen and sediment without integrated modelling at the source-to-sea scale is likely to result in unmet goals for water quality in coastal waters (Figure 6).

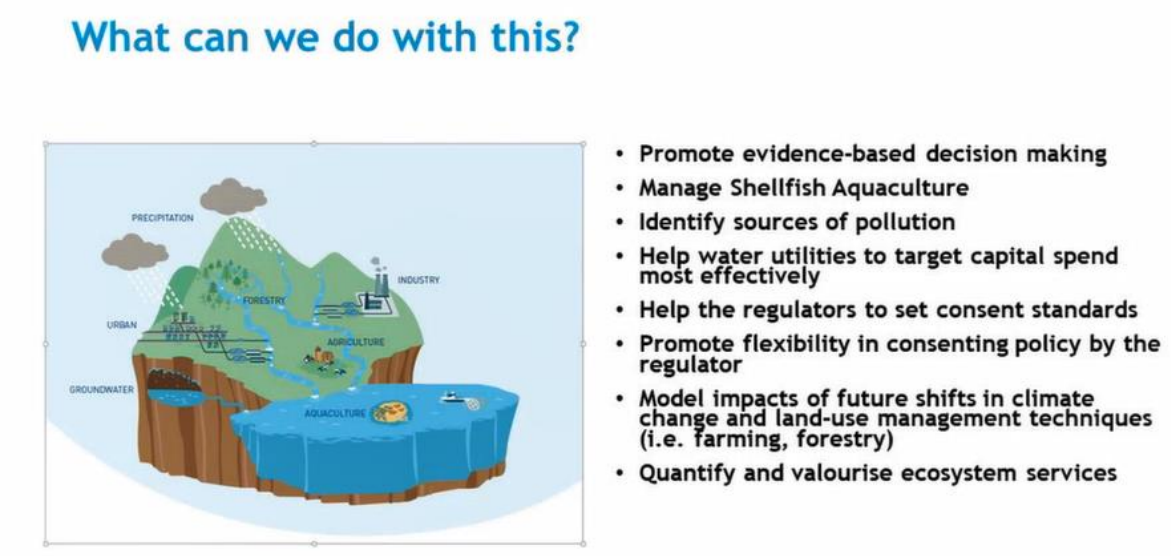


Figure 6. The various influences on the source-to-sea continuum, accounted for in models supporting evidence-based shellfish aquaculture management. Source: Matt Service (AFBI).

Discussion

Presenters and participants engaged in a plenary discussion and post-event feedback, focusing on the themes below.

1.Research needs and approaches

What science do we need to provide evidence at the source-to-sea scale?

The Participants noted that source-to-sea discussions are occurring alongside many other initiatives during a period of shifting policy priorities for planning and management. While policy can enable source-to-sea synergies, including in research, the true impact lies in research and policy acting in tandem to provide evdience-based solutions. It was agreed that identifying priority ‘source-to-sea’ themes is crucial, or there is a risk of losing focus and momentum in an 'everything is connected to everything else' mode of information overload. Tying in with ongoing research that integrates scientific disciplines and existing models and embeds participatory approaches to evidence gathering could be beneficial. Three pathways of enabling this integration were discussed.

1. Learning from interdisciplinary research consortia. For example, the UKRI Global Challenges Research Fund (GCRF) Hubs, particularly the global interdisciplinary research hubs that aim to tackle problems resistant to interventions and which cannot

be solved by one single organisation, discipline or country alone, as this could bring together diverse ideas to address 'wicked' challenges.

2. Integrating climate scenarios into current land use, ecosystem, hydrological and hydrodynamic models will be crucial for highlighting the importance of source-to-sea research and accounting for change and uncertainty, as shown in the AFBI presentation. This will also enable embedding resilience to environmental challenges within management.
3. Planning for a readiness assessment for adopting S2S more widely, as part of the NCEA work in England, could also help integrate existing research with future evidence needs to inform policy by highlighting the research gaps, but also look at the social, governance and policy structures that can enable or block adopting the S2S approach.

Additional suggestions for mainstreaming source-to-sea research included:

- Reviewing existing surveillance methods, data (research, regulatory and citizen science) and models, to understand whether existing evidence and tools can address source-to-sea challenges.
- Developing a plan for joining the data and evidence tools from terrestrial, freshwater, transitional and marine science programmes and regulatory frameworks to support source-to-sea research and make their collective power greater than the sum of their parts.
- Implementing Scotland-specific proof-of-concept projects with detailed monitoring that can demonstrate clear downstream benefits all the way to the sea from upstream and terrestrial action (e.g. riparian planting).

What indicators, monitoring and modelling are suitable for source-to-sea research?

Participants highlighted that first, we need to understand what surveillance is currently happening in Scotland (e.g. by the Scottish Government, SEPA, NatureScot and research projects, either as direct measurements or proxy indicators) and what its limitations are. This should be combined with a review of existing methods to identify gaps for different kinds of source-to-sea flows (nutrients, carbon, microbes, contaminants/pollutants, litter, and water). They also stressed the need to focus on setting up long-term monitoring to gather data and develop spatially-referenced open-access, interactive and updateable databases to enable evidence synthesis, and help track changes over time, season and in relation to specific events and source-to-sea flows.

The discussion on indicators highlighted the need to develop indicators that account for flows and changes at the source-to-sea scale. By contrast, a lot of monitoring effort has focused on collecting data to inform the Water Framework Directive's indicators, which are static, not representing interlinkages between the different components of the source-to-sea system. A step forward would require identifying indicators that integrate pressures across the source-to-sea continuum, and account for impacts on the delivery of ecosystem services. A source-to-sea indicator could highlight the cumulative impacts on downstream environments and the trade-offs between upstream and downstream ecosystems or sectors. The participants also agreed that source-to-sea indicators should help articulate more nuanced and realistic messages about decision impacts. For example, indicators could highlight when we are making progress, or when decisions are helping us move in the right direction. There was consensus in that at the moment biophysical indicators are not working effectively for us and policy making, therefore

research on source-to-sea indicators will be key.

2.Technology

What are the priorities for surveillance systems (e.g., real-time monitoring, remote sensing, e-DNA, regulatory etc.)?

The participants highlighted that simplifying technology could enable wider use of surveillance through citizen science and community-led, participatory approaches. However, this needs to be balanced with the development of cost-effective, user-friendly technologies and data portals that allow easy access to robust data. The roundtable suggested:

- Launching a CivTech challenge -inviting anyone with a brilliant idea to work hand-in-hand with the Scottish Government to create the solution-asking "How can technology provide a step-change in our ability for surveillance of source-to-sea interlinkages?"
- Integrating technologies like:
    - **LiDAR**, for high-resolution topographic mapping and vegetation monitoring across source-to-sea continuums,
    - **e-DNA**, for detecting species presence in samples from interlinked environments, and
    - **AI and automated data analysis** enabling data sharing across multiple organisations, could greatly enhance the capacity for source-to-sea surveillance, collaboration and coordination.
    - Low cost, reliable **sensor networks** would help to measure and quantity freshwater inputs to estuaries and coastal systems.

3.Funding and finance

How do we finance and stimulate a pipeline of research opportunities?

Participants agreed that understanding the nuances and challenges of source-to-sea research could help attract funding. Pilot and proof-of-concept projects that demonstrate the potential of source-to-sea thinking to deliver sustainable solutions can reassure public funders and private investors. The SEFARI Gateway Source-to-Sea Specialist Advisory Group identified completed and ongoing research projects that can guide future research calls and provide evidence on the interlinkages within Scotland's source-to-sea systems.

Finally, the conversation expanded to research funding more broadly, exploring how research can address policy questions on net zero, biodiversity loss and rural community resilience. The role Scotland's Centres of Expertise can play in synthesising existing evdience from different scientific disciplines, and especially SEFARI Gateway due to its interdisciplinary orientation, as well as UKRI's LUNZ Hub and particularly the Agile Policy Centre were highlighted. Some participants noted that research funding often operates in silos, making it difficult to secure funding for interdisciplinary projects. There are already government funding opportunities, however I do think bespoke pots to address these research needs for regions important (focus on Scotland) - you know the money will go there. An open discussion followed revolving around the following questions:

- Can we, as a collective (i.e. SEFARI Gateway specialist advisory group), influence research calls?
- How can we harness the current momentum for system approaches through UKRI and

Scottish Government's future Strategic Research Programme (SRP) calls?
- How can we engage with the Scottish Funding Council to influence research priorities and funding allocations?
- What is the next step for this SEFARI Gateway Source-to-Sea Specialist Advisory Group, if there is no immediate buy-in among researchers?
- Could learned societies (e.g., Royal Society of Edinburgh) be valuable allies in highlighting science and research needs?

A key recommendation was to build funding in a mosaic approach, creating a compendium of various types of knowledge, information, and funding sources, alongside different grant styles, project types, and personnel. This type of ongoing conversation is crucial to show that "many hands make light work," and that cross-disciplinary collaboration is vital for developing the science we need. In this respect, our Source-to-Sea Advisory Group is called upon to play a catalytic role.

4.Actions and progress

What are the next steps to implementing S2S in Scotland?

The participants discussed the barriers to interdisciplinary and transdisciplinary collaboration between upstream and downstream research and community stakeholders. The key takeaway was that these challenges can be leveraged as opportunities to mainstream the S2S approach in governance and break down scientific and funding silos.

1. **Working at Scale**

Key Challenge: Ensuring that best practices from pilot projects or specific regions can be expanded and coordinated at broader geographic and governance levels.
Example: NCEA examples from England show that best practices emerge in specific "pockets of action," but applying them nationwide remains a challenge.
Opportunity: Elevate the conversation to a national level, enabling ideas and funding to flow from the top down while being demonstrated from the bottom up.

2. **S2S Championing**

Critical Issue: Ensuring that all parts of the source-to-sea system—land, freshwater, marine environments, and upstream and downstream communities and economic sectors—benefit from interventions.
Opportunity: Champion S2S by:

- Breaking down scientific silos, as our Source-to-Sea Group strives to do.
- Encouraging policymakers to highlight opportunities for cross-sector policy alignment.
- Promoting collaboration among organisations, communities, businesses, and researchers to secure funding for projects that integrate systems thinking.

Specific Actions:

- **Business Investment**: Incentivising businesses to invest in nature at the source-to-sea scale, such as restoration or plastic litter prevention.
- **Learning from Others**: Learning from the successes of others in the UK and internationally, with participation in international forums like SIWI being a key avenue, as shown by the source-to-sea events presented by the James Hutton Institute.

2. **Keeping the S2S Conversation Flowing**

Challenge: Mainstreaming the principles of the S2S approach and ensuring its relevance within

ongoing discussions around nature restoration and the Sustainable Development Goals (SDGs).
Opportunity: Host UK-wide events with a specific source-to-sea focus to continue and expand the lines of communication and demonstrate how source-to-sea thinking can underpin and expand existing science and policy frameworks.

3. **Capacity Building**

Challenge: Current efforts to drive the S2S agenda are often sidelined by other core responsibilities.
Opportunity: Secure dedicated human resources to drive forward the S2S agenda. One suggestion is to bid for cross-sector, transdisciplinary 'Centre' or 'Hub' funding to build capacity and ensure that people have both the time and the funding to contribute effectively. Platforms like UKRI and SEFARI Gateway, which funded our Source-to-Sea Group, are key sources of funding for mainstreaming source-to-sea work.

4. **Timing**

Current state of play: The efforts of our Group align with key policy changes, such as the introduction of the Natural Environment Bill in Scotland, the formation of a new UK government (in 2024), the implementation of the Environmental Improvement Plan in England, and post-Brexit agricultural reforms. These changes provide an opportunity to highlight the multiple benefits of S2S.
Opportunity: Leverage these developments to ensure S2S is well-positioned within upcoming policy and funding discussions.

5.Impact on policy, practice and innovation

Policy Development

The consensus was that funding source-to-sea projects can bridge critical knowledge and practice gaps between sectors, driving collaboration across policies, environments, and scientific disciplines to deliver system-wide, sustainable solutions. The holistic nature of the S2S approach helps move beyond siloed thinking, addressing interconnected challenges in a coordinated way that benefits both scientific research and policy development. Furthermore, source-to-sea research addresses urgent environmental challenges, aligning the pace of scientific research with the speed of policy-making, and translating findings into actionable solutions, as demonstrated by presentations from NatureScot, the Environment Agency, and AFBI. However, those leading the agenda from public bodies often do so as a sideline to their core work. To make real progress, dedicated human resources are necessary. Bidding for cross-sector 'Centre' or 'Hub' funding could help build the capacity needed to move forward. SEPA was mentioned as a key player in driving the S2S vision in Scotland. Engaging with the ENRA and Marine Scotland Chief Scientific Advisers could further ensure their influence on source-to-sea initiatives.

Practice

The Dornoch Environmental Enhancement Project (DEEP) oyster restoration partnership between Heriot-Watt University, the Marine Conservation Society, and Glenmorangie Distillery at Dornoch Firth serves as an excellent example of innovation's role in building social capital and engaging local communities in the source-to-sea context. The restored oyster reefs work alongside Glenmorangie's anaerobic digestion plant, purifying the by-products of distillation though their water-filtering function, and contributing to a sustainable, circular system. However, a key issue remains: there is a lack of shared vision between policymakers and

researchers, which has hindered the implementation of recommendations from completed source-to-sea research projects. This gap was attributed to a lack of political will, capacity, financing, and incentives. This is a call for researchers to actively engage with policy makers, communities and investors to move things forward.

Research Collaborations

There is a need for networking events that use creative engagement methods, providing sufficinet time and space for attendees to participate in an inclusive way. Participants suggested that source-to-sea events should help gauge different research backgrounds and careers, explore multiple perspectives, and facilitate collaboration between diverse groups and to encourage actionable insights. Connecting marine and freshwater researchers, institutes, and networks is crucial, and hosting cross-sectoral conferences (e.g., ENRA and MASTS) could help strengthen these connections. There were also concerns about relying on initiatives (such as the SAGES Source-to-Sea forum) that lack financial, institutional or research group support, which can limit their effectiveness.

Innovation

There is a need for tools tailored to practitioners at the local or sector-specific level, such as farmers, water managers, and aquaculture ventures. These tools could include apps or decision-support systems that help manage land use or water quality, and guide sustainable practices. Such tools bridge the gap between policy and practice, enabling effective, sustainable action on the ground.

Recommendations from the workshop roundtable discussion

1. Recommendations to the Source-to-Sea Specialist Advisory Group

- Focus on clear research and policy priority themes to ensure impact and avoid information overload.
- Enhance collaboration between marine and freshwater researchers through cross-disciplinary events (e.g., co-funded by ENRA and MASTS).
- Embed comprehensive reviews of current ‘source-to-sea’ surveillance methods, data, and models in funded research projects to identify gaps and improve integration across sectors.
- Develop a unified source-to-sea analysis framework that integrates terrestrial, freshwater, and marine research.
- Develop Scotland-specific proof-of-concept projects to demonstrate clear downstream benefits from upstream action and land use and vice versa.
- Establish long-term monitoring in selected source-to-sea systems, with open access to data and services that provide key social-ecological information, to help share data, track and understand changes over time as well as patterns and trends that are critical for evidence-based decision-making and sustainable planning.
- Seek and deepen engagement with RESAS’ SRP and other relevant bodies.

- Ensure future workshops allocate sufficient time for discussions, balancing presentations with interactive sessions, networking opportunities, and understanding diverse backgrounds and expertise.
- Use creative engagement methods to provide attendees with sufficient space and tools for meaningful connections.
- Establish a cross-sector research and impact 'Centre' or 'Hub' to provide institutional support for mainstreaming the S2S approach in research, practice and governance.
- Ensure that any extension of Defra's NCEA programme includes co-funding for UK-wide alignment of source-to-sea data and research initiatives.
- Advocate for dedicated source-to-sea funding within existing government frameworks.
- Engage learned societies (e.g., RSE) to champion the importance of source-to-sea interlinkages.

2. Recommendations to funding bodies

- Invest in low-cost, reliable sensor networks to monitor freshwater inputs to estuaries and coastal waters.
- Launch a CivTech challenge to stimulate innovation in tracking S2S flows.
- Support development and operationalisation of emerging technologies like LiDAR, e-DNA, and AI.
- Allocate dedicated human resources to drive source-to-sea initiatives, ensuring consistent progress and leadership.
- Promote interdisciplinary and transdisciplinary approaches, drawing from initiatives like the GCRF Hubs.

3. Recommendations to policy makers

- Address source-to-sea gaps by commissioning review and synthesis of recommendations in earlier policy reports.
- Expand SEPA's role in supporting source-to-sea research, governance, and implementation in Scotland.
- Engage Chief Scientific Advisers to integrate source-to-sea principles into national policy agendas.
- Influence UKRI, SEFARI Gateway, and the Scottish Funding Council to prioritise integrated source-to-sea research.

Conclusion

This workshop continued an ongoing conversation across time, sectors, regions, and countries. As environmental and societal challenges become more complex and urgent, the need for source-to-sea evidence grows. The interconnectedness of ecosystems—from land and rivers to

groundwater, estuaries, and the sea—demands collaborative, systems-based solutions. Effective action requires that interventions and decisions benefit all parts of the source-to-sea system, both upstream and downstream.

The research projects discussed at the workshop framed research questions to provide evidence for holistic, fair and sustainable decision-making. We agreed that breaking down scientific silos for source-to-sea research presents a major opportunity for knowledge consolidation and innovation.

A key takeaway was the need for greater alignment between funding schemes and source-to-sea thinking. Further, the study of source-to-sea interlinkages requires repurposing and expanding the applications of existing technologies as well as use of emerging technologies, including AI, even though in ways not yet fully understood. The workshop also sought to gauge interest in source-to-sea research collaborations, especially within Scotland. There was a consensus that more involvement from Scottish academia and research institutes is needed. We acknowledge that key knowledge exchange activities, such as in-person meetings, inviting businesses and investors, and engaging with various communities of practices such as farmers and coastal communities, were missing, limiting the full potential of these discussions. Moving forward, dedicated resources, strategic partnerships, and ongoing dialogue are essential to ensure that source-to-sea research delivers sustainable, actionable outcomes.