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NORTH SEA OPEN SCIENCE CONFERENCE

Interdisciplinary science to support North Sea marine management: lessons learned and future demands

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Abstract The expected increase of maritime activities in the North Sea and the growing awareness of its natural environmental value require enhanced science-based environmental advice for more efficient and effective marine management. The North Sea Open Science Conference organised by the Royal Belgian Institute of Natural Sciences and the Belgian Biodiversity Platform in 2016 aimed to take stock of the present-day scientific knowledge on the North Sea ecosystem, its interactions with human activities and its management. The conference was structured along three themes: (1) 'the scientific backbone of the North Sea ecosystem: adequacy of the knowledge base?', (2) 'A new era in environmental monitoring and assessment: what is at stake?', and (3) 'Sustainability: one for all, all for one?'. Focusing on 'open science', we welcomed about 200 participants from around the North Sea with different backgrounds and interests in environmental sciences. The participants were challenged to reflect on current and future challenges for the North Sea management and, in particular, to explore possible nature-friendly solutions for addressing these challenges during a series of introductory oral (69) and poster (59) presentations, and World Café and Fish Bowl participatory sessions. The participants agreed on six main actions to (1) provide

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a solid scientific base for marine management decisions; (2) develop society-driven research; (3) increase interdisciplinary science; (4) recognise the need for system knowledge; (5) improve communication, knowledge exchange, and collective implementation of scientific knowledge; and (6) build integrated knowledge bases. For each of these, concrete action points were identified, and this review gives the most important and relevant ones for creating the knowledge base and managerial framework for a sustainable North Sea.

Keywords Science-based management · Society-driven research · Interdisciplinary science · Integrated knowledge bases · Science-policy-stakeholder communication · System knowledge

Introduction

Oceans and seas are of capital economic importance to their surrounding countries and their hinterland, the so-called 'blue-economy'. However, the seas, coasts, and estuaries are subject to what might be called a 'triple whammy'—the threats caused by increased industrialisation and urbanisation, increased use of physical and biological resources, and decreased resilience to external pressures such as climate change (Elliott et al., 2019). This particularly holds true for the North Sea, surrounded by densely populated and heavily industrialised countries with some of Europe's largest ports, having been used by industry for centuries (Emeis et al., 2015). Hence, in a worldwide relative comparison, the North Sea ecosystem ranked amongst the most impacted marine ecosystems in the World's oceans (Halpern et al., 2008), enduring a multitude of anthropogenic activities and their impacts, such as eutrophication, fishing, transport, and offshore oil and gas production. In addition, the North Sea is a climate change hotspot, with large seasonal shifts and climate change velocity (Burrows et al., 2011; Holt et al., 2012).

The ever-expanding pressures on the environment require a well-constructed management that allows for a sustainable conservation and—where needed—restoration of the marine ecosystem structures, functions, and services. At present, offshore wind farm siting and environmental impact mitigation, for example, are increasing the cumulative and widely ranging environmental impacts possibly affecting populations of, e.g. commercial species, ecosystem functions, such as carbon flow, or hydro- and sediment dynamics (Elliott, et al., 2018). Decommissioning oil and gas platforms in its turn poses new kinds of questions on its advisability with respect to the loss of newly created habitats, used by, e.g. species in need of protection (e.g. *Lophelia pertusa* Linnaeus, 1758), but also non-indigenous species, or the effects on ecosystem functioning (e.g. see Burdon et al., 2018, and

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results from the INSITE project at https://www.insitenorthsea.org/projects/). Given the ever-increasing demand for space and the spatial and temporal effects-footprints of activities (Elliott et al., 2018), management tools such as marine spatial planning (MSP, European Commission, 2014) are worldwide advocated to balance multiple interests and therefore challenging us with questions on environmental sustainability of, e.g. multi-use platforms or the possibilities of co-using marine space.

In addition to longstanding human industrial activities at sea, the European Commission's (EC's) Blue Growth Strategy further identified five focal areas for blue growth: coastal and maritime tourism, aquaculture, renewable energy, mineral resources, and biotechnology (European Commission, 2017). The Marine Strategy Framework Directive (MSFD; European Parliament & Council, 2008) on the other hand aims to (1) protect more effectively the marine environment across Europe, (2) achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend, and (3) facilitate cooperation between the EU Member States of one marine region and with neighbouring countries sharing the same marine waters through Regional Sea Conventions, such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) for the North Sea. Complementary to the MSFD is the European Directive for Maritime Spatial Planning which aims to achieve a wise and sustainable use of these seas (European Commission, 2014). An integrated implementation of these EC ambitions is facing a multitude of challenges and is at the basis of the EC's Integrated Maritime Policy (IMP) seeking to provide a more coherent approach to maritime issues, with increased coordination between different policy areas (European Commission, 2011).

The expected increase of marine activities in the North Sea and the growing awareness of its natural environmental value require enhanced environmental advice for more efficient and effective marine management. In particular, there needs to be a coordination of all the management and governance aspects, the plethora of activities, and a knowledge of the cumulative effects of the pressures emanating from those activities (Cavallo et al., 2017; Elliott, Burdon et al., 2017a, 2018). Hence there is a need for a continued—and at the same time major scope for—better uptake of interdisciplinary science in marine management. How to tackle this issue is a multi-faceted challenge, and thus calls for integrated science and assessment within which interdisciplinarity is key. In November 2016, the North Sea Open Science Conference (NSOSC) was organised by the Royal Belgian Institute of Natural Sciences and the Belgian Biodiversity Platform and was especially dedicated to discussing the importance of interdisciplinary science in managing the North Sea. This paper aims at summarising and integrating the lessons learned from the conference and advice for the way forward to achieving a science-based sustainable management of the North Sea.

Conference set-up

Being an open science conference, the NSOSC envisaged a high level of interdisciplinarity, targeting participants with different backgrounds and interests in natural sciences, social and economic sciences, policy making and governance, and marine management with industry representation. The conference aimed at considering the present-day scientific knowledge on the North Sea ecosystem, and its interactions with human activities and its management. All participants were asked to reflect on current and future challenges for the North Sea management and particularly, to explore possible nature-based solutions for addressing these challenges.

The four-day conference was organised around three themes:

1. 'The scientific backbone of the North Sea ecosystem: adequacy of the knowledge base?', dealing with (a) a stock-taking of the structural and functional spatio-temporal patterns and processes within the North Sea ecosystem, from a physical, chemical, and biological perspective, (b) an identification of the need for interdisciplinary research, and (c) data accessibility and associated confidence levels.
2. 'A new era in environmental monitoring and assessment: what is at stake?', dealing with (a) how to assess the North Sea ecosystem status, with emphasis on innovative and integrated approaches, (b) how to define baselines for the definition of and how to reach good environmental

status (GES), and (c) what indicators to use to validate assessment tools.
3. 'Sustainability: one for all, all for one?', dealing with (a) future North Sea usage and associated management issues and challenges, (b) how to secure long-term sustainable use of resources and the socio-economic potential, and (c) the policy framework needed.

In order to complement inspiring keynote presentations, the NSOSC had plenary sessions only, ensuring everyone had a chance to present in front of the entire audience in a sharp and innovative manner using extended and flash presentations (see Degraer et al., 2016). The conference covered a total of 69 oral presentations and 59 poster presentations. The stock-taking formed the basis for participatory discussions: two sessions offered the opportunity for constructive interactions between all participants using effective participatory methodologies. Firstly, a 'fish bowl' process allowed the audience to participate in a focused and interactive conversation on the identification of major management challenges. Secondly, we used an adapted 'world café' to mix views and to target specific questions related to research needs in support of management issues identified during the 'fish bowl' exercise. Dynamic and interactive presentations and discussions all provided an update on lessons learned and future prospects for the North Sea ecosystem management.

The lessons-learned from the discussions during the conference, and the participatory sessions in particular are presented below. These are structured along three main lines, framed within the context of providing scientific advice in a marine ecosystem management context, i.e. science as solid base for marine management decisions, developing society-driven research, and integrating science (in casu interdisciplinarity and system knowledge) in support of integrated marine management. From these lessons learned, the discussion then aims at methods of maximising the impact of scientific advice on the management of the North Sea, with special attention to communication and knowledge exchange, building of knowledge bases, adaptive marine management, and collective implementation supported by appropriate funding.

Resulting insights from the conference

Six overarching actions were flagged important by the NSOSC participants, spanning a wide range of approaches, from the adequacy of the knowledge base via developing and designing research to its application in marine management and policy making, and, as such, covering the full span of the conference. For each of these, a series of action points have been identified of which the most important and relevant ones are listed in this paper.

Provide a solid scientific base for marine management decisions

The increased use and rapid exploitation of the marine environment to support the development of blue growth activities across the North Sea (e.g. Ecorys et al., 2012; Ehlers, 2016 and many conference contributions, see Degraer et al., 2016) have resulted in degraded marine ecosystems across coastal and offshore areas, creating a cascade of effects across these ecosystems (Korpinen & Andersen, 2017; Elliott et al., 2019). Although site-specific changes associated to these effects are expected to be localised, effects can be perceived over a wider range of spatial and temporal scales (Willsteed et al., 2017). Furthermore, cumulative effects of various activities are expected (Judd et al., 2015), adding a greater challenge and complexity to the study of these systems. It is especially important to understand the effects of endogenic pressures operating inside the management areas and whose causes and consequences require to be managed, and exogenic pressures operating from outside the management area and whose consequences inside the management area need to be managed (Elliott, 2011). There is a clear need to support the understanding of such effects and impacts on ecosystems processes, based on the most adequate, fit-for-purpose, cost-effective, and robust science-based evidence—including the understanding of natural variability—acquired at the most appropriate scales to support decisions (Elliott, 2011).

To advance research, complement existing knowledge, and ensure the advice and management is based on the most up-to date and the best science to support decision-making processes, the NSOSC highlighted the importance of:

1. Continued investigation of ecosystem impacts from various human activities, such as maritime transport (e.g. oil and antifouling pollution), renewable marine energy developments, dredging, fishing, harbour development, and climate change; and their in-combination and cumulative effects; this includes defining the spatial and temporal effects-footprints.
2. Interdisciplinarity and combining complementary data such as in situ observations, mesocosm experiments, and numerical modelling to maximally comprise the complexity of marine ecosystems, their evolution, and their managerial challenges;
3. Covering the wide range of spatial and temporal scales needed to address the ecological repercussions of locally observed effects.
4. Demonstrating the adequacy of databases and new tools to support and develop targeted scientific knowledge bases and descriptors to help achieving an integrated ecosystem assessment.

Develop society-driven research

Worldwide, marine ecosystems suffer from cumulative effects of anthropogenic activities calling for an integration of ecological, economic, and socio-cultural scientific approaches as required for ecosystem-based management (EBM) (Halpern et al., 2009, 2012; Korpinen & Andersen, 2016; Borja et al., 2017; Stelzenmüller et al., 2018). EBM is advocated as a way forward to ultimately safeguard the provision of ecosystem services from which societal goods and benefits are created and on which humans depend (Elliott et al., 2017). EBM accounts for ecosystem-relevant boundaries and aims at balancing multiple management objectives, including marine conservation and restoration. In the North Sea, EU legislation, such as the MSFD or MSPD, promotes a paradigm shift in marine management towards EBM. The science needs to underpin sustainable spatial planning calling for interdisciplinary approaches and the recognition of the complexity of socio-ecological systems, ultimately steering management objectives (Elliott et al., 2017a, b). Socio-ecological systems describe the level of connectivity of the ecological, economic, and social sub-systems. Up-to-date socio-ecological systems analysis is often restricted to conceptual approaches lacking the quantification of their vulnerability and the impact of management measures on respective sub-systems. The conference revealed clearly that recognition of the complexity of socio-ecological systems requires also a solid understanding of the *modus operandi* of the science-policy interface. Hence, defining the science–policy interface within a management system is a key challenge in achieving sustainable development while maintaining the current state of ecosystems. Only then, the delivery of scientific advice can directly support a given management process.

The NSOSC conference called for supporting the development of societally sound research, to be achieved by:

1. Engaging stakeholders in helping to define the research questions, with, based on an in-depth stakeholder analysis, a clear plan on the modus of collaboration, communication, and the way stakeholders will be informed. This requires finding out what questions are relevant and addressing questions such as: What processes play a key role in their business? What would help their enterprises further?
2. Addressing stakeholder concerns in an interdisciplinary manner and by a multi-disciplinary team of scientists acknowledging the complexity of the socio-ecological system at stake.
3. Ensuring scientific integrity, by following good scientific practice to produce transparent and well-documented results, eventually to be verified with stakeholders to build trust. This requires a scientifically rigorous approach of defining aims and objectives followed by hypothesis testing and using quality-assured methods and data.
4. Stimulating stakeholders to actively get involved and (financially) invest in research (incl. citizen science) and innovations to facilitate education of and gaining ownership of results and solutions by the stakeholders.

Increase interdisciplinary science

To comprehensively understand the North Sea ecosystem, especially the interaction between individual scientific disciplines is important. The conference presented the impacts of several interactions of natural environmental conditions and anthropogenic stressors

on the marine ecosystem. For example, interactions between climate change and pollution were shown to affect zooplankton biodiversity and functioning, physical and biogeochemical interactions affect the structure of benthic communities, macro- and microorganisms affect the biogeochemical cycling, and overfishing and global warming affect grey seal behaviour (see Degraer et al., 2016). It is therefore essential that biologists, chemists, geologists, biogeochemists, and others work together more closely in the future to obtain further knowledge of the marine system and to facilitate an integrated knowledge-driven marine management. In particular, this type of systems analysis revolves around a risk-assessment and risk-management framework whereby the causes, consequences, and management of adverse effects need to be considered (Cormier et al., 2018, 2019).

Integration of different disciplines and datasets also brings additional complexity, entailing a crucial role for data managers and modellers. In itself, coupling empirical research and modelling is also an interdisciplinary approach. The way in which modelling provides valuable insights in marine systems was presented for e.g. the modelling of the dynamics of different trophic levels in function of nutrient dynamics and primary production, modelling multiple stressors for the assessment of marine protected areas, and using an integrated ecosystem-economy model of the coastal fisheries, including anthropogenic dynamics (Peck et al., 2018).

The NSOSC participants emphasised the need for:

1. National and international project calls focusing on ecosystem-based management to stimulate and facilitate interdisciplinary research by promoting collaboration and requesting truly interdisciplinary deliverables, i.e. those combining the natural and social sciences.
2. Young researchers to be stimulated by promoters and other senior scientists to look beyond their own discipline(s) from the start of their career, taking advantage of the inherent interdisciplinary contact when working with open-access research facilities.
3. Creative minds, recognising and creating opportunities for bridging different disciplines and professional communities, to be promoted and educated in the academic curricula and throughout the professional career.
4. Creating national and international platforms and other opportunities that unite researchers of different disciplines, ideally also industry, managers, and policy makers around specific topics.

   Good examples of the latter platforms are the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR; www.ospar.org, and the corresponding Regional Seas Conventions for the Baltic, Mediterranean and Black Seas), the International Council for the Exploration of the Sea (ICES; www.ices.dk), the Marine Geological and Biological Habitat mapping group (GeoHab; geohab.org), and the Netherlands Centre for Coastal Research (NCK; www.nck-web.org), as well as the pan-European research infrastructure European Marine Biological Resource Centre (EMBRC, www.embrc.eu).

Recognise the need for system knowledge

Sustainable ecosystem management relies on ensuring a proper functioning of the ecosystem. Achieving an understanding of the processes and cause–effect relationships in marine systems should hence become a fundamental part of scientific research (natural and social sciences), as highlighted in several contributions to the conference (Degraer et al., 2016 for an overview). The knowledge about these processes and their linkages is essential, since without at least an approximate and fit-for-purpose understanding of cause-effect relationships, mitigation measures would not achieve the required aims.

Marine management can only be successful if the spatial and temporal scales at which the ecosystem is managed correspond to the scales on which natural processes operate. Therefore, the delineation of management units can be essential for efficient management. It is necessary to accept what activities create pressures inside the management space (endogenic pressures) and what pressures emanate from outside the management area, such as climate change responses (the exogenic pressures) (Elliott, 2011). Classification based on physical characteristics of the ecosystem has become an important tool to define these units (Roff et al., 2003; Davies et al., 2004) and the mapping of marine landscapes was also shown at this conference as an essential way forward in North Sea marine management. As shown by global

examples, mapping the natural and anthropogenic features of any area is a prerequisite for successful and sustainable management in any assessment (Borja et al., 2016). However, since it is not yet clear precisely how spatial patterns of environmental variables reflect natural faunal communities and the biological processes, and since marine research is often confronted with fragmentary data on small spatial (and temporal) scales, an up-scaling is often needed before research becomes relevant for management. This is particularly important given the complex spatial use and multiple activities in most urbanised and industrialised seas such as the North Sea (Elliott et al., 2018).

Spatial modelling can provide larger-scale projections based on relatively few data (e.g. Reiss et al., 2015). This conference illustrated the potential of niche modelling to provide full-coverage biological data for spatial management and the value of modelling to increase knowledge on trophic relationships and carbon cycling. While the first approach mainly addresses spatial patterns of ecosystem components, the latter focuses on understanding ecosystem dynamics, including the underlying processes. Modelling approaches were further shown to allow for a spatial up-scaling of local-scale anthropogenic impacts as demonstrated by the larger-scale ecosystem effects of offshore wind farms on primary production.

Based on the participatory discussion sessions, the NSOSC highlighted:

1. The need for funding agencies to foster fundamental sciences and system-scaled process-understanding as part of their programmes in order to further the knowledge of the cause–effect relationships driving ecosystem dynamics.
2. The importance of modelling approaches (both process- and pattern-driven, and both conceptual and predictive) as an additional but necessary tool for successful marine management.

Improve communication, knowledge exchange, and collective implementation

Effective and continuous communication between different stakeholders (covering policy, science, public, industry, etc.) is essential. Such communication should facilitate dynamic interactions between scientists, regulators, and industry on focal themes, and target all the relevant types of stakeholders (Newton & Elliott, 2016). This is imperative for well-designed and effective cross-border science and management of the North Sea, as illustrated by many examples during the conference.

There is the need for more networking between scientists and policy implementers, to ensure that science can inform policy and policy can inform the science. Closer collaborations are needed for all actors to get to know each other, to develop science programmes jointly and to develop common language and understanding. This may require scientists to be creative for new ways of interactions and to make sure their science is useful. Excellent science and understanding of the North Sea marine system will have no impact or value on its management unless it is communicated to the right audience, at the appropriate time and in an appropriate manner. The audience must be receptive and the scientists have to realise that different audiences require information in different formats (Elliott et al., 2017b). It was emphasised that many hurdles are yet to be overcome here. It is emphasised that the policy makers/implementers, managers, and other stakeholders, such as industry and NGOs, are unlikely to be able to use and appreciate detailed scientific documents and so the onus is on the scientists to produce suitable documents (Elliott et al., 2017b). Scientists may wish to rely only on peer-reviewed international literature (Snoeijs-Leijonmalm et al., 2017), whereas other stakeholders have little access to large academic libraries and may wish to rely on their own reports (Elliott et al., 2017). Furthermore, scientists often take a more international view in the dissemination of their information, whereas other stakeholders often need and rely on local, case-specific literature.

Around the North Sea, there are some good examples of initiatives aiming at facilitating the communication and knowledge exchange between the stakeholder groups, often across boundaries, e.g. networks such Netherlands Centre for Coastal Research (NCK, www.nck-web.org) or the UK Knowledge Transfer Partnerships for specific industries (http://ktp.innovateuk.org/). Other initiatives aim to expand international (cross-border) communication, such as North Sea Hydrographic Commission (NSHC), OSPAR, and the International Maritime Organization (IMO). Lastly, the highly successful joint Baltic Sea research and development BONUS

programme for the Baltic Sea has heavily influenced policy (Snoeijs-Leijonmalm et al., 2017; Elliott et al., 2017b).

The NSOSC concluded that:

1. In addition to having recognition based on typical research metrics, scientists need to be recognised and awarded for their work in public communication because of the increasing importance of science beneficial to society, especially when publicly funded.
2. Scientists should be trained in communication to learn to communicate and listen effectively, and coupled to communication professionals to improve communication outreach to the public.
3. All stakeholders would benefit from a continued education in different types of communication depending on the requirements, outputs, and audience.
4. To achieve a closer collaboration of scientists and managers towards marine management and policy, attuning research topics to actual societal issues and evaluating management measures will need to be explicitly built-in in projects, or, otherwise, be supported by additional funding.

Build integrated knowledge bases

Pivotal in interdisciplinary research is the accessibility of data. Datasets need to be collected with the view to be used many times and over multiple exercises (e.g. from monitoring, and/or research initiatives), integration into national databases has become good practice, as well as their uptake into international initiatives (e.g. ICES and the European Marine Observation and Data Network, www.emodnet.eu). Incorporating industry data in community databases is relatively new yet considered important to serve wider applications (see INSITE; www.insitenorthsea.org). National and international research funding agencies already play an important role in the disclosure of data to the entire scientific community. As an example, all new data collected by Belgian Science Policy Office-funded projects must be published in the IDOD database of the Belgian Marine Data Centre (www.bmdc.be).

A remaining and challenging task is the exchangeability of datasets and building integrated knowledge bases facilitating swift cross-institute, cross-sector and/or cross-border collaboration. This starts with ensuring a most versatile use of data by incorporating the original data at the maximum level of detail to serve multiple purposes (i.e. the maxim of '*collect once, use many times*'). A remaining critical issue is the coding of metadata and storage in data portals following international standards, thereby allowing harmonisation of data products (e.g. SeaDataNet for oceanographic data, www.seadatanet.org). Along these lines, it is equally important to establish procedures on how best to quantify the uncertainties associated to the data as illustrated during the conference. Although this type of AQC/QA (Analytical Quality Control and Quality Assurance) is fairly standard for scientific analytical results, it remains new for other data types, as well as for metadata (e.g. related to positioning and source of the data). Inter-calibration exercises also provide more insight in the range of uncertainty, e.g. as performed in optical remote sensing, but also in sampling and laboratory procedures (e.g. monitoring of benthos in EU Water Framework Directive). Only when sensors and techniques are calibrated can management applications from the remote monitoring of water column and seabed parameters fully emerge. Furthermore, data platforms providing full-coverage maps of ecosystem components and human activities are increasing (e.g. EMODnet), whereas data in time series serving the analysis of ecosystem dynamics and trends are mostly lacking. Finally, knowledge bases should easily support managerial decisions, which is best accomplished when data and their uncertainties can be queried in a most flexible way to produce customised answers, datasets, and products (e.g. Van Lancker et al., 2017; www.bmdc.be/tiles-dss). Ideally, such tools are expanded into an interconnected modular adaptive data hub serving integrated marine management and user applications. The NSOSC participants therefore recommend that:

1. Governments and researchers should make their data public, the latter not only by writing peer-reviewed publications, but also by making raw and processed data available in international databases.
2. National and international research funding agencies should encourage and reward the scientific community to disclose data.
3. Databases are organised so that data are easy to find and queryable on common data platforms, and

are extractable in a straightforward way (uniform metadata) and easily understandable for scientists from other disciplines.
4. Historical data availability should be expanded thereby enabling more consistent analyses of long-term time series.

This special issue

In this thematic issue, seven papers of the 128 NSOSC presentations (Degraer et al., 2016) provide an overview of the current state of the science on the North Sea ecosystem. Contributing to the knowledge base (Theme 1) insight was provided on the origin of nitrogen in the English Channel and Southern Bight of the North Sea ecosystems, hence contributing to understanding causes of marine eutrophication (Dulière et al., 2019). Building upon the investigation of the accumulation of epifauna on turbine structures, Slavik et al. (2019) simulated the large-scale impact of offshore wind farm structures on pelagic primary productivity in the southern North Sea. Regarding environmental monitoring and assessment (Theme 2) methodological papers related to the improvement of (1) acoustic seafloor classification techniques and their integration into existing mapping products to reduce uncertainty in full-coverage sediment mapping (Gaida et al., 2019); (2) acoustic telemetry, by providing insight into the environmental factors that influence the detection probability of animal behaviour in the marine environment (Reubens et al., 2019); and (3) the use of otolith shape, and their differences in size, asymmetry, and small-scale spatial variation, e.g. to trace juvenile sole in the Southern North Sea (Delerue-Ricard et al., 2019). Related to assessments, Carpenter (2019) showed the impact of governance measures on oil pollution over several decades. Supporting Theme 3 on sustainability, Blanz (2019) showed that in economic modelling of fisheries, bycatch should be accounted for when modelling interactions of fish, fishers, and consumers.

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