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Managing marine resources sustainably: A proposed integrated systems analysis approach

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ABSTRACT

Marine and estuarine management requires an excellent understanding of the interacting, interrelated and interdependent sub-systems comprising ecological, societal and management complexity. Managing such a complex system sustainably relies on knowing what aspects can be managed, and conversely what aspects are outside the control of the manager. Accordingly, by taking elements from existing environmental management approaches, especially in Europe and Canada, here we propose an integrated systems analysis approach which links 14 component sub-systems. Using these cases shows that while all elements exist, they have hitherto not been combined into a holistic decision support system. These components are linked here in a cycle of three Parts - (A) defining the policy problems facing the seas, (B) obtaining the relevant and fit-for-purpose natural and social sciences data and information, and (C) creating an input for policy and decision-making which involves stakeholders. The component sub-systems are: an Underpinning Framework Sub-system (1), which then leads to the Issue Sub-system (2), which is vision-related and includes causes and/or consequences of pressures to be managed. The Ecological Sub-system (3) links the biota and its environment to the Socio-ecological Sub-system (4) and the Socio-economic subsystem (5), which considers the macroeconomic aspects. The Resources and Delivery Sub-system (6) considers which scientists do what and how do they do it and the Provenance Sub-system (7) checks that there is a fit-for-purpose and defendable science evidence base. The Governance Sub-system (8), incorporates policies and politics as well as horizontally and vertically integrating the Legislative (8A) and the Administrative Sub-systems (8B). The Communication (8C) and Stakeholder Sub-systems (8D) ensure involvement across the stakeholder typology (of formal and informal actors). Finally, the Achievement Sub-system (9) and the Feedback Sub-system (10) ensures that all of these actions achieve successful and sustainable marine resource management.

1. Introduction – what is systems analysis and why is it needed for the marine environment?

The marine ecosystem is a complex and highly variable system of abiotic and biotic components and processes (Tett et al., 2013) and the sustainable management of human activities in the marine ecosystem is by its nature complicated, given the wide ranging societal demands for resources and management practices (Elliott, 2011; Borja et al., 2017). Most importantly, that management must create a sustainable system in which the natural system is maintained and protected but which at the same time delivers the ecosystem services to supply goods and other benefits to society (Turner and Schaafsma, 2015; Costanza et al., 2017). Therefore, to achieve sustainable resource management requires an understanding of the seas and our use of them via an integrated system which merges the natural and human aspects (Elliott, 2013; Borja et al., 2020). Such a holistic approach has to integrate the environmental and biotic ecosystem components and processes with the cultural and social aspirations that generate the resource demands, the governance policymaking process to address the drivers of these demands, and the management of the activities generated by the drivers to achieve societal goals and aspirations (Cormier et al., 2017; Cormier and Elliott, 2017).

Many policy-centric, eco-centric and socio-economic centric approaches have been developed to inform policymaking governance processes (e.g. Ostrom, 2009, 2011; Binder et al., 2013). However, few

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of the frameworks explicitly conceptualize or integrate the management and operational aspects for implementing sector management measures to achieve common objectives established through marine planning (Domínguez-Tejo and Metternicht, 2018; Stephenson et al., 2019). Few papers consider in detail the legal and administrative aspects of marine management within the context of the political system that is driven by cultural and societal aspirations (Boyes and Elliott, 2014; Barnard and Elliott, 2015). In addition, most papers discuss the technical aspects of ecological sustainability in contrast to economic viability without examining the technological feasibility of the solutions required to achieve objectives or effective ways of communicating the messages to non-technical stakeholders and managers responsible for decisions.

While not focussing on the marine system, Ostrom (2009) was one of the first to identify the need for Social Ecological Systems (SESs) as a need for creating a common management framework and proposed a SES of 10 subsystem variables to aim for a self-organising and sustainable system. Although she advocated the separation of, and the need for, the natural and social-economic sciences, the links between and interdependence between these were not emphasised. Similarly, being from a social scientist, that SES approach was especially anthropocentric and had little emphasis on gathering and using information from the natural sciences. Furthermore, the Institutional Adaptation and Development Framework created by Ostrom (2011) created an overtly behavioural approach to sustainability management including the resources that an 'actor' (stakeholder) contributes to the situation, the value placed on the prevailing situation, the way information is delivered and used by the actors and the means by which actors make decisions.

In the ensuing decade since the Ostrom (2009, 2011) papers there has been an increased focus, and development of ideas that can now build on her original concepts. These include ecosystem services and societal goods and benefits, more complex governance systems, and the fit-for-purpose and provenance nature of the science data and information underpinning policy. Hence any systems analysis approach for the current and holistic marine resource management should expand on the SES advocated by Ostrom (2009) which focussed on four aspects – the resources system, the resource unit, governance and the users. However, the 'users' in that scheme are those mostly exploiting the environment rather than the 'influencers' (Newton and Elliott, 2016) whose role is to create the timely and fit-for-purpose data and information and advice.

Recent marine science papers discuss the more analytical aspects of the interconnected systems which develop environmental management strategies to address human well-being expectations (Gavaris, 2009; Domínguez-Tejo et al., 2016). Therefore, here we aim to show that the complexity and need for a holistic and integrated approach requires systems analysis and systems mapping techniques. Logic models and system thinking have long been around linking policy to management performance of plans and programmes (McLaughlin and Jordan, 1999; Mingers and White, 2010) but not proposed for marine management. In addition, such approaches partly increase the understanding in governance and management to identify gaps and constraints in political and management sciences (Drewry, 2014; Anderson, 2011; Anthony and Dearden, 2006).

Despite the need for such a complex and integrated system and, as will be shown below, the fact that we now have most of the elements in the science and management of the marine system, it is contended here that as yet such a system does not exist and hence there is the need to propose such a framework – this is the overarching aim of this paper. Therefore, by building upon the lessons learned from systems analysis and systems mapping, this paper proposes and then examines the use of such an approach in increasing the understanding of the interconnectedness of the network of ecosystem, cultural, social and economic systems; this will then drive the implementation of governance, policymaking and management of human activities to achieve policy objectives and reach societal goals.

As with Ostrom (2009, 2011), we take an anthropocentric view for the analysis of these system, since policymaking and management implementation occurs in the human realm and not in the natural ecosystem realm of environmental and biotic components and processes. However, and unlike Ostrom (2009, 2011), we emphasise the role of the natural sciences in providing fit-for-purpose data and information on which to base policy decisions. Accordingly, we start from a set of generic questions developed from decades of marine ecosystem and management discussions to develop a system analysis framework to support the above (e.g. Borja et al., 2017). The proposed framework aims to structure the analysis of the ecosystem in relation to the cultural and social systems that drive governance and management processes to ultimately gain a better understanding of their interplay in marine planning.

Given this overall aim, we use the following definitions: a *system* is a set of things working together as parts of a mechanism or an interconnecting network; a set of principles or procedures according to which something is done; an organized scheme or method. A *process* is a series of actions or steps taken in order to achieve a particular end. *Management* is the process of dealing with or controlling things or people, and *governance* is the action or manner of governing through authority, decision-making and accountability. *Governing* is having the authority to conduct the policy, actions, and affairs of a state, organization, or people. We use the term *framework* as a basic structure underlying a system, concept, or text and follow Ostrom (2011) who separates approaches into frameworks, theories and models – hence the approach proposed in the current paper is a framework (*sensu stricto* Ostrom, 2011) which aims to identify the necessary components and the links between them prior to analysing, interrogating and then using the framework. This also allows the questions and hypotheses in sustainable resource management to be defined and addressed.

It is not an aim of this paper to comprehensively review all examples of marine management systems, especially as some cover only a small part of the framework, although a few illustrations are relevant. For example, Alexander et al. (2017) emphasised the horizontal and vertical integration for socio-ecological management of a Marine Protected Area network and ecological connectivity and so they had a more conservation basis. However, their framework needed to be more applicable to wider sea areas and to show the collaboration between actors and stakeholders, and the importance of horizontal and vertical governance.

More recently, Stephenson et al. (2019) give an integrated management system with pathways covering the planning, decision-making, and stakeholder input. However, they focus less on what scientific and economic information is needed, the links to ecosystem services and societal goods and benefits. Støttrup et al. (2019) come closest to the approach proposed here with their valuable Systems Approach Framework (SAF) which has a six-step approach covering issues, system design and formulation, implementation, monitoring and evaluation, although the latter can be considered synonymous. However, again it gives less emphasis on obtaining, and the provenance of, the ecological, societal and economic information, on the way in which the aspects of governance (policies, politics, administration and legislation) are vertically and horizontally integrated. They suggest that a holistic system is required but advocate that this cannot be broken down into its component parts and so should be treated as a whole. Despite their advocacy to treat the system holistically, Støttrup et al. (2019) then break it down into the component parts. We take the view that this is the only way that the system can be addressed but that the essence of a successful approach is in the way and order in which the parts are combined. It is of note that the development of the papers by Stephenson et al. (2019) and Støttrup et al. (2019) overlapped in time with our paper but independently from it.

The objectives of the current work are to indicate the nature and role of systems analysis, to present a set of questions pertinent to sustainable marine management, to use those questions to propose the subsystems required in the resulting systems analysis, and then to indicate and compare how such an approach relates to marine management in a country (Canada) and a bloc of Member States (the European Union, EU).

2. Analysing and mapping a network of interconnected systems

Systems mapping should encompass the inputs and output of energy, money, materials and information (skills/capabilities) of each part of the system to achieve an objective to reach a strategic goal (Cormier et al., 2017). Here, such a goal is the successful and sustainable overall and agreed vision for the seas, i.e. what society wants from the environment (in terms of its status, management, exploitation, nature, blue economy, etc.). Hence, marine system mapping is required for the integration of ecosystem, social, economic and legal systems operating dependently or independently and which requires an excellent understanding of the interrelated complexities of interactions and interdependences.

While we emphasise that ‘stakeholder engagement and consultation’ and ‘scientific advice’ do not constitute a management system, these are regarded as due diligence components of the policymaking, planning or operational processes (Anderson, 2011; Anthony and Dearden, 1980; Giraud et al., 2011, respectively). Each of these involve different stakeholders, scientists and technical experts for very different reasons and questions. We emphasise that there are no governance or management systems *per se* in ecology only in the management of human activities and their ecological effects as is implied by ecosystem-based management. Science is a key input for any evidence-based process to inform decisions (Cormier et al., 2017). However, cultural, social, economic and legal advice also provides the necessary evidence to understand what should be the policy context, as well as how best to manage human activities and their pressures.

Although much has been written about the need for new ecosystem-based management approaches to human activities (e.g. Ostrom, 2009, 2011; Long et al., 2015), these often relate to site-based ecosystem protection and conservation considerations. They seldom integrate the management of human activities and their pressures outside of their precise sites or spatial marine protection (e.g. Elliott et al., 2020). In fact, ecosystem-based management adds ecosystem considerations to well-established governance and management practices that drive the processes and decisions regarding policies, plans and programmes (Bovaird and Loffler, 2003; Bourgon, 2007). Putting into practice the so-called science-policy interface implies the need to understand how the scientific community generates knowledge as evidence for the administrative and management community to develop their policies, plans and programmes in consultation with stakeholders. The competencies of both communities is truly needed to successfully and sustainably implement an ecosystem management approach to human activities and their pressures. Analysing the governance, administrative and regulatory systems is therefore needed to understand the policy constraints of administrations and authority constraints of the regulators to act even though the need to address a particular issue is backed by scientific evidence.

Although the ecosystem is controlled by natural processes on which the human system is superimposed, each social, economic and legal component is typically managed independently by a hierarchy of governance, management and regulatory structures operating within a causal loop (Cormier, 2019; Ferraro et al., 2018). Marine environmental effects result from a causal loop generated by social and economic activities where the legal system used should manage the activities at the root causes of those effects. All of this fits within an overall integrated marine risk assessment and risk management framework which has been previously identified and refined as DAPSI(W)R(M) (pronounced *dap--see-worm*, derived from DPSIR, Elliott et al., 2017a; EEA, 1999; details given below).

Coffman (2007) emphasised the understanding, mapping and evaluating change in a system as “*a group of interacting, interrelated, and interdependent components or not that form a complex and unified whole*”. Coffman (2007) used a social system to link the context, components, connections, infrastructure and scale for each of the activities, outcomes and impacts in an area. The overall purpose or goal of the system is achieved through the actions and interactions of its components, its values, its actors (stakeholders) and their relationships, its policies and its resources, and techniques and technologies, thereby showing the complexity of coupled socio-ecological systems (Liu et al., 2007; Ostrom, 2009). Accommodating or manipulating these is therefore the challenge for systems analysis and system management.

Here we aim to show that the marine ecosystem consists of many aspects, each of which has its own system map to be interlinked. Systems mapping therefore visually represents the structures and links of multiple components, to analyse and interpret the structure (the systems at one time) and processes, to understand how they function in order to develop effective management strategies (*inter alia* controlling the flows of money, time, energy, information and materials through the systems) (Mingers and White, 2010). Therefore, based on our previous discussions (example papers cited herein), we contend that these system maps should include, for any geographical area:

- Conceptual organograms of the key stakeholders to show the individuals and/or organizations and the way in which they are interconnected (Newton and Elliott, 2016; Oates and Dodds, 2017).
- Conceptual models or mind maps (‘horrendograms’, for example Boyes and Elliott, 2014) that show the internal (intrinsic) and external (extrinsic) influences and pressures which dictate the pathway in the system.
- Conceptual models showing the main structural concerns or aspects affecting an area and the range of measures available to address the challenges (Elliott, 2013).
- Links between the above models showing the influences, solutions and feedbacks (such as in causal-loop or Bow Tie diagrams) and which can be negative or positive, which constitute the system behaviour or functioning (Borja et al., 2017; Cormier et al., 2019).

3. Defining and addressing the challenges for marine science and management

Within the above context, this paper builds on decades of our practical involvement in managing the marine environment in Europe and Canada by combining current tools but especially indicating the sequence in which these tools need combining. For example, we build on Borja et al. (2017) using the experience from the European project DEVOTES (www.devotes-project.eu) which synthesised the science and management links required for implementing the European Marine Strategy Framework Directive (MSFD; European Commission, 2008). Similarly, we build on the marine management experience in Canada through the Department for Fisheries & Oceans. Derived from this experience, we suggest that defining and designing an integrated marine management system needs to address a set of fundamental questions (Table 1).

We contend that to answer these questions requires tools embedded in a set of sub-systems to create the entire framework. Hence, here we propose such a framework, and even show it as a recipe, to be used both by developed maritime countries, as an objective system which can fulfil current and future obligations, and also by developing states without a long history of marine management.

This approach takes the view that the policy-making process is ultimately an embedded series of sub-systems of vision-goals-objectives-outcomes in which system mapping has to be sufficiently clear to avoid confusion between the roles of the various actors. This means that we need an overall system in which (i) the priorities for management have to be decided and agreed (termed Part A), (ii) then the means of getting data and information to satisfy those (Part B), and finally (iii) the management and governance system shows how that information and those data are used (Part C); it is then emphasised that the governance

Table 1
Questions to be addressed in defining and designing an integrated marine management system.

- What is the overall underlying framework used and/or needed?
- What is the overall vision for a marine area, who derived it and under what authority?
- How were the relevant marine environmental pressures and activities identified and prioritised for a given area?
- What ecological knowledge is required to determine the cause and consequences (effects) as a result of these pressures?
- What are the socio-ecological knowledge and socio-economic basis and repercussions of current management practices?
- Who has the ability/duty to achieve an independent science evidence-base and what resources are required and can this be separated from any inherent bias?
- How good is the science-base to implement the appropriate management measures for the activities to reduce their pressures?
- What are the aims and objectives for science-informing management?
- What are the management questions that science is trying to answer?
- What regulatory and non-regulatory instruments need to be implemented?
- What is the legal basis of marine management, what laws and agreements are needed (at national, regional, international level)?
- Who will implement the legislation and/or regulatory framework?
- Who are the stakeholders in the process and how are they involved?
- What indicators are used to determine both the status of the area and the efficacy of management measures; who decided these and how were they decided?
- What environmental, conformity and compliance monitoring takes place against those indicators and who does it?
- How defendable, in scientific or governance terms, is the monitoring and the data produced?
- How is success in monitoring and management defined and by whom?
- How will success in implementing such a management framework be determined?

and management imperatives are used cyclically to define the priorities (Fig. 1). This has the basis that a policy logic management model always works downwards from the vision, goals, objectives and outcomes. In contrast, regulations, legislation and policies are developed upwards from the outcomes to the vision (Knowlton and Phillips, 2013, see also Cormier et al., 2017). Hence, the starting point could be an overall desire to achieve the vision or it can be the result of legal obligations (i.e. respectively 'a carrot or a stick approach'). Therefore, while these sequential components are termed A, B and C, the starting point can be at either A or C and it is emphasised that there are feedback loops in which successive iterations make improvements – for example, the priorities may be set (A) but then modified once relevant information has been gained (B) and used in governance (C).

4. Component subsystems

Given the above background, here we propose an integrated marine management systems analysis in which the cycle in Fig. 1 integrates 14 numbered component subsystems (with feedback and causal loops, Fig. 2).

4.1. Part A – setting the priorities

(1) The Underpinning Framework Sub-system – this is needed to link causes, effects and responses (Borja et al., 2017), as with the DAPSI(W)R(M) framework (Elliott et al., 2017a, which was developed from

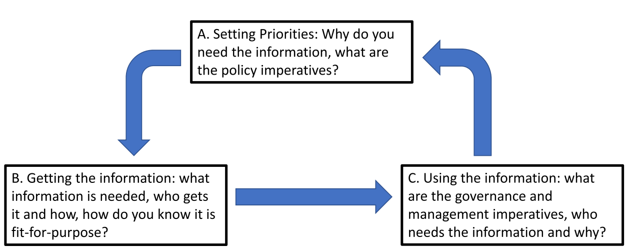

Fig. 1. The underlying rationale of the proposed management systems analysis (see the description in the text).

the previously well-used DPSIR framework, Patrício et al., 2016a). The latter paper gives the historical development of this framework from the 1990s to present and shows why each iteration has been an improvement of previous versions; for example Activities have been added as otherwise there is a step missing between basic human needs producing the causes of change. This cyclical framework combines **D**rivers (the basic human needs such as food, shelter, security, life fulfilment, etc.), **A**ctivities (the means of obtaining those human needs, such as fishing for food), **P**ressures (the mechanisms of change in the natural or human systems emanating from the activities e.g. trawling for fishing), **S**tate changes (the degree of change on the natural system and ecology resulting from the pressures e.g. erosion and turbidity from trawling), **I**mpact (on human **W**elfare) (e.g. reduction of fish stocks) and **R**esponses (using management **M**easures) (e.g. seasonal closure, changes in net size) (Elliott et al., 2017a, lists examples of each of these elements). This framework focusses on what problems are created and why (for nature and society, e.g. loss of ecosystem services and societal goods and benefits) (Turner and Schaafsma, 2015) and hence leads us to identify what can be done, when, how and by whom. The Responses are achieved through relevant legislative, policy and regulatory tools that addresses many facets (the so-called 10-tenets) which reflects the complexity of the whole system (Elliott, 2013; Barnard and Elliott, 2015). The 10-tenets suggest that successful management actions need to be: *ecologically sustainable, technologically feasible, economically viable, socially desirable/tolerable, legally permissible, politically expedient, ethically defensible (morally correct), culturally inclusive* and *effectively communicable*. Applying the DAPSI(W)R(M) framework and these 10-tenets relies on knowing what aspects can be managed and why and how, and conversely what aspects are outside the control of the marine manager (Elliott, 2011, 2013).

(2) Issue Sub-system – this is related to the overall vision adopted for an area. It includes activities emanating both inside the sea-area to be managed (the endogenic pressures where causes and consequences are managed), and from outside that area (the exogenic pressures where only consequences can be managed) (Elliott, 2011). It allows us to identify the causes of the problems (for example, based on an existing risks and hazards typology, Elliott et al., 2014) and it requires an ability to prioritise challenges but also know the repercussions of natural and anthropogenic changes. Hazards occur in the environment and may be natural or human-created whereas risk occurs if those hazards endanger something valued by society (health or well-being) (Elliott et al., 2014). In any policy analysis, the risk of not achieving a policy objective needed to reach the goals is described as the occurrence or probability of an undesired event given the hazard and the causes of such an event.

In risk management, the occurrence of an unwanted event is the result of a loss of control or ineffective management measures (Pitblado and Weijand, 2014; Cormier and Lonsdale, 2019). Operational measures and controls are implemented in turn to produce or meet the expected outcomes to achieve the objectives and reach the goals. In policy-making, the operational control processes of everyday procedures, tasks, controls, and measures carry into effect the policy objectives. If the control is ineffective (i.e. it does not work), only reactive management strategies of mitigation and recovery can attempt to remediate the consequences to achieve the objectives. Given that hazards are the sources of risk, the root causes and the consequences of such undesired events show the need for the management of both causes and consequences (for endogenic pressures) and consequences (for exogenic pressures).

We emphasise that there is the need to have a well-defined direction for marine management and so we use the term environmental objective, to cover what is to be achieved and whether it is measurable, and the term goal and vision as the future outcomes. We also emphasise that, in order to be successful, objectives have to be SMART (specific, measurable, achievable, realistic and time-bounded) to show if the goals are being reached within the vision of the policy (see Cormier and Elliott, 2017).

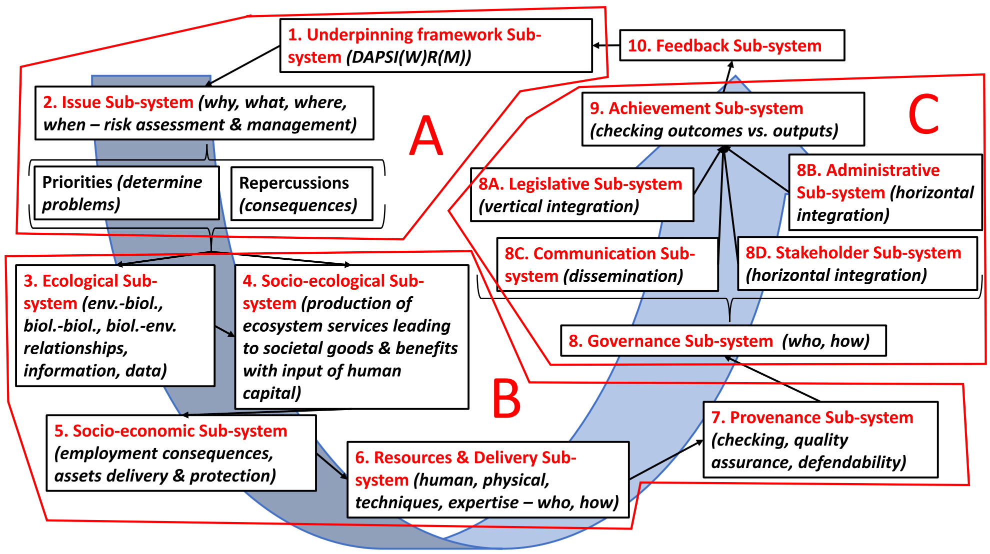

Fig. 2. The subsystems of an integrated marine management systems analysis, indicating the three Parts (A, B and C) denoted in Fig. 1.

There are many examples worldwide of high-level 'visions' being adopted, for example: (i) the European MSFD (European Commission, 2008), for which *"the marine environment is a precious heritage that must be protected, preserved and (…) restored with the (…) aim of maintaining biodiversity and providing (…) oceans and seas which are clean, healthy and productive"*, (ii) the UK and Marine Scotland vision ("*clean, healthy, safe, productive, biologically diverse marine and coastal environments, managed to meet the long-term needs of people and nature*", and (iii) Canada's Ocean Strategy paraphrased as '*to enable sustainable development, achieve the ecosystem approach, follow the precautionary approach and lead to integrated management and economic diversification*' (see https://www.dfo-mpo.gc.ca/oceans/publications/cos-soc/index-eng.html#id1). These visions are often both pliable and subjective, are rarely measurable and usually express social or political aspirations of what the future should look like. They need to be accompanied by firm, measurable objectives as in a marine plan and hence the success of marine management should be decided by the managers and stakeholders after scientific evidence which is generally a consensus among scientists regarding causality (for example, to achieve Good Environmental Status in the MSFD, Borja et al., 2013). In contrast, policy or regulatory evidence is generally a consensus among managers and stakeholders and both rely on a defendable view of the facts and uncertainties.

In being the source of the risks, the uses of and challenges to the marine ecosystem and its resources derive from the overall societal drivers, the activities and pressures, emanating both inside and from outside the management area. Part A therefore indicates the early stages of the DAPSI(W)R(M) framework and thus allows us to objectively address each of the D, A and P components.

4.2. Part B obtaining fit-for-purpose data and information

(3) Ecological Sub-system – underpinning marine management is the need for a good understanding of ecological structure and functioning which can be summarised as understanding three sets of relationships. Firstly, for creating and filling fundamental niches (the 'environment-biology relationships'), for example the waves, tides, geomorphology, salinity, temperature, etc., create a fundamental niche which then is available for colonisation by organisms. If the hydrographic conditions are suitable then, depending on their environmental tolerances, organisms will colonise the area and create the ecological structure (e.g. Gray and Elliott, 2009; Wolanski and Elliott, 2015). Secondly, once the biological structure (the community or assemblage at one time) is established then it becomes modified by internal functioning (the rate processes, what may be termed the 'biology-biology relationships'), for example by predator-prey relationships, competition, migration and recruitment, etc. Thirdly, there is the influence of the biota on the environment (the 'biology-environment relationships'); for example, the seabed biota can modify sediment structure (by bioengineer species) and water column organisms can modify water quality through respiration and excretion. Of course, there are many uncertainties with the direction and outcome of these ecological processes, both deterministic (such as the sediment type created by hydrographic forces) and stochastic, such as the outcomes of the net total of ecological interactions. This compounds the uncertainty of knowing the expected outcome of a management measure such as habitat restoration.

Superimposed on these environment and ecological relationships is the influence of anthropogenic pressures such as pollution, human-mediated species movements (such as introduced or alien species), or even ecoengineering to create or maintain habitats and restocking species, etc. (e.g. Elliott et al., 2016). Each of these requires management measures for the causes and/or consequences of the changes. Therefore, this sub-system determines the effects of the hazards and risks on the ecological structure and functioning, i.e. the sequence and adequacy of the science in determining State changes to the physical, chemical and ecological aspects of the ecosystem.

(4) Socio-ecological Sub-system – an effective ecological structure and functioning will then deliver ecosystem services (Turner and Schaafsma, 2015; Chicharo et al., 2015), such as the delivery of good water quality, healthy fish populations, seabed sediments suitable for aggregate extraction, etc. (see the model in Elliott et al., 2017a). The ecosystem services then create the means to obtain societal goods and benefits, after inputting human complementary assets and capital (natural, human, skills, built, economic, energy), which can then be valued in economic or cultural terms (Pouso et al., 2018, 2019). For example, a successfully functioning ecosystem will produce fish of the appropriate type, size and quantity but it requires the funding to build boats, harbours and restaurants and skill to catch and prepare the fish in order to obtain the societal goods and benefits. Any management system then needs an objective way of determining both the ecosystem services produced from the ecological structure and functioning and then the societal goods and benefits being derived from the ecosystem services. As an example of a method, Burdon et al. (2017) give a well-defined matrix approach as an objective way of obtaining and using the relevant information in this sequence.

Linked to DAPSI(W)R(M), this sub-system indicates the effects of the

State changes on the production of ecosystem services and in turn their repercussions for Impacts on human Welfare. In essence, such impacts represent the reduction or loss of societal goods and benefits resulting from the risks to the natural and human ecosystem.

(5) Socio-economic Sub-system – this includes both the macro- and micro-economic structures such as employment consequences, assets delivery and protection (Langeweg, 1998). Using cost-benefit and cost-disbenefit analyses, it considers which of the different groups of stakeholders benefit (and indeed, it should also catalogue those that do not benefit) from the management of ecosystem services and societal goods and benefits (Shaffer, 2010; Cormier et al., 2015). This sub-system should determine how the drivers (the basic human needs) translate into economic products and indications of well-being including how the societal assets and demands are delivered and protected. This can increase the Blue Economy through ecosystem services and societal goods and benefits then leading to increased employment, greater assets and the greater use of those assets in the sea and at the coast. It includes the ability to create an increased infrastructure and supply chain and hence there are repercussions for taxation and the overall output of per capita Gross Domestic Product and other Well-being Indices.

Permitting such wealth-generating activities relies on the science needed for the licensing system (Lillebø et al., 2017; Mulazzani and Malorgio, 2017). For example, this includes objectively determining the assimilative capacity of an area to encompass all the necessary and desired marine activities without having a deleterious effect on marine status and health (e.g. Elliott et al., 2018). In turn, this requires knowing the spatial and temporal effects-footprints of all the marine activities and pressures (Elliott et al., 2020).

(6) Resources and Delivery Sub-system – increasing our ecological understanding, monitoring the health of the system, and obtaining those societal goods and benefits, requires scientific resources and facilities, such as vessels, equipment and consumables, and skills, such as the expertise and ability to operate that equipment and interpret the data (similarly for social sciences such as economics). This needs an assessment of who does what and how they do it, and so it requires an adequate quantity and quality of personnel, and outcomes from training and Continued Professional Development. Excellent examples for this assessment of the science needs include the Baltic Sea BONUS programme (Snoeijs-Leijonmalm et al., 2017), the EU DEVOTES project (Danovaro et al., 2016; Patrício et al., 2016b), and the European Marine Board horizon-scanning exercise (Benedetti-Cecchi et al., 2018). Each of these indicates where science is needed, the adequacy of that science and the funding available. However, we are conscious of the decreasing science budgets and even what might be called the 'marine-assessment paradox' (that there are more requirements for marine monitoring but less funding for it) (Borja and Elliott, 2013).

Within the Part B of the proposed systems approach, it is possible to have an internal cycle, in which the manager starts with an assessment of what societal goods and benefits are required from the marine system, and then what ecosystem services are needed to provide those (Turner and Schaafsma, 2015). In turn, such an even more anthropocentric view would then need to know what physical and ecological science information is needed to quantify the produced ecosystem services. However, policy-makers will still have to be reminded that a healthy Blue Economy is dependent on a healthy ecology.

(7) Provenance Sub-system – this centres around both the ability to perform quality assured techniques (i.e. with standard operating procedures) and produce quality assured and controlled data, i.e. with suitable AQC/QA (analytical quality control and quality assurance). These and intercalibration exercises are imperative to ensure that the quality status assessments of all water bodies are comparable even if they have been derived through different assessment methods (Borja et al., 2008; Poikane et al., 2014). This has to be underpinned by fit-for-purpose science and hence we emphasise the separation between the *need-to-know* (i.e. what is needed for policy questions) versus the *nice-to-know* (i.e. our innate desire to try to understand everything about the system irrespective of whether the information is to be used in management).

As with any good science, it can be distilled into the aims of the research (the 'why', the big idea), the science objectives (what/how to reach the aims) and hypothesis generating and testing (the testable questions, usually with a statistical rigour, to indicate success). This in turn should ensure a defendable knowledge-evidence base of data, and their conversion to information and knowledge (i.e. *science-for-policy* and *policy-for-science*) and it will also enable/require a predictive approach (e.g. Peck et al., 2018). With regard to emerging forms of information, as well as conventional laboratory and field science, this should include traditional knowledge (i.e. indigenous knowledge) (Kaiser et al., 2019), but also citizen science generating knowledge (perhaps employing computer applications (apps) for biodiversity, alien species, pollution or litter tracking) (Crain et al., 2014; Vann-Sander et al., 2016; Addison et al., 2018).

Scientific data are not only required to support statutory instruments, such as setting licence and permit conditions, but as such are increasingly challenged in legal proceedings. For example, a legal challenge (court case) to a marine developer accused of damaging the environment due to their activity will centre on whether the developer can prove that they did not cause an environmental change or the statutory body (such as an Environmental Protection Agency (EPA)) proving that the developer did cause such an impact. It is axiomatic in environmental legal proceedings that, under the precautionary principle, the developer is required to prove that they did not (or will not) cause an impact rather than the EPA proving that the developer did (or will) cause the impact (e.g. Puig and Villarroya, 2013). As such, the debate often becomes a judgement between competing interpretations of scientific facts and opinion. Hence the need for rigorous quality controls on producing and using scientific information.

4.3. Part C the management and governance use of information

(8) Governance Sub-system – here governance is defined as the policies, politics, administration and legislation. Firstly, **(8A) the Legislative Sub-system** – the system of laws, regulations, statutes and agreements which constitute 'hard law' and 'soft law' – the former refers to legal obligations which are binding on the parties involved and which can be enforced in a court of law. Soft law refers to declarations, agreements and principles, even to treaties, which are not legally binding although they may involve a legally-binding arbitration (such as with the Regional Seas Conventions, e.g. OSPAR and HELCOM).

This sub-system centres on a vertical integration from local instruments and regulations, through national (e.g. Canadian, UK or Spanish Law) and regional statutes (e.g. Directives within the EU) to global initiatives (such as the UN Convention on Law of the Sea (UNCLOS), the jurisdiction of the International Maritime Organization and the Regional Seas Conventions) (e.g. Boyes and Elliott, 2014). It has to be noted that International (e.g. UNCLOS) or EU Law relates to the Member State, which, in the case of the EU, is placed in Infraction Proceedings (and could be fined) if a Directive is breached; in contrast, the national law relates to an individual or body (e.g. company) inside the country then being taken to the national court. Fulfilling the competing legislative requirements also requires horizontal integration in which instruments are coordinated across the sectors (fishing, aquaculture, sea-bed mining, navigation, etc.) (Boyes and Elliott, 2014). Hence, the horizontal and vertical integration should produce a holistic, coordinated legal system for managing the seas by merging legally-binding and non-binding instruments.

This plethora of legislation then requires **(8B) the Administrative Sub-system,** the national and regional bodies, agencies, departments, etc. to implement, enact and enforce the vertical hierarchy of legislation. As with the instruments under which they are constituted, these bodies (summarised as a management organogram, e.g. Boyes and Elliott, 2015) need to be coordinated and integrated horizontally to accomplish the vision and objectives described above, particularly across interested stakeholders (Stephenson et al., 2019). In many countries, marine administration is sectoral – one body for fisheries, another for nature conservation, a third for navigation, a fourth for land-based pollution and planning such as with aquaculture and so on. We note that very few countries have a single marine management organization which covers all of the sectors, hence the need for effective coordination between these bodies.

(8C) Communication and **(8D) Stakeholder Sub-systems** also require horizontal integration to achieve informed dissemination across the stakeholder typology (of formal and informal actors) (Mea et al., 2016; Newton and Elliott, 2016). The different types of stakeholders, firstly, are those creating the marine pressures (the 'inputters' and the 'extractors' – respectively those who put waste, structures, land-claim, etc., into the sea, and those who remove resources such as space, fish and shellfish, seabed and water, from the sea). Next, the 'regulators' include those who have a duty to control these potentially-damaging activities. The 'affectees' are the parts of society affected by these activities and regulations, either positively or negatively, and the 'beneficiaries' are those who benefit from the uses and users of the seas. Finally, the 'influencers' are the policy makers, politicians, educators, researchers and lobbying groups (e.g. environmentalists, conservationists) which attempt to control the behaviours of the other stakeholders (Newton and Elliott, 2016). It is of note that some bodies, such as a port authority or fishing cooperative, can be included in all of these types.

The Communication sub-system then contains all means of interpreting and disseminating the relevant information both within and between the various stakeholder groups. It also includes the means of advising those involved in taking decisions, whether the administrators or legislators, and those affected by the decisions, the whole of society. The '*science-to-science*' communication and the '*science-to-policy*' (and vice versa) communication each have their own methods and constraints – the former may be more formal (as journal articles, books, theses, symposia) and easier to measure whereas the 'science-to-policy' communication involves summaries of the science as well as more formal or informal dissemination (e.g. discussions and presentations by the scientists to administrators) (Snoeijs-Leijonmalm et al., 2017; Keller, 2009).

Mostly importantly, the communication has to be in the appropriate format, recognising that perhaps the general public, the policy-makers and politicians may want very brief information (sound-bites, headlines, tweets and one-page briefing notes). In contrast, specialists may create a large amount of (often unsuitable) material (theses, reviews, scientific papers, consultant reports) which then needs 'interpreting' and usually summarising for the public and politicians (the so-called 'dissemination diamond'; Elliott et al., 2017b; Rice, 2011; de Kerckhove et al., 2015).

It is frequently argued that different disciplines and different sectors are 'not talking the same language' (Ostrom, 2009), so an improved fit-for-purpose communication strategy between stakeholders will be needed to achieve conflict resolution and thus enable complementarity between stakeholders. The various stakeholders have to be included in all aspects and there should be feedback loops to ensure that they can receive information, act on it and have an influence (as in theory should be the case in all Environmental Impact Assessments; Glasson and Therivel, 2019).

(9) Achievement Sub-system – this will determine the success of the whole process by monitoring all stages of the DAPSI(W)R(M) framework - the number of activities, the levels of pressures, the changes to the natural state and the impacts on human welfare, and the efficacy of the management responses and the effectiveness of the measures in fulfilling human drivers. This will require the scale of achievement (both temporal and spatial) to be determined and should be based on SMART indicators, i.e. whether the desired outcomes are Specific, Measurable, Achievable, Realistic and Time-bounded (Teixeira et al., 2016; Cormier and Elliott, 2017). Given the business maxim that '*you cannot manage anything unless you can measure it*', it relies heavily on indicators for each component of the framework (Fig. 3). A rigorous assessment of whether the vision and objectives set for the management area are achieved is required to determine whether all the previous actions in the proposed approach have been achieved. It is emphasised here that all of these attributes, even if general, require indicators otherwise it is not possible to determine if the management has had the desired effect. For example, community structure requires indicators for the level of biodiversity (such as species richness, presence of alien species), human health status is now being determined through indices of welfare and well-being (Biedenweg et al., 2016; Breslow et al., 2016), and societal benefits can be measured in terms of the amount of cultural heritage, recreational opportunities and fish caught, among others.

(10) Feedback Sub-system – this will complete the management cycle and indicate the success of societal Responses (using management Measures) to problems controlling Drivers, Activities and Pressures to stop State changes and Impacts on human Welfare. It will focus on risk (and even opportunity) assessment and management (Cormier et al., 2018, 2019).

5. Fitting the proposed approach to sustainable Canadian and European marine management

In order to show that this is not merely an academic exercise but how the proposed system was derived and more importantly to show that such a systems analysis is implicit even if it has not been described or previously presented as such, we use the marine management features of Canada and the EU as examples (Table 2). In order to show that the approach works both with a single country and with a regional bloc of countries, here we centre (and uses as a contrast) on the modus operandi of Canada, as a separate country, and the EU as a regional bloc, complete with its own Member States (and their devolved countries in the case of the autonomous regions of Spain). The aim here is not to suggest that the EU legislation is directly comparable to that of a sovereign country such as Canada but rather that the same framework is applicable irrespective of whether we are dealing with a political and economic bloc (the EU) or an individual country. Table 2 aims to demonstrate the complexities of marine environmental management in the two areas and show the similarities between national law, regional directives and even conventions while understanding that they have different characteristics in terms of enforceability between countries, region to country, and country to the individual stakeholder. In the case of Canada, the laws and regulations will respectively indicate what is to be achieved and how. In the EU, the European Directives have the force of 'hard law' but usually require regulations in the Member States to be enacted as enabling legislation; transgressions are then reported to the European Court of Justice. The table also shows that a synthesis of all the elements

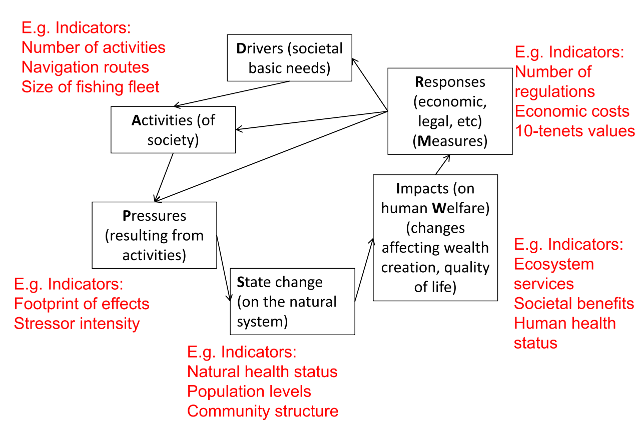

Fig. 3. Examples of quantitative indicators for each element of the DAPSI(W)R(M) framework.

Table 2
Comparison of European Union (EU) and Canadian approaches within the integrated marine management systems analysis.

Topic	Canadian context	European context
What is the overall framework used? (Underpinning framework sub-system)	In the marine environment there is the Fisheries Act, Oceans Act, Species at Risk Act and the regulatory framework of those acts together with other water quality, environmental protection and environmental assessment legislation.	Water Framework Directive (WFD), in transitional and coastal waters; Marine Strategy Framework Directive (MSFD), in territorial and Economic Exclusive Zones; Habitats Directive; Maritime Spatial Planning Directive (MSPD).
What is the overall vision and who derived it? (Issue sub-system)	Fisheries management and habitat protection policies are developed by designated administrations across jurisdictions under the mandates of each act such as the Canada Oceans Strategy creates the vision.	EU Integrated Maritime Policy, but also the basis of Regional Sea Conventions and Common Fisheries Policy. Important relationships with Biodiversity Strategy and Climate Change Policy. In recent times, also related to the UN Sustainable Development Goals.
How were pressures and activities prioritised? (Underpinning framework)	Based on the Acts and their policies, the relevant pressures and their human activities are identified and prioritised.	Mostly from the MSFD and MSPD, but also insights from Blue Growth Strategy, with the DAPSI(W)R(M) framework and its variants.
What ecological knowledge is required? (Ecological sub-system)	As with all marine areas, pathways of freshwater and marine effects caused by human activities and their demands on ecosystem services are used to identify the ecological knowledge required.	In transitional and coastal waters (WFD), five biological elements and supporting physico-chemical elements; in marine waters (MSFD), 11 qualitative descriptors (biodiversity, alien species, fishing, food-webs, eutrophication, seafloor, hydrography, contaminants (including seafood), litter, noise); Framework Programmes and Horizon 2020 have long been used to providing this information.
What is the socio-ecological knowledge and economics basis? (Socio-ecological and socio-economic sub-systems)	The administrations from individual jurisdictions acquire socio-ecological and socio-economic knowledge through formal and informal consultations with the public and stakeholders as well as scientific and technical advisory processes.	Uses and activities, as well as ecosystem services provided by sea, as creating goods and benefits for humans; relate to the Blue Growth and Blue Economy policies.
Who to perform the science and what resources are required? (Resources & Delivery and Provenance sub-systems)	The federal and province administrations have scientific and technical capacities and advisory processes to implement their respective programmes and regulatory processes to manage mandated human activities. This may also include academic and international subject matter experts.	The Member States and Regional Seas Conventions, through scientific experts, including international and national working groups on implementation, intercalibration (WFD, MSFD), monitoring, etc.
What preparation is needed for implementation?	Implementation of policies as well as regulatory and non-regulatory requirements are done though public consultation processes and ultimately through regulatory impact assessments.	Public consultation, development of Programmes of Measures, development of monitoring plans, environmental quality assessments every 6 years for the main assessment Directives (WFD, MSFD, Habitats and Species, etc).
What are the aims and objectives for science informing management and who checks they are achieved? (Achievement sub-system)	It is the administrations and stakeholders that formulate the questions to drive the aims and objectives of science in such processes. Academic research is conducted independent of the management process.	To achieve Good Ecological Status (WFD), by 2021, and Good Environmental Status (MSFD), by 2020 (in both cases, in cycles of 6 years); the designated competent bodies in each Member State are responsible but in coordination with the Regional Seas Conventions (such as OSPAR, HELCOM).
Who determines the evidence base and how? (Administration sub-system and Stakeholder sub-system)	Scientific advisory processes composed of scientists from administrations and academia review the scientific knowledge needed to prepare the advice to management and the stakeholders. The advice provided is based on the consensus of the scientist and technical experts that are part of the advisory processes. Evidence is determined through management and stakeholder processes within the context of the legislation and policies.	Scientific advisory processes, composed of scientific experts from Member States, Regional Seas Conventions, international organizations (e.g. International Council for the Exploration of the Sea (ICES)), the Joint Research Centre (JRC), as well as European research projects (Framework, Horizon, 2020).
What is the legal basis, what laws and agreements are needed (national and regional level)? (Legislative sub-system)	For example, the Fisheries Act, Oceans Act, Species at Risk Act and the Canadian Environmental Protection Act and their regulations provide the legal authority to manage human activities in the marine environment as well as enter into agreements with other jurisdictions, organizations and commissions to manage human activities and coordinate implementation through respective authorities.	For example, via the WFD, MSFD, MSPD, Habitats Directive, Regional Seas Conventions, and then to the Member State Regulations and Agreements.
Who will administer the legislation? (Administrative sub-system)	Mandated departments at federal and province level administer programmes and regulations needed to implement their respective legislation.	The European Commission, European Parliament and then through enabling legislation to the Member States.
How are stakeholders involved? (Stakeholders	Through informal and formal consultation	Through public participation, especially

(continued on next page)

Table 2 (*continued*)

Topic	Canadian context	European context
and Communication sub-systems)	including advisory boards and committees at federal and province level.	in the EIA Directive, and the parliamentary process.
What indicators are used and how were they decided? (Achievement sub-system)	Indicators are developed through scientific and technical advisory processes within the scope of the legislation and the questions asked by management and stakeholders.	Building on expert working groups, the European Commission provides a decision and guidelines on the criteria to be followed. Each Member State can use their own indicators, but some guidance on primary and secondary indicators is provided. Also, the Regional Seas Conventions have their own core indicators. The European Environment Agency also develops indicators that can be used across Europe, to ensure a certain harmonization.
What monitoring takes place and who does it? (Provenance and Resources & Delivery sub-systems)	Legislated and regulatory monitoring is conducted by the mandated administrations at federal and province level. Monitoring of ecosystem trends and status are conducted by the mandated administration in collaboration with academia and interest groups; developers are legally-bound under permitted activities.	Each Member State decides on the monitoring effort. It should be coordinated at regional or subregional level with other Member States. Within a Member State, companies and individuals are responsible under national law and regulations and under the sanction of the national courts.
How is success defined and by whom? (Achievement and Feedback sub-systems; Governance composite sub-systems)	Success is defined by performance evaluation of programmes conducted independently by an administration or a commission. Success is also ascertained through consultation processes	The European Environment Agency, JRC, and the European Commission report on the achievements, after each reporting period; fulfilling the Directives uses the European Court of Justice as the ultimate arbiter.

in the systems analysis approach encompasses the complex nature of marine resource protection and access but also that there are analogous approaches, mechanisms and instruments in both cases.

As indicated in Table 2, the systems analysis proposed here is underpinned by the Part C (input into policy and decision-making) and hence the suggestion that this may be the start or the end of the cycle, i.e. the starting point of the cycle is either from the vision and issues created (a bottom-up approach) or the law imposed (from the top-down). This emphasises that it is the parliamentary processes that enact laws that express the collective aspirations of society, as for example sustainability and development goals, both in Canada and the EU. Parliamentary and other elected members represent the values and concerns of their constituents which also defines the authority for the Executive branch to govern. The Executive branch governs through mandated administrations (i.e. the competent authorities such as Environmental Protection Agencies and nature conservation bodies) to administer the necessary programmes and policies within the scope of the law. Through the competency afforded by the laws and regulations, the Executive can implement regulatory frameworks to regulate the individuals and their activities. In most administrations, the regulator (a person or body) has the competence to administer the regulatory framework by issuing licences and permits. In cases where non-compliance to a regulation is ascertained by a regulator, it is the judiciary that determines the level of enforcement needed based on the charges brought by the regulator – hence the importance of enforcement in marine management (Agardy et al., 2011; Katona et al., 2017). Again, the ultimate enforcement is through national laws (Canada) or the European Court of Justice. In Canada, there is a separation of power between the Federal Government and the Provinces and Territories where fisheries including fish and fish habitat concerns fall under the Federal authority while freshwater fisheries are delegated to the Provincial and Territorial jurisdictions. In the case of the EU, the different directives provide a general framework, which is further developed and adapted to the national needs by Member States. However, EU Member States are required to collaborate within each regional sea (i.e. Baltic Sea, Atlantic Ocean, Mediterranean Sea and Black Sea), as well as to follow common guidelines to ensure harmonization among states (European Commission, 2017, 2018; Cavallo et al., 2019). The EU MSFD in particular is implemented via the Regional Seas Conventions (RSC).

In Canada, the Fisheries Act and the Oceans Act have different roles. The Fisheries Act provides the authority to establish measures to manage fisheries and to conserve and protect fish habitat from human activities. It has enforceable prohibitions regarding fish and fish habitat protection and pollution prevention with the authority to set conditions and regulations for works, undertakings and activities. The Oceans Act defines the Canadian maritime zone and facilitates the development of ocean management strategies, integrated management planning and the designation of marine protected areas. It does not have any prohibitions and can only enforce its own regulations as in the case of a Marine Protected Area.

In Europe, the overarching initiative is the Integrated Maritime Policy (IMP), which is based upon developing international consensus on integrated ocean governance (Koivurova, 2009). The IMP appears to be the first-ever social experiment in integrated ocean policy where the governing entity is a supranational organization. Under this umbrella, the MSFD can be seen as the 'environmental pillar' of the marine policy, whilst the Maritime Spatial Planning Directive (MSPD; European Commission, 2014) is the 'socio-economic pillar', linked to Blue Growth. Additional strategies (the Common Fisheries Policy, Biodiversity Strategy, etc.) are directly or indirectly linked to the IMP and the mentioned directives, in order to achieve the objective of a Good Environmental Status, by 2020.

Scientific research or changes in ecosystem services may influence public opinions regarding the marine environment. In turn this can drive the Executive via the statutory authorities to take regulatory actions that are provided by the legislation or drive the legislative branch to amend existing laws or enact new laws to address the public concerns. In doing so, scientific advice may be initiated to inform the regulatory or legislative processes. International agreements and conventions can also drive the executive and legislative branches to act, hence the importance of vertical integration of legislation.

6. Discussion

6.1. Implementing the proposed systems analysis approach

This paper reflects the first stage in implementing the systems analysis approach by setting the questions and problems which need to be addressed and defining the framework based on previous experience and knowledge. The second stage will be to operationalise and refine the approach with real case-studies. In building on experience, it is shown that the systems analysis approach in ecology has developed from earlier works (Langefors, 1973; Reichle et al., 1973) linking systems to ecology as networks, pathways and vectors of causes, effects or risks which lead to the operational controls to prevent something. In leading to operationalising the framework, these approaches have been expanded to include Bayes and decision/management theory (and other techniques indicated below) and together indicate the intent of the systems analysis, i.e. (with techniques examples and topics):

1. A communication network of linked nodes showing communication exchange or transfer of energy (Ecosystem or social systems);
2. A process system of input and output between nodes starting with an initiating node and ending with one node as the product (such as a 'Fishbone diagram');
3. A system of pathways of risk of cascading events (nodes) starting with root causes and ending with multiple endpoints (Vector analysis, fault tree or event tree analysis);
4. A logic model of policy integration linking outcomes to objectives to goals to vision (Logic models) (management);
5. An organizational diagram of roles and responsibility (organizational chart) (governance);
6. A system of management controls preventing the root causes of an event (node) and the mitigation and recovery controls if the event occurs (HACCP, Bowtie diagram) (regulatory).

These topics all give techniques which can then be built into the proposed systems analysis to lead to an integrated and achievable framework. Given that all of these techniques and all the elements of the framework mentioned above exist then combining them into a decision support system (DSS) is the logical next step. The DSS would relate to a hierarchy in that culture drives society which then drives policy which in turn drives the regulatory system, i.e. culture indicates to society to decide what type of environment it wants and then society has to encourage the policy makers and politicians to bring in controls to regulate the environment (Fig. 4). Of course, this could imply that each informs the other independently from one another but the cyclical approach given here suggests that there should be interdependence amongst the various elements of the approach. Societies depend on cultural groupings and policy only exists because society understands the need to survive with limited resources and to partition those resources (as is implicit in basic human needs as Drivers). Regulations only exists because the policy cannot be implemented on its own without controlling our actions. If not, a group or person would naturally continue to compete blindly for resources with the all the others until

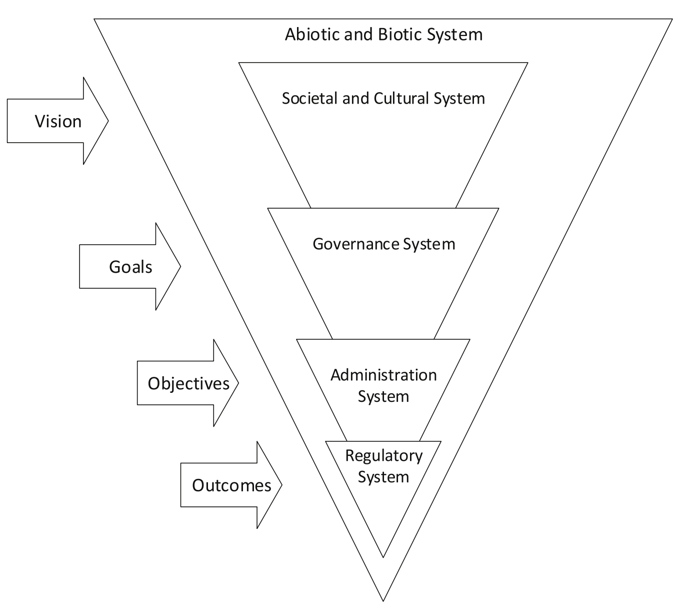

Fig. 4. The reactive management strategy as a reverse triangle, showing that the pressures from societal and cultural visions are contextualized by governance policy, scoped by administration objectives and regulated by regulatory frameworks.

the resources have gone (e.g. 'the tragedy of the commons', Ostrom, 2009).

The proposed marine approach presented here is deliberately a very anthropocentric view, in which the ecosystem responds to the pressures while maintaining balance, and where the societal aim is to manage the human activities and their pressures on the marine environment to extract the resources but minimize state changes or tipping points (Horan et al., 2011). Indeed, we emphasise that the framework needs to succeed at '*managing people rather than managing the environment*'! The word 'impact' assumes that pressures will cause a harmful change while in fact the pressures simply alter habitats and start biotic reactions. The policy response implies that we know what pressure could cause a harmful effect on the natural or human systems and we have strategically planned a response. Although policy should reflect a proactive management strategy, experience tells us that more often a reactive management strategy of mitigation and rehabilitation of ecosystems is used (Cormier et al., 2016). The main outcome of the proposed framework is in knowing what the management response should be before the human activities and their pressures are sanctioned and the monitoring has started. Here, true monitoring should be related to the defined end point of change, as an indicator of the efficacy of the associated management response(s) (Elliott, 2011).

As indicated above, it is not the aim here to rigorously compare and contrast the marine management approaches which have been proposed over the years. Despite that, and contrary to similar recently-produced management approaches (Stephenson et al., 2019; Støttrup et al., 2019) and those produced a decade ago (Ostrom, 2009, 2011), the proposed system here gives equal weighting to all elements and to both the natural and social sciences; furthermore, and again in contrast to Støttrup et al. (2019), it emphasises that there is a logical and chronological sequence which should relate to a set of accepted questions (Table 1).

Furthermore, whereas Støttrup et al. (2019) suggest that the whole system should be tackled holistically without separating it into the constituent parts, here we take the view that this is not possible nor the way in which the governance and management systems mentioned above work. In particular, a system map is essentially a description of a network of nodes very much as a network of organisms in a food web. Sustainable management relies on good, robust, hypothesis-driven science (with testable questions) (Part B) framed by the policy questions (Part C) which are both informed by and inform the issue definition (Part A). It is of note that the IAD (Institutional and Development Framework) of Ostrom (2011) sets the groundwork for successive social-ecological systems and in turn the systems analysis proposed here but it focussed mostly on the C sector and components and to a lesser extent on the A sector and did not consider in detail the B sector; it especially focused on what the 'actors' (stakeholders) do.

Furthermore, system mapping aims to link the nodes of the system and, as proposed here, it shows the links which are likely to be sequential. Management and operational controls require a critical path showing their influence leading to strategic planning to achieve the objectives to reach the goals within the context of the vision. However, compared to mechanistic approaches used in ecosystem modelling to predict effects, such a system cannot predict what the management or operational response could be. Science can only offer options that can attempt to predict the outcomes (with the associated uncertainty) but cannot predict what management will do, as such this is currently a limitation of systems and modelling thinking in planning and policy-making.

6.2. The importance of timing in the systems approach

The proposed framework has to respond to the sequence of activities, their pressures, their consequences and the required responses, each of which operate on different timescales. The biotic ecosystem processes continuously respond and evolve to changing abiotic environmental conditions that can span decades through a succession of state changes and natural selection. Cultural systems also adapt to those changing environmental conditions and both systems co-evolved as the pressures generated by human activities could be assimilated by the ecosystem. An increase in human activities and their pressures has increased the frequency and magnitude of state changes at a rate that surpassed adaptation capacities and required improved management responses. Governance addresses cultural values and societal visions through policymaking and setting longer-terms goals and may mandate administration systems to set shorter-term objectives within the scope of these goals through planning; for example, in the UK the high-level 25-Year Environment Plan appears aspirational which then needs translating into policy action (https://www.gov.uk/government/publications/25-year-environment-plan). Under such objectives, the regulatory systems establish the expected outcomes to regulate in the immediate term the relevant human activities and their pressures to avoid or mitigate the state changes. Even though cultural values are the basis for freedom of individuals and communities, society ultimately has to understand the need to regulate its activities and their pressures to ensure that the ecosystem services and societal goods and benefits are maintained. The proposed approach here should ensure that the provenance and adequacy of the information produced (Part B) are suitable for management but it is questioned whether the public can cope with uncertainty and/or whether science can communicate it.

If the cycling of Parts A to B to C is repeated, the policy-science or science-policy interface should ever-improve with a focus on controlling impacts as the ultimate goal and expecting that policies and regulatory frameworks will achieve the desired effects. Achieving this lay in the need to analyse the pathways of risk to develop management and operational controls processes (i.e. a business process). For example, as shown in Table 2, in Europe, this starts with a policy question (MSFD), then determines what science is needed and how (via 11 qualitative descriptors to be assessed) and then how to measure and determine these are met (by indicators) (Borja et al., 2016a; Teixeira et al., 2016). However, the Member States have to implement the programme of measures through their regulatory frameworks to manage the human activities and their pressures through licencing and permitting to reduce the effects and to achieve Good Environmental Status (Cavallo et al., 2018). As shown in Table 2, it is notable that through a series of interlinked Directives (legal instruments), all the parts of the framework proposed here are given even if they are not yet formally linked into a unified holistic system. Similarly, the description of the marine management for Canada shows that it also has all the elements of the systems approach but again these have not yet been linked in a unified decision support framework. The adoption of the framework proposed here would create a decision framework whether for a single country or a bloc of countries.

As emphasised here, the governance-policy interaction (Part C) both drives and is driven by the whole process ('the carrot and the stick approaches') where governance is defined as the sum total of policies, politics, legislation and administration. The elected, parliamentary processes sets government priorities and the law from the goals, rationale and even the direction that should reflect societal wishes (hence the Framework Directives in the EU; Borja et al., 2010). The elected members represent the views of their constituencies and hence should include several or all stakeholder types (Newton and Elliott, 2016).

The term 'management system' implies that legislation scopes what is to be achieved and that the legislation also identifies the competent authority who will make the decisions regarding (and be responsible for) the applicability of that legislation to a given situation. Most countries have separate competent authorities for each sector (fisheries, energy, navigation, etc.) (Boyes and Elliott, 2015) and hence the challenge is to harmonise these thus vertically and horizontally integrating the governance. In turn, the communication sub-system allows consultation amongst those that have an interest (all parts of the stakeholder typology) although the consultation is often not used to draft the policy interpretation but rather determine the repercussions of the interpretation.

The competent authority has to implement the legislation although it could amend policy interpretation as necessary, even though the latter may be more static. Here is where the concepts of precaution and adaptation can be integrated in evolving policy interpretation as new information appears (scientific, cultural, social, economic and legal). The proposed systems analysis ensures that the operational aspects delegate the authority to sign or issue approvals via authorizations, licences or permits. These authorizations are then agreed between the operators (the inputters and extractors) and regulators (in the stakeholder typology) but require the information and data provided by Part B of the approach and, in most cases, such as within Environmental Impact Assessments, consultation and communication with all stakeholders.

6.3. Achieving the proposed approach and implementing the responses (using management measures)

In order to ensure that the systems analysis approach can be achieved for sustainable management, the type of science advice required will differ greatly across the governance, management and operational systems. That science will emanate from Part B and above all needs to be fit-for-purpose. Science advice at the governance system level will mostly be knowledge-generated through research as inputs into the goals (Fig. 5). As shown by the combination of elements both for the EU and for Canada, the rationale and directions being considered by the European Commission and government and civil service respectively (the policy-makers) will, for example, reflect environmental concerns. A formal scientific advisory process will allow the necessary debate among scientists (hence the 'influencers') as to the pertinence (rather than just the validity) of the current scientific understanding to the concerns raised. The term 'normative science' is used here to represent the required information (being created and analysed) to fulfil a stated or assumed policy or other outcome (Röckmann et al., 2015; Rice and Rochet, 2005).

Science advice to management will need to validate the policy interpretation and the potential outcomes of the courses of action enabled by such interpretation. As shown in Table 2, both the EU and Canada have many points where the science information is linked to the development and achievement of policy. This includes the science of assessments and predictions that indicate potential impacts, for example defining thresholds as targets, environmental quality standards or tipping-points (e.g. Borja et al., 2012; Rossberg et al., 2017; Lauerburg et al., 2019). The science advisors, often through large integrated projects such as DEVOTES (Borja et al., 2016b, 2017) and VECTORS (Austen et al., 2018) can deliver the information but then it requires to be acted on – often a more difficult challenge (Snoeijs-Leijonmalm et al., 2017). This emphasises the importance of getting the advice in the appropriate format, at the right time and through the appropriate channels (Elliott et al., 2017b; Cavallo et al., 2019).

Science advice at the operational level will need to validate the technical design of the conditions or measures with which the regulated party will have to comply in order to conform with both the policy interpretation and the legislation (i.e. an industry is given a licence to operate which indicates the monitoring required and the science reasons for this). There is the need for 'technical measures' in regulatory frameworks, hence the importance of technology as well as the other 9 parts of the 10-tenets approach (Barnard and Elliott, 2015). Here the science and technology have more to do with effectiveness such as reducing a pressure to an acceptable residual level. This relies on how good is the definition of an activity-footprint, a pressures-footprint and an effects-footprint (Elliott et al., 2018, 2020). Such a science advisory process informs management of what could happen while the communities of interest provide feedback as to what should be done. When science moves into a debate as to what should be done, the scientist

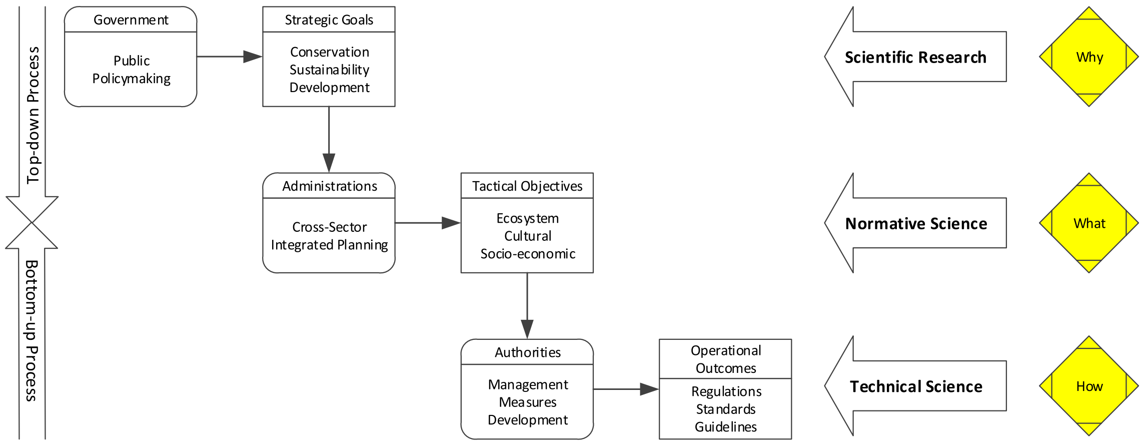

Fig. 5. The top-down and bottom-up input of science advice to inform the management process in which strategic goals set the top-down context to develop the tactical objectives that will be used to scope the operational outcome for the management measures to be implemented. However, it is the implementation of the management measures that provides the bottom-up approach to produce the outcomes to achieve the objectives and reach the goals (adapted from Cormier et al., 2017).

becomes another stakeholder that perhaps does not carry any greater weight than any other stakeholder.

The actual measure to achieve an unimpacted (or at least a functioning) ecosystem could involve engineering or ecoengineering or economic or legal instruments; for example, marine science may be able to set the effectiveness parameters for a given allowable residual pressure (i.e. what pressure is allowed before the system reaches its assimilative capacity, Elliott, et al., 2018). The engineering (e.g. a pollution-reduction technique) is required to determine the best controls and measures to feasibly meet the allowable residual pressure (i.e. the BPEO, Best Practicable Environmental Option) (e.g. MEMG, 2003; Sharma, 2017). However, this is complicated further as ecosystems, and particularly complex marine ones, have a degree of what has been termed 'environmental homeostasis' i.e., that they can absorb change (Elliott and Quintino, 2019), thus related to the assimilative and carrying capacities of a sea area (Elliott et al., 2018). In environmental management, it is assumed, through the precautionary approach, that a pressure will lead to a state change and an impact on human welfare; for example, it is assumed that scraping the seabed with a trawl will kill or dislodge benthic species but, despite that, benthic species are constantly dislodged by storms or killed by many causes. Hence, the ability to absorb change may mean that this sequence cannot be assumed to occur (and even more so if mitigation measures are put in place) (Cormier et al., 2019). In a marine area, mechanistic and deterministic processes in the ecological system and stochastic processes in complex socio-ecological systems mean that the certainty of response cannot be predicted, hence the need to adopt the precautionary approach based on avoidance and prevention measures (e.g. Cormier and Lonsdale, 2019). It is also necessary to question whether management can cope with both such a flexible system and a precautionary approach – i.e. by assuming that there is a problem that has to be tackled even if it is not possible to see the problem.

6.4. Final comments

The systems analysis approach proposed here shows the complexity of the science-policy links and the role of all the stakeholders. Each of the sub-systems is underpinned by further conceptual models which in many cases (e.g., the ecological structure and functioning) are informed by empirical evidence. We make no apologies for the complexity of the proposed approach and indeed take the view that other similar systems are of value but do not encompass all the necessary facets of the science and policy components.

We recognized that there are uncertainties and challenges in carrying out the approach especially as environmental and biotic ecosystem components and processes follow a mix of mechanistic and non-linear interaction and responses to disturbances from human activities. However, it is much more uncertain if not unpredictable what the specific policy or management approach should be given the complexity of the cultural, social, and economic interactions that drive policymaking from governance processes, policy objectives from management processes or standards and codes of practices from regulatory and non-regulatory processes based on ecosystem tipping points or regime shifts.

As shown by the information for Canada and the EU and the references and experience given here, we take the view that the approach is not an academic exercise but is underpinned by all the relevant tools and experience. Indeed, we emphasise that each subsystem is already in place although there is the particular need to further coordinate and integrate them. We emphasise that although it may be regarded as a personal view, the system proposed has been developed as the result of several decades by each of the authors working not just on academic aspects of marine management but also working within marine management regulatory and monitoring organizations. As shown in Table 2, all of the elements are in place for an example of both a country and a bloc of many countries and so there is the opportunity to link these in a decision support system to achieve successful and sustainable management of marine resources. Accordingly, we emphasise that the approach here is proposed in order to be tested on wider systems in order to achieve such an overall aim. While Ostrom (2009) lays the foundation for a holistic and integrated framework such as that proposed here and those other schemes referenced in the current paper, it has required the developments in the intervening decade to provide a detailed recipe showing that all the elements exist and are ready to be linked into a framework for use in marine areas. It is suggested that the current scheme has now given that detail and proposed a recipe for testing on marine areas to ensure the sustainable marine resource management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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