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Putting on a bow-tie to sort out who does what and why in the complex arena of marine policy and management

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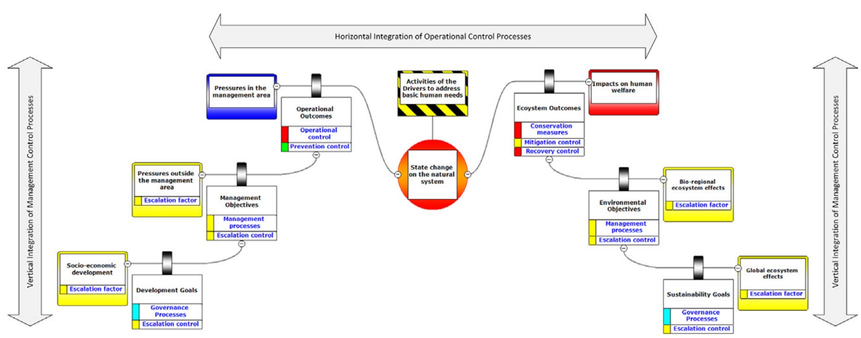
HIGHLIGHTS

- Marine risk management aims to achieve a vision and objectives through measures.
- Operational controls effect marine environmental policy objectives.
- Successful outcomes of sector and conservation controls need horizontal integration.
- Marine management needs vertical integration of outcomes, objectives and goals.
- Stakeholder roles have to be aligned with the horizontal and vertical processes.
- Integration of ISO standards into marine and coastal management is important.

GRAPHICAL ABSTRACT



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ABSTRACT

Marine policy and management has to cope with a plethora of human activities that cause pressures leading to changes to the natural and human systems. Accordingly, it requires many policy and management responses to address traditional, cultural, social, ecological, technical, and economic policy objectives. Because of this, we advocate that a fully-structured approach using the IEC/ISO 31010 Bow-tie analysis will allow all elements to be integrated for a cost-effective system.

This industry-standard system, described here with examples for the marine environment, will fulfil many of the demands by the users and uses of the marine system and the regulators of those users and uses. It allows for bridging several aspects: the management and environmental sciences, the management complexity and governance demands, the natural and social sciences and socio-economics and outcomes. Most importantly, the use of the Bow-tie approach bridges systems analysis and ecosystem complexity. At a time when scientific decisions in policy making and implementation are under question, we conclude that it provides a rigorous, transparent and defendable system of decision-making.

1. Introduction

The intent of the ecosystem approach is to ensure a coherent and integrated management of human activities to achieve desired objectives and reach societal goals in line with prevailing governance processes

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and the stakeholder consensus (Cormier et al., 2017). Even if many of the objectives are social and economic and not about the state of the ecosystem itself, delivery of social and economic goods and benefits depends on the sustained provision of ecosystem services (Elliott et al., 2017; IPBES, 2018). Thus, the ecosystem approach requires methods that should manage human activities to protect and maintain the ecological structures and functions while ensuring that the ecosystem continues to provide those ecosystem services and deliver societal goods and benefits (Elliott et al., 2017). Similarly, even if each sector is applying an ecosystem approach to achieve only sectoral goals, their achievement requires coherent measures and integration of management actions across sectors[1] (Garcia et al., 2014; IPBES, 2018). This article aims to show how an integrated and coherent framework for marine environmental management can be achieved despite the plethora of activities, uses and users, regulators and governance instruments and stakeholders and their interests.

For the marine environment, the ecosystem approach must be achieved through a background of extensive legislation, regulations, policies, standards and guidelines that are now used to manage all human activities (e.g. see the 'horrendograms' in Boyes and Elliott, 2014, 2015). Public perceptions of the causes of environmental change have driven our policymaking governance processes to adopt a plethora of complex management systems and processes dealing with human activities and environmental concerns (Lonsdale et al., 2017). These have generated sector-specific and ecosystem-specific legislation and policies, albeit largely independent from one another, for example fisheries or nature conservation (Garcia et al., 2014). Because of this, many management and conservation approaches have not produced adequate integrated frameworks for managing activities (Jameson et al., 2002; Ricketts and Hildebrand, 2011; McDorman and Chircop, 2012; Baker and Harris, 2012; Mach et al., 2017). Furthermore, the complexity and fragmentation of these management systems is considered a problem (Sardà et al., 2014; Alexander et al., 2015; Diehl et al., 2015) and made even more complex as not all so-called management tools actually manage an activity (Jessen, 2011; O'Boyle and Jamieson, 2006; Elliott, 2014; Cormier et al., 2017).

Even the term management can be confusing (Chun and Rainey, 2005; Loehle, 2006; Mingers and White, 2010) – it may refer to managing governance or planning processes, managing specific human activities, managing classes of pressures or stressors collectively, delivering desired results, or limiting impacts on the environment through management actions. It may aim to ensure coordination between authorities and jurisdictions as well as communication and consultation processes to engage stakeholders (Long et al., 2015; Creed et al., 2016). Thus the confusion can arise from mixing considerations of environment-management in contrast to people-management-measures adopted to guide human behaviour to produce the desired environmental outcome.

This confusion also arises through the use of other terms such as ecosystem assessments and environmental monitoring. Both are used to inform and show possible effects of management decisions and actions, although assessments and monitoring do not in themselves manage human activities (Browman and Stergiou, 2004), i.e. monitoring marine environmental quality only provides information to assess if management decisions are needed or are working. We often refer to environmental management as habitat compensation, offsetting, restoration as well as invasive species eradication; these are mitigation and remediation measures used to recover ecosystems from the damages caused by human activities whereby the measures do not manage the human activities *per se*. Although the form and magnitude of environmental changes are strongly influenced by past human activities making the measures necessary (Jones, 2016), the expected benefits from that remediation can be easily undone by other human behaviours not compatible with achieving the desired objectives. Hence, the links to managing human behaviours are pervasive, whether the 'management' intentionally focuses on the human behaviours or on the outcomes of those behaviours.

This confusion increases when the effectiveness[2] of the environmental management measures are not assessed appropriately. Consequently, management success typically is determined not by actually assessing the effectiveness of those measures in producing the intended outcome, but by monitoring the state of environmental variables relative to established thresholds or targets and inferring that deviations reflect ineffective measures (Noble and Birk, 2011; Cormier and Elliott, 2017). Conclusions may be wrong or misleading as the overall environmental status is the sum of the collective pressures and their measures superimposed on natural processes (Stelzenmüller et al., 2018). Failure to assess accurately the effectiveness of measures increases management shortcomings, firstly, by perpetuating inadequate measures which do not suitably change behaviour and sector practices to reduce collective pressures and reach the intended environmental outcome, and, secondly, possibly allowing an effective measure to be abandoned because some other factor is impeding achievement of the desired outcome. In addition, changes to the management of one activity can have unintended consequences for the effective management of other activities given the complexity and frequent lack of coherence between sector and conservation management systems (Boyes et al., 2016). For example, managing fish stocks to reduce the impact on non-target species may adversely affect seabird populations dependent on fish discarded as bycatch.

Although developing environmental goals and objectives is most effective if underpinned by scientific advisory and stakeholder engagement processes (Burgess et al., 2016), an operational-centric approach is needed to achieve the goals and objectives in an ecosystem approach (Gavaris, 2009; Murawski, 2007; Cormier et al., 2017). In organizational management (Anthony and Dearden, 1980; Chenhall, 2003), management control processes set objectives and manage the operations of the organization to reach the goals established by governance (e.g. integrated coastal and oceans planning processes, policies, politics, administration and legislation that set environmental objectives for a management area). As goals and objectives are intended to guide behavioural changes, operational control processes ultimately implement the controls needed to produce the expected outcomes that in turn achieve those objectives (Girling, 2013; Green, 2015; Hupe and Hill, 2016) (e.g. effluent discharge conditions in a pollution control permit). Operational controls are specifications, procedures and tasks that manage the daily activities of a given sector. For example, the programmes of measures implemented by Member States for the European Marine Strategy Framework Directive (MSFD) (EU, 2008) define the expected outcomes to achieve a Good Environmental Status within the overarching joint goals of the sustainable use of the seas and conserving marine ecosystems (Borja et al., 2010).

There is now substantial attention to vertical integration and coordination of development policies and sustainability policies, i.e. from local through national to international levels and vice versa. This paper explains the joint need for a horizontal integration of operational controls and conservation measures across sectors. We further explain why the Bow-tie analysis of IEC/ISO 31010 (IEC/ISO, 2009), one of the risk assessment techniques of the ISO 31000 risk management standard (ISO, 2018), is and efficient method well-suited to this role. We emphasise the value of the risk management process of ISO 31000 given that an analysis of the measures and actions is needed both to reduce the risks and horizontally to integrate operational controls and conservation measures. The Bow-tie analysis is also promoted here with the further benefit to analyse international conventions, legislation and

[1] Here, a sector is taken as a broad group of activities reflecting marine uses and users such as fishing, navigation, shipping, energy, etc.

[2] Effectiveness is the inherent capacity of a measure to reduce a pressure as specified at the outset.

regulatory practices to better understand the vertical integration of such policies including risk assessments.

2. Source of the problem

Ecosystem and environmental policy objectives may be prevented from being achieved due to the sectoral operational controls not being designed to achieve ecosystem scale outcomes, or not being implemented effectively (Groeneweg et al., 2003). Sector activities and their generated pressures are mostly managed independently (non-coordinated) to achieve sector objectives as required by the legislation and regulators (Sardà et al., 2014). For example, countries often have one agency and legislation to manage fisheries and another to manage conservation (Boyes and Elliott, 2015). Individually, the sectors may fully conform to their own operational standards and regulatory requirements but that does not constitute integration between sectors (Garcia et al., 2014). For example, in the early 1990's, Canadian water quality guidelines and pollution regulations were developed to limit toxicity to fish adjacent to an activity (CCME, 2007). Despite the best intentions, these guidelines could not achieve the intended prevention of the effects of nutrients at an ecosystem scale, as the activities increased in number and scale over time (Creed et al., 2016). When developed, the guidelines did not consider catchment and diffuse nutrient loading of estuaries and eutrophication effects.

Even when the sectors are effectively regulated to keep within their own regulatory requirements, the suite of sector legislation and policy objectives may not be fit for purpose when considering broader ecosystem and environmental policies (Boyes et al., 2016; Cormier et al., 2018). Instead of a lack of legislation, regulations or standards, the problem may be caused by a lack of coherence and alignment between sector operational practices and environmental legislation and policy objectives (Behn, 2003; Baehler, 2003; Ferreira and Otley, 2009; Cavallo et al., 2018).

An additional challenge arises when ecosystem objectives may not be achieved because the selected protection and conservation measures, such as designating a marine protected area, did not consider all of the pressures or natural processes affecting ecosystem components and functions (Agardy et al., 2011; DFO, 2011, 2015; Mach et al., 2017). A marine protected area is only a spatial measure that can offer protection to habitat components and features, especially sedentary species, which support ecosystem functions. The arrival of invasive species, a change in the water quality, the introduction of contaminants and noise from outside the protected area can cause unforeseen changes that were not, at the time the MPA was designed, considered and assessed. As with sectoral legislation and policies, protection, conservation and management also need a coherent approach and measures, especially for highly mobile migratory species such as seabirds and cetaceans. Achieving this coherent approach requires that all relevant pressures generated by human activities to be identified. A comprehensive suite of environmental targets, environmental quality guidelines and supporting measures in addition to protected areas should be implemented to achieve ecosystem objectives and services, to deliver societal goods and benefits and to provide environmental policies which encompass the intrinsic value of nature.

National legislation and policy are guided by international agreements, conventions and protocols (Rice, 2014; Cormier and Elliott, 2017). National governance should ensure vertical integration by adopting the goals and objectives of international conventions into national legislation and eventually into management processes and regulatory approvals. Coordination and integration of management policy objectives (Fig. 1) should provide the necessary horizontal integration of development and sustainability goals and objectives to guide the implementation of the so called ecosystem approach. With such horizontal integration in place, approval of development projects (e.g. the building of a new coastal power plant) would only be done when nature conservation was also ensured (O'Boyle and Jamieson, 2006; Hall et al., 2011).

Regulatory planning and approvals for land-based and sea-based development activities (e.g. wastewater outfalls) are conducted independently from the ecosystem outcomes required for conservation measures (e.g. marine protected area processes) (Jessen, 2011; Ricketts and Hildebrand, 2011; Salafsky, 2011). Environmental impact assessments of development projects inform competent authorities and the public of the potential impacts of the project (Lonsdale et al., 2017). Regulators subsequently use these assessments to identify the operational controls that are enforced such as licensing and permitting conditions to mitigate the potential impacts, but only relative to the

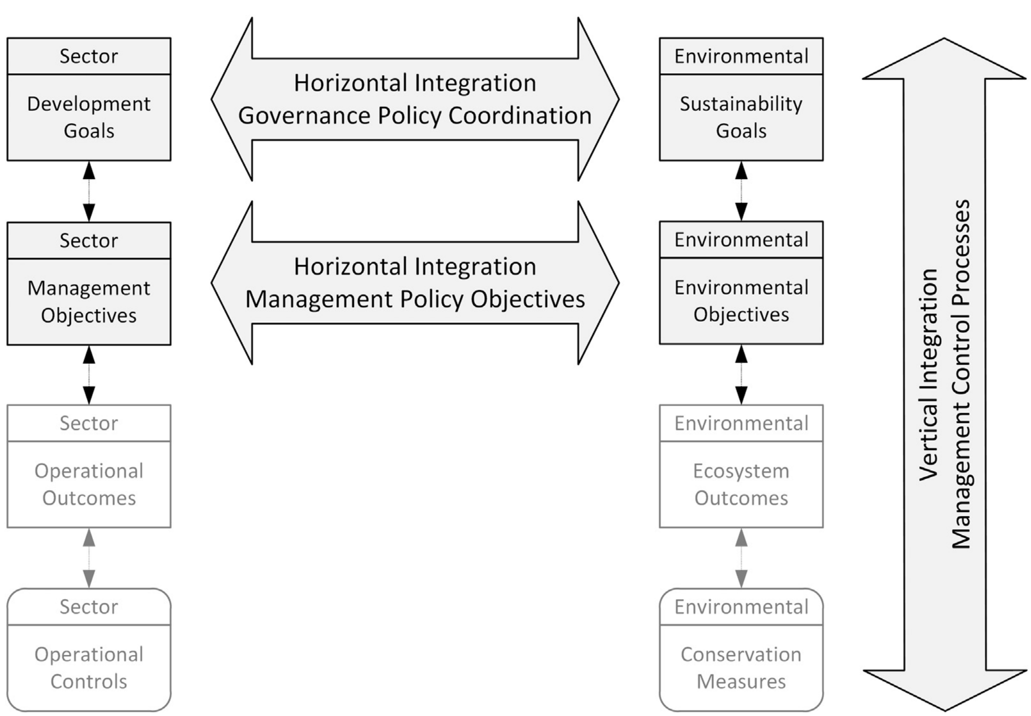

Fig. 1. Vertical and horizontal integration of environmental policies.

objectives (the expected outcomes) of the specific project (Cormier et al., 2017).

Although maritime spatial planning (MSP) aims to allocate space for human activities, few of the plans have operational objectives or fully integrate marine protection and/or resolve user conflicts with marine protected areas (Collie et al., 2013; Elliott et al., 2018). This is further complicated when cumulative effects assessments are introduced to understand the ecosystem repercussions of marine legislation based on sustainability goals and objectives which are often separate from sector development goals and objectives (Borja et al., 2008; Creed et al., 2016; Stelzenmüller et al., 2018).

Worldwide, marine protected areas are impacted by external human activities (Agardy et al., 2011; Mach et al., 2017) and so horizontal integration of operational controls is needed to ensure that the effects-footprints sanctioned by regulators consider ecosystem scale effects as well as ecosystem services impacts (Ban et al., 2010). While aiming for the better management of human activities, these cumulative assessments reflect the net ecosystem effects of several activities combined rather than single activities. Because of this, regulators rarely get the information they need to adjust and improve their operational controls to address the shortcomings of the conservation efforts (Agardy et al., 2011; Bennett et al., 2017).

Despite the above difficulties, there are cases where such vertical and horizontal integration is progressing and where management controls intend to ensure that objectives are linked to the goals. The EU Maritime Spatial Planning Directive (MSPD) (EU, 2014) and the MSFD (EU, 2008) are examples of vertical and horizontal policy integration. The MSPD needs to vertically integrate sector development policies and objectives in order to promote *'sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources'* through spatial and temporal distribution of relevant existing and future activities and uses. Maritime spatial planning must also integrate horizontally the policies of the MSFD to achieve environmental objectives (Elliott et al., 2018). Hence, the ecosystem outcomes of the spatial and temporal distribution of activities (the MSPD) should agree with the expected outcomes of the MSFD to address economic, social and ecological objectives (i.e. Good Environmental Status). The programme of measures of the MSFD outlines the operational controls to manage human activities (i.e. input controls and spatial and temporal distribution controls) and achieve the expected ecosystem quality outcomes (i.e. output controls). The MSPD should aim to horizontally integrate the environmental goals and policies of the MSFD, in which the implementation of the MSPD will have to horizontally resolve the spatial and temporal allocation of activities (operational controls). The MSFD programme of measures aims to achieve sustainability and ecosystem outcomes (Fig. 2).

In essence, the expected outcomes of the operational controls should align with the ecosystem outcomes needed to achieve environmental objectives instead of only relying on the integration of these objectives in sector and development policy (Salafsky, 2011) (Fig. 2). In the case of the MSFD/MSPD, almost a decade was required to propose the processes for the degree of alignment achieved horizontally and vertically; as yet this alignment is only now being considered given that the MSPD was passed in 2014. Given this challenge of alignment and integration of legislation for quality protection and spatial planning of potentially damaging activities, there is the need for a risk assessment and management framework. This should enable the vertical and horizontal integration of operational controls with conservation measures including governance and stakeholder input. As such, this paper describes the use of the industry-standard Bow-tie analysis as an approach that significantly may expedite this challenge. We further aim to show here that the Bow-tie technique is valuable in problem formulation and solving for environmental challenges, both in tackling the increasing number of 'wicked-problems' (Curtin, 2014; Zijp et al., 2016) and in bridging the language barriers with industry experts and engineers in ecosystem-based approaches to marine management (Burdon et al., 2018).

3. Bow-tie analysis

As a controls assessment, the Bow-tie analysis is one of the adopted risk assessment techniques of IEC/ISO 31010 (IEC/ISO, 2009) (Fig. 3). The technique, developed in the early 1980's by the petrochemical industries to manage health and safety risks (Lewis and Hurst, 2005), is now widely-used by industry to analyse the connections between risk controls and the management system (de Dianous and Fiévez, 2006;

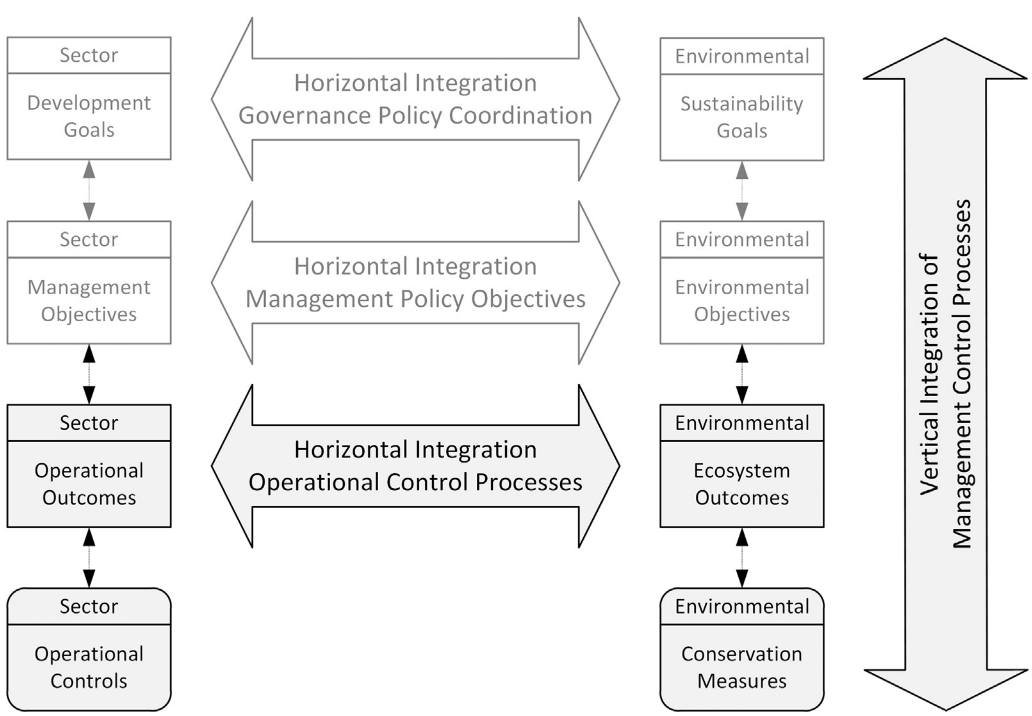

Fig. 2. Horizontal integration processes of operational and ecosystem outcomes.

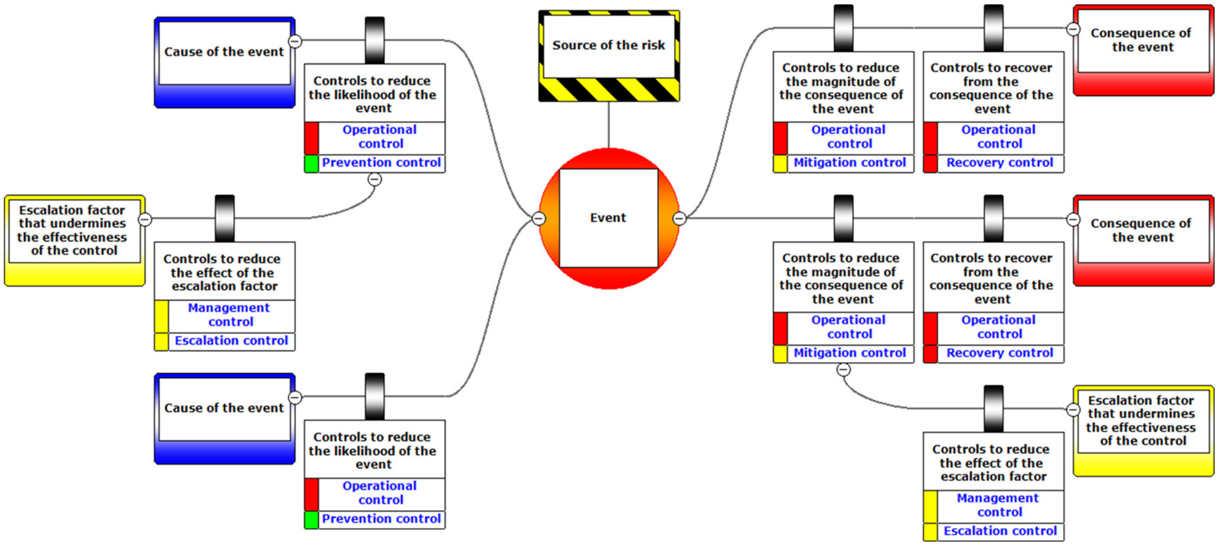

Fig. 3. Bow-tie analysis based on BowTieXP (version 9.0.10.0) representation of IEC/ISO 31010 (adapted from Cormier et al., 2018).

Ferdous et al., 2013). The process of generating a Bow-tie and its diagram is a valuable and transparent approach for raising awareness of risk and understanding the management of those risks by managers and stakeholders (Chevreau et al., 2006; Saud et al., 2014). It incorporates multiple causes and consequences of a given event, in order to analyse existing and possible controls that are used to prevent the causes of the event both individually and collectively and to mitigate and recover from consequences of the event.

The yellow striped box in Fig. 3 represents the hazard of concern or the source of the risk. The middle circle represents the event that could occur given the source of the risk while the blue boxes (left side) represent the mechanism by which the risk source could cause the event. The red boxes (right side) represent the potential consequences of the event if and when it occurs. Prevention controls are inserted between the causes and the event to reduce the likelihood of that event. Mitigation and recovery controls are inserted between the event and the consequences to reduce the magnitude of the consequences and/or to recover from the consequences that could not be mitigated. The yellow boxes represent the escalation factors that could undermine the effectiveness of any of the prevention, mitigation or recovery controls. Additional escalation controls are added to reduce the likelihood of undermining the effectiveness of a specific control.

Bow-tie analysis is now an accepted conceptual model for analysing legislation and policies for managing the environmental risks of human activities whether land or sea-based (Creed et al., 2016; Smith et al., 2016; Cormier et al., 2016, 2018; Elliott et al., 2017; Kishchuk et al., 2018; Stelzenmüller et al., 2018). It is also considered as a valuable tool to integrate stakeholder risk perception and their interests in the risk management process (Gerkensmeier and Ratter, 2016). As a widely-used, industry-standard technique, it has a particular advantage for environmental regulators in discussions with industry as the structure of the Bow-tie places risk management in the context of a policy objective, making it particularly valuable for planning and management.

By building upon the Bow-tie basic description above, we expand the technique to integrate industry environmental practices with conservation strategies as a comprehensive risk analysis approach to development and sustainability policy implementation. We also integrate the different roles that stakeholders play in the risk management process including the roles of various assessments throughout the process. From this point onwards, the prevention, mitigation and recovery controls are considered as the *operational controls* implemented by sectors while escalation controls are considered as the *management controls* to bridge management and operational control processes with the Bow-tie standard.

4. Bow-tie of DAPSI(W)R(M)

In order to underpin the underlying Bow-tie structure in environmental management, we use the DAPSI(W)R(M) (pronounced *dap-see-worm*) conceptual framework as an extension and refinement of the widely-used DPSIR framework (Patrício et al., 2016; Elliott et al., 2017). The **D**rivers of basic human needs (such as food, security, energy) can be obtained via **A**ctivities which then produce **P**ressures. The latter are the causes and mechanisms of the source of the risk and, hence, effect a **S**tate change on the natural system as the event of concern with the **I**mpacts on human **W**elfare as the consequences of the event (Fig. 4). The prevention, mitigation and recovery controls are the **R**esponses in terms of management **M**easures (R(M)).

In a standard Bow-tie, prevention controls would be implemented to reduce the likelihood of a State change outside tolerable levels (Cormier et al., 2018). The tolerable level would have to reflect the permitted degree of perturbation of an ecological component needed to prevent State changes at an ecosystem scale; for example, the removal of a fish stock within Maximum Sustainable Yield (MSY) levels keeping the ecosystem effects of fisheries sustainable. At the ecosystem scale, mitigation controls would be implemented to reduce the spatial scale, duration or intensity of the effects and impacts to ecosystem components and functions needed to support ecosystem services (Cormier et al., 2016). Recovery controls would be implemented to restore damaged ecosystem components. In regulatory regimes, recovery controls could include biodiversity offsetting and compensation measures to restore some of the ecosystem components and functions, for example habitat restoration or fish re-stocking activities as ecoengineering (Elliott et al., 2016). From a human welfare perspective, recovery controls could also include remediation of affected communities or financial compensation for losses resulting from a state change such as reduced fisheries landing because of a loss of productivity. It could also include changes to cultural sites because of a development or the displacement of economic activities (Elliott et al., 2016; Gee et al., 2017).

The source of marine problems are the result of endogenic managed pressures and exogenic unmanaged pressures (Elliott, 2011) (Fig. 5). The former include those activities and pressures within the marine area to be managed and in which the causes and consequences of state change and impacts on human welfare can be managed, for

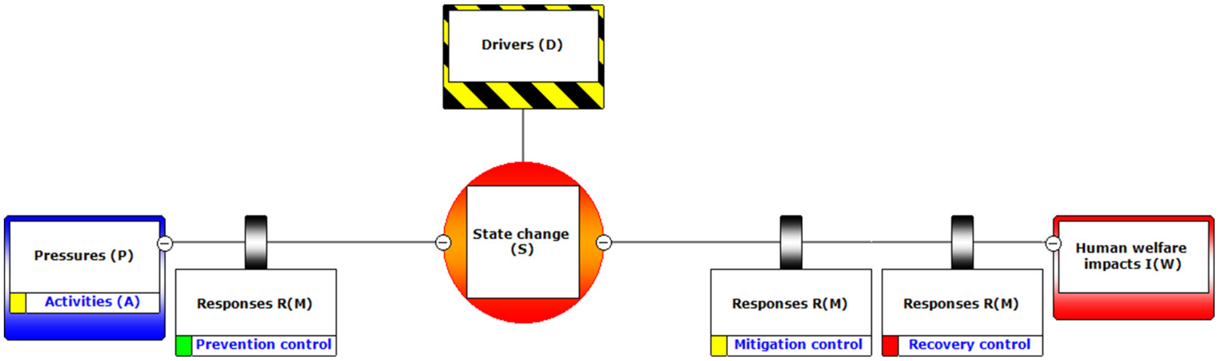

Fig. 4. Bow-tie structure of DAPSI(W)R(M).

example the effects of trawling by scraping nets over the seabed, or operating a fish farm or offshore wind farm. In contrast, the exogenic unmanaged pressures emanate from outside the area being managed and in which the consequences have to be managed within the management area whereas the causes can only be managed with wider, perhaps global measures and responses. For example, environmental effects of climate change such as sea level rise, natural processes, tsunamis, or nutrient inputs from the wider catchment outside the management area require wider action on the consequences. Here, we use escalation factors to integrate exogenic unmanaged pressures that can undermine the effectiveness of the responses to endogenic managed pressures.

The relationship between these aspects illustrates differences in management approaches within a managed area and trans-boundary issues. Vertical integration of policies across geopolitical levels led by governance processes would be considered as the management controls needed to address those pressures. For example, the causes of global climate change have to be addressed by instruments such as the PARIS COP Agreement (UN, 2015a) whereas mitigation or recover controls are implemented locally to reduce the consequences of the effects of climate change such as sea level rise.

In Fig. 5, shifts in natural processes are shown as a consequence of climate change which we recognise as occurring from past and current pressures at a global scale and will be difficult to reverse on even centennial scales. Hence, any changes in the state caused by climate change leave mitigation and recovery as the only options to reduce the magnitude of the consequences on ecosystem components and accommodate the people who would be impacted. Without a comprehensive management strategy of prevention, mitigation and recovery from both endogenic managed and exogenic unmanaged pressures, policy objectives will not be achieved. Given that mitigation will have limited success, recovery and societal adaptation may be the only option to deal with the consequences to human welfare. The resulting Bow-tie structure therefore provides a comprehensive and holistic risk assessment and management framework for analysing the horizontal integration of cross-sectoral operational controls (i.e. all controls for different parts of the same operation) in relation to their respective vertical integration of the management controls (i.e. the controls from local to international) (Elliott, 2014). Consequently it is considered here that the tool is valuable in designing integration strategies.

As endogenic managed pressures are reduced by prevention controls within the managed area, their effectiveness can also be undermined by exogenic pressures if not appropriately managed. For example, shoreline erosion protection to accommodate urban development can be undermined by erosion caused by sea-level rise due to global climate change. It is possible that controls implemented outside the management area are not as targeted or effective as the ones implemented inside the management area, and so their effect may be more diffuse and so lessened in the management area. Managers and the relevant sectors would have to identify additional controls to reduce the likelihood that such exogenic pressures undermine the individual prevention controls. Given that the state change is the initial central event that we wish to avoid or keep within bounds, prevention controls are applied to reduce the likelihood of such change due to these pressures; this may be preferable to implementing a priori the mitigation and recovery controls on the consequences of the state change. This follows from the definition of the DAPSI(W)R(M) framework for the state changes and impacts on human welfare as the natural and societal events respectively we want to prevent.

The State change can be effected by natural perturbations in marine ecosystem properties such as species richness and abundance. In such cases controls may still be needed, but they are not intended to achieve

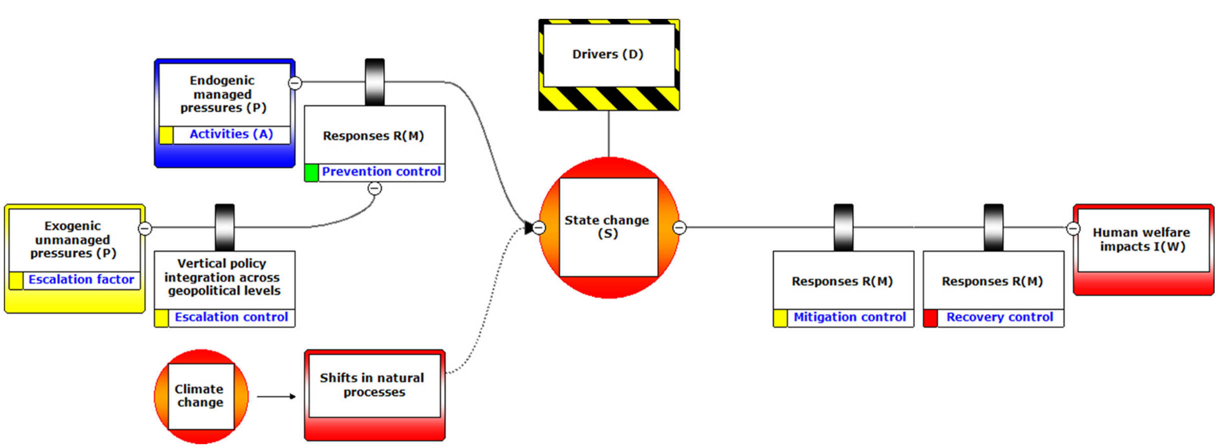

Fig. 5. The influence of endogenic managed and exogenic unmanaged pressures.

full prevention of change in state and as long as the change is maintained at a magnitude less than the 'event horizon' (the threshold or reference condition) for the state change of concern, the prevention is considered effective. That implies that the detection of change due to the pressures has to be measured against the background natural variability, i.e. the signal-to-noise ratio; for example polluting discharges may reduce species richness and individual abundance but natural predator-prey interactions can also have the same effect (Gray and Elliott, 2009). However, once the state change threshold is passed, only the mitigation and recovery controls can reduce the magnitude of the consequences.

In environmental management, mitigation controls are well-established practices outlined in environmental assessment legislation, such as the European Environmental Impact Assessment Directive (Lonsdale et al., 2017). Recovery controls would be equivalent to compensation, biodiversity offsetting, restitution or remediation measures used in environmental management. As an example, pressures resulting from urban and agricultural nutrient inputs will require prevention controls. If prevention controls do not reduce the pressures appropriately and effectively, the nutrient levels will increase and can eventually lead to eutrophication (de Jonge and Elliott, 2001). Thus, it is the likelihood of eutrophication that depends on the effectiveness of the prevention controls in reducing the release of the nutrients below the threshold levels in a given marine ecosystem. Once eutrophication occurs (e.g. a state change such as anoxia or toxic algal blooms), its consequences would be expressed as changes in ecosystem processes and features, ecosystem services, and/or societal goods and benefits; for example eutrophication symptoms such as algal blooms will reduce the recreation potential of waters. Mitigation and recovery controls would then be needed to reduce the magnitude of the consequences of eutrophication (i.e. the right hand side of the Bow-tie). The mitigation and recovery controls may also help to reduce the controls on the nutrient inflows to the area thus giving valuable co-benefits. Nevertheless, the first-response measures for reducing the likelihood of continued eutrophication would still be the prevention controls – hopefully strengthened to increase their effectiveness.

Shifts in natural processes as a consequence of climate change as in the example of Fig. 5 can contribute directly to State changes that cannot be prevented. In such situations, the only management strategy is to implement mitigation and recovery controls for the consequences. From an ecosystem perspective, recovery controls could include restoration initiatives, i.e. the creation of compensating habitats (Elliott et al., 2016). In terms of human welfare, recovery controls could include financial, habitat or material compensation and remediation for the losses experienced by a given sector and individuals. In this case, there are three types of compensation: to directly compensate the user (e.g. pay the fishermen for a loss of stock or indigenous people for the loss of traditional uses), to compensate the resource (e.g. by re-stocking fish or crustaceans in the expectation that catches could be sustained on the enhanced stock), or to compensate the habitat (e.g. by re-creating new habitat lost by the pressures) with an aim to increases in ecological benefits, stocks and then yields (Elliott et al., 2016). In a Bow-tie analysis, however, it is assumed that mitigation and recovery controls cannot return the situation to the pre-event state given the uncertainties involved (DFO, 2015).

5. Horizontal integration across levels of governance

It is necessary to adapt the Bow-tie to support effective horizontal integration of those cross-sectoral operational controls needed to achieve ecosystem and environmental policy objectives. The implementation of operational controls at the local scale requires national and local integration of the stakeholders. Those stakeholders, using a pre-defined typology (Newton and Elliott, 2016) linked to the DAPSI(W)R(M) framework, are composed of Regulators, Extractors, Inputters, Affectees, Influencers and Beneficiaries (Fig. 6). Incorporating all stakeholders in the framework is thus designed to ensure that sector activities and their pressures are managed effectively to reach the broader policy goals and objectives.

The Extractors (those taking resources such as fish, water or space out of the system) and Inputters (those putting materials and structures into the seas) are the stakeholders that generate endogenic and exogenic pressures from their activities (i.e. the D, A, P). They also play a key role in the development of prevention controls that would be led by the Regulators who manage (via the R(M)) the endogenic pressures to ensure that these controls can be efficiently implemented. The Affectees (those affected by any impacts) are the stakeholders being adversely affected by the state changes and impacts (on human welfare) (the S, I(W)) because the pressures were not effectively managed. The Beneficiaries are those benefitting from resource use and therefore having a stake in maintaining the resource availability (i.e. the benefit from the welfare being recognised by I(W)). However, both the Affectees and Beneficiaries are key consultees on the development of mitigation and recovery controls led by the Regulators who manage the impacts. They would also have a stake into the effectiveness of the prevention controls. The Influencers (such as NGOs, policy makers, educators, researchers) can play a role in all aspects including minimising the sources of the risk, and tackling the cause and the

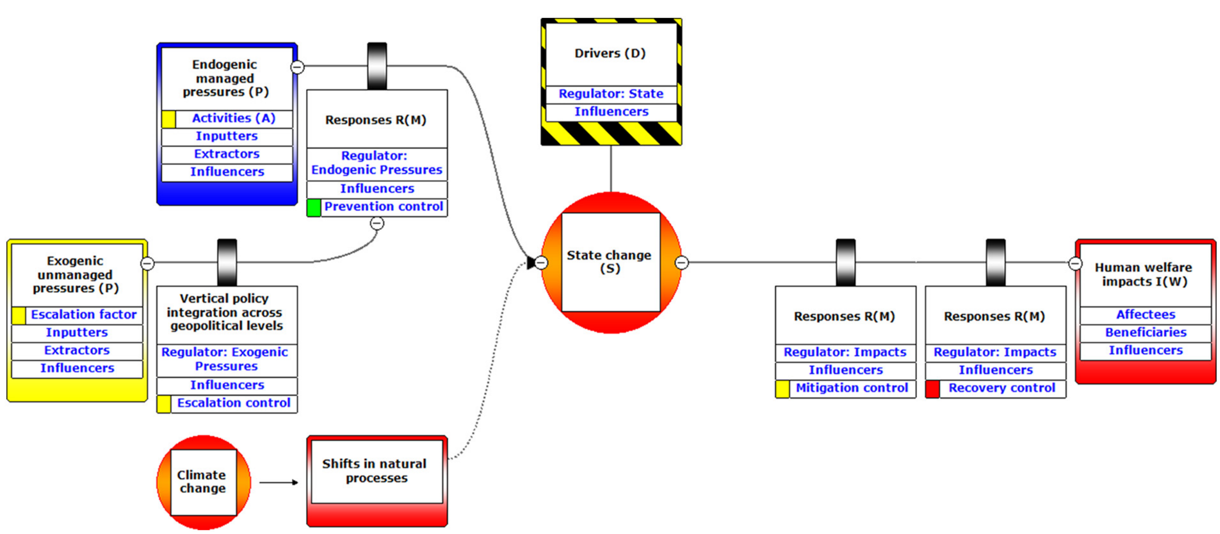

Fig. 6. Horizontal integration of stakeholders.

consequences of such an event and the controls needed to be implemented (such as aiming to stop I(W) and bring about R(M)). Influencers could lobby to warn about decreasing or increasing the risks of not achieving policy objectives depending on their agenda and objectives. However, conversely they could also lobby to increase the use of the resources and the pressures on the system if they saw incentives arising from resource uses. Certain stakeholders, such as fishermen, can be members of all of these types (Newton and Elliott, 2016).

Although the Regulators (those with a statutory remit such as an Environmental Protection Agency or other licensing body, or agencies managing industries such as fisheries or aquaculture) would typically control the responses (operational controls), the mandates are complex. Even when a single regulator has the authority to maintain the state of the ecosystem, as for example the English Marine Management Organisation or Marine Scotland, a single competent authority rarely has the authority to manage all the prevention controls necessary to deliver that outcome. There are typically several regulators that manage sector activities and their pressures (Boyes and Elliott, 2015) and different authorities that have a mandate to mitigate and enable recovery from impacts to human welfare as well as reduce the escalation factors, for example nature conservation bodies or harbour authorities. The framework here emphasises that the Inputters and Extractors have to be involved to develop the prevention controls and that the Affectees and Beneficiaries have to be involved to develop the mitigation and recovery controls.

The Bow-tie analysis suggests that the horizontal integration of agencies and stakeholders has the ability to align sector prevention controls to achieve a common objective for the acceptable level of state change, avoiding negative consequences for human well-being and the need for mitigative or recovery controls. The horizontal integration has to ensure coherence of prevention controls implemented within the operations of the Inputters and Extractors and across the different Regulators. This, for example, satisfies the marine conservation and fisheries aspects during an Environmental Impact Assessment, such that collectively the separate sectoral prevention controls reduce the pressures to minimize (or at least society to tolerate) the likelihood of a state change. However, this also implies that Affectees and Beneficiaries are involved in setting the state change objectives, in the best case to levels that are within their tolerance for potential risks of impacts on their welfare. However, such risk-averse state change objectives may require highly restrictive prevention controls, with costs paid by the Extractors and Inputters (i.e. the 'polluter-pays' or 'damager debt' principle). This potentially opens a dialogue about the feasibility, costs and benefits of slightly less-restrictive state change objectives paired with additional mitigation and recovery controls, with the package safeguarding the interests of the Beneficiaries and Affectees. It is suggested here that the Bow-tie may be particularly valuable in providing a comprehensive, transparent and inclusive processes for informing such a dialogue.

As an example of the interplay between stakeholders, a marine dredging company (Inputters of suspended sediments and Extractors of bed material) have to follow licence conditions set by Regulators to control their adverse effects, by actions such as putting silt curtains around a dredging site to prevent the smothering of sensitive marine benthos. In addition, they also need prevention controls to constrain what level of extraction is tolerable before the extraction removes too much habitat for marine animals using the gravel, or dredging is too deep through the desired material and into clay, which would increase the siltation and increase the costs to the dredging company. Fishermen in the area could be Affectees if silt disturbed by the dredging or habitat loss affects the spawning beds or physiology of fish and shellfish. However there are also Beneficiaries, such as shipping companies that have safer navigation channels and construction companies that have lower cost building materials (or materials at a lower environmental impact than land-based gravel extraction). Society as a whole can both benefit from cheaper or more sustainable building materials and more efficient shipping, and suffer losses of seafood and cultural uses of the areas being mined. Thus different Influencers could lobby both for greater controls, e.g. to stop the suspended silts affecting marine life, but also for less restrictive controls arguing that aggregate extraction may be more suitable and cheaper and less environmentally damaging than land extraction.

6. Vertical integration of governance across geopolitical levels

Given the multi-sectoral, cross-boundary and multi-stakeholder demands of national and international marine management (Boyes and Elliott, 2014; Elliott, 2014), we adapt the Bow-tie to inform the vertical policy integration (i.e. from local to international governance) that is needed to ensure coherence and equivalency of operational controls implemented in multi-sectorial, trans-boundary or international situations (Fig. 6). For example, fisheries are managed by local co-management in regional seas initiatives (such as the European Common Fisheries Policy) under the UN Law of the Sea (UNCLOS). Used as a tool for analysing and supporting development of marine environmental policies, we propose that the Bow-tie analysis provides a transparent and structured approach to evaluate whether existing sector legislation, policies and regulatory regimes are fit for the purpose of achieving such ecosystem objectives.

Policymaking processes are dependent on vertical governance approaches which produce a hierarchy in the development of global, ecoregion, and regional goals to guide the development of national and local objectives (Boyes and Elliott, 2014; Cormier et al., 2017), and to allocate responsibility for their delivery. For example, the global International Maritime Organisation regulations on ballast-water management carry through to the European Ballast-Water Regulation and then to local port operation controls. Similarly vertically-integrated policymaking and governance approaches are also required to ensure that the operational controls implemented within the managed areas under relevant jurisdictions can meet the same common objectives as the stakeholders involved in the horizontal integration. This is particularly important when different causes of the pressures (sectors) are frequently expressed and managed at different spatial scales.

As with the Regulators, each operational control may be governed by different national, regional and international organizations and bodies. This implies that each prevention, mitigation, recovery and escalation aspect may be managed by different management control processes. As a Canadian example (DFO, 2009), protection and conservation of marine waters, including the management of marine fisheries and sectors, is under Federal jurisdiction while the management of land-based and coastal activities and their pressures comes under Provincial and Territorial jurisdictions. Relevant jurisdictions may implement prevention controls for various pressures while other relevant jurisdictions implement mitigation and recovery controls for the consequences. For example, prevention controls may deal with wastewater effluents, infilling and the use of siltation curtains during dredging activities while mitigation and recovery controls may deal with protection and conservation measures for unique ecosystem features or recovery plans for endangered species. For the pressures to be managed adequately to achieve environmental scale objectives, governance and management processes must be vertically integrated (Cormier et al., 2017). Without effective vertical integration, prevention, mitigation and recovery controls will be inefficient and eventually not succeed because efforts at each scale are uncoordinated.

In a Bow-tie analysis, each national authority and geopolitical level constitutes a management control to coordinate the development and implementation of controls for endogenic managed pressures and exogenic unmanaged pressures (Fig. 6) to avoid a state change and achieve environmental objectives. National enabling or primary legislation (such as the Canadian *Oceans Act*) constitutes the overarching management control processes, under the authority of the Regulator for the state change, needed to address the endogenic managed pressures occurring within their managed area. However, this overarching control still needs to be scaled down to guide actions by Regulators and resource users in progressively more local scales. For example, discharge controls through licensing of a conventional power plant discharging a thermal effluent into the local waters (Wither et al., 2012) would have to be managed to avoid a state change of the ecosystem (e.g. a thermal plume in the water column) with negative impacts to human welfare (e.g. aesthetic effects spoiling recreation), but may have to address a hierarchy of standards (e.g. discharge limits on chlorination antifouling chemicals) set at federal, provincial, and municipal levels. In contrast, transboundary agreements under regional or global authorities would require management control processes to ensure that the prevention controls of the endogenic managed pressures are as effective as those used for the exogenic unmanaged pressures (i.e. those emanating outside the management area), if those pressures were manifested on a large scale (e.g. climate change, overfishing of migratory fish stocks). For example, international conventions and agreements such as the PARIS COP agreement for climate change (UN, 2015a) represents another level of management control if the recommendations are translated into national actions.

Finally here, during international negotiations of an instrument to augment or amend UNCLOS, there is debate about the desirability and feasibility of subordinating all sectoral management to a single overarching environmental authority (UN, 2018). However, no solutions have yet been proposed to address the challenges of making sectoral regulatory authorities with social and economic as well as environmental responsibilities, subordinate to an environmental overarching agency for ecosystem objectives, yet still able to make effective policies to achieve social and economic objectives.

7. Holistic and adaptive marine environmental management

Traditional regulatory approaches to environmental management have been developed for localized project impact ‘effects-footprints’ and do not necessarily accommodate the collective impacts of multiple projects in terms of cumulative and in-combination effects (Elliott et al., 2018). For example, an Environmental Impact Assessment focuses simply on the effect of an activity, at a specific place and time, carried out in a defined way, with a specified level of mitigation and/or compensation and communicated in a specific way (Glasson et al., 2012; Lonsdale et al., 2017). A more holistic approach requires that regulatory regimes used to manage sector activities and their pressures be aligned to address objectives for ecosystem services and societal goods and benefits that depend on broader ecosystem scales. Those scales will need to be managed by multiple national legal instruments as well as regional and international governance. This is where a Bow-tie analysis not only identifies the operational controls needed to achieve a given objective, it also clarifies both the agencies with full or partial authority to implement such measures.

The Bow-tie approach has great value in assessing the operational controls and evaluating the management controls (Fig. 6). As this Bow-tie diagram reflects the real-world complexity, it structures risk management in terms of the source of the risk, the causes of an event of concern and the consequences of such an event to clearly understand the roles of the prevention, mitigation, recovery controls and escalation controls used to reduce the risks operationally. It also delineates the management controls needed to address the individual endogenic and exogenic pressures to ensure that the effectiveness of the operational controls are fit for the purpose of achieving broader environmental objectives. Moreover, the Bow-tie diagrams do not need to be fully integrated to the lowest spatial and temporal level for every application. The holistic integration for the overarching objectives can represent the interactions, responsibilities and opportunities of all the pressures and players, to create a holistic framework. Then, with the roles and responsibilities for outcomes agreed in the overall framework, more focused analysis of individual nodes and pathways can be undertaken. This keeps the individual diagrams from becoming unnecessarily complex, but does require that at some point before implementation, the matrix of nodes and pathways are checked for coherence.

As described here, the entire Bow-tie diagram constitutes the holistic marine management approach needed to achieve the objectives. As it sets the risk management context as the central source of the risk and event, its power is in avoiding inadvertent omissions in identifying the relevant causes and consequences that should be assessed. Based on monitoring and review activities as defined in ISO 31000, the Bow-tie analysis can identify which operational controls that need to be implemented or updated as well as the causes, consequences or escalation factors that need new controls. Based on the operational controls that need to be addressed, the Bow-tie also identifies the stakeholders as well as the national, regional and international organizations involved. The horizontal integration of the stakeholders is achieved by the cause-event-consequence pathways of risk whereas the vertical integration is provided by the linked escalation factors. Management responses and measures can then focus on what needs to be adapted instead of trying to include aspects that are not either relevant or needed to achieve the objective.

8. Risk assessment methods and responses

A key challenge to any ecosystem-based management for managers and stakeholders includes accounting for the potential outcomes of their decisions following ecological, social, regulatory/governance, technical and economic assessments (Assmuth et al., 2010; Barnard and Elliott, 2015). The policy makers who make the decisions, and the managers who implement them, require supporting expert and community-based advisory processes including appropriate information from comprehensive assessments of ecological, social and economic factors. Moreover the information does not just need to be presented in separate thematic chapters in the Environmental Statement, but it does need to be systematically organized and interconnected across all those dimensions of the decisions.

Integrated ecosystem assessments have been increasingly promoted for systematically collating information and making it available to decision-makers. However, this depends on what is being ‘integrated’. Each assessment informs very different aspects of the risks which also have very different implications depending on the decisions being considered by managers and stakeholders. There are multiple types of ‘integration’ (Box 1).

As emphasised here, the central purpose of the Bow-tie diagram is to systematically organize and interconnect across all aspects of decision-making. The Bow-tie thus transparently displays the scientific and technical knowledge in relation to the specific risks examined (Fig. 7). By linking the assessments to the various elements of the risks, a further knowledge gap-analysis can be undertaken by managers and stakeholders while showing the scientific and technical experts the type of information needed in decision-making. However, the Bow-tie analysis has the added advantage that requires that the effectiveness of the controls and the integration of policies be assessed as specified by the ISO 31000 risk management standard which is not traditionally done by other assessments.

Combining the ecological, multi-sectoral, socio-ecological and socio-economic assessments provides a comprehensive overview of the knowledge base needed to inform a decision with regard to the management and operational controls needed to achieve a policy objective, i.e. what responses using feasible measures can produce the desired outcomes. Managers and stakeholders can review the knowledge regarding the source of the risk and the event that could undermine a given policy objective if not managed adequately (Loizidou et al., 2017). They can consider the level of endogenic managed and exogenic unmanaged pressures to prioritise the greatest risks to achieving required objectives. They can then decide where best to put their resources to either develop the operational controls or collaborate with

Box 1
Types of environmental integration.

Ecological/ecohydrological ('physics to fish'):	Integration of ecological components (populations, habitat features, etc.) with the hydromorphological conditions through their documented or hypothesized inter-relationships provides a sufficient basis to identify conservation priorities such as ecologically and biological significant areas (Dunn et al., 2014; Dunstan et al., 2016) and threatened species (UN, 2015b, 2017, 2018) in the spatial planning area. If the integrated assessment incorporates the underlying ecological processes then it shows how current ecosystem status may have been influenced by past pressures (mortality rates, nutrient levels, etc.) and how the system might respond to increasing or decreasing one or more of those pressures. Hence this illustrates the importance of ecohydrological principles in integrated management (Wolanski and Elliott, 2015).
Multi-sectoral:	Integration of the pressures generated by each current or potential ocean sectoral activity (e.g. Elliott et al., 2017), and of the impacts of these on ecosystem components and processes. This allows the decision-making process to both trace back responsibility for current ecosystem status and model scenarios of consequences of adding new uses or changing the balance of existing uses on ecosystem status and processes. This is valuable information if decision-making can address burden-sharing for improving the status of ecosystem components in unacceptable conditions, explore what balances of ocean uses are compatible with ecosystem status and the policy objectives, or consider cumulative effects of multiple ocean uses.
Social-economic-ecological:	The integration of how social and economic benefits and costs to society vary with the intensity and type of each ocean use, and of how those benefits and costs vary with and are imposed on ecological factors, is the part of integration most crucial to decision-making. Such an assessment should also include traditional uses and cultural impacts to local communities (Gee et al., 2017). This is where the synergies and trade-offs of various combinations of ocean uses are apparent, and where the ecological burdens imposed by the combinations of levels and types of ocean uses are exposed. It is only when this level of integration is reached that the assessment process makes the science support for decision-making (whether via social dynamic or institutional authority) meet the necessary standards for traceability, objectivity and transparency.
Policy integration:	The integration of the policies, politics, administration and legislation has to ensure that the management of each activity and involving each regulatory body are coordinated. For example, laws and bodies related to fisheries, impact assessment, water quality and conservation need to be harmonised.

external jurisdictions and stakeholders. Based on the effectiveness of the prevention, mitigation and recovery controls, they can, finally, determine whether or not the potential consequences are acceptable to society and economically feasible. For example, building infrastructure such as a port extension will remove habitats but can be mitigated, as required by national and regional legal instruments (such as the EU Habitats Directive), by siting considerations and compensated with biodiversity offsets and habitat creation (Elliott et al., 2016). However, if that mitigation and compensation does not fully replace the habitats lost then a derogation needs to be applied for the consequences (e.g. lost carrying capacity for bird feeding) being accepted by society/regulators or a case made that the loss is in the wider interest (e.g. societal benefits of a larger port); in the UK the latter is termed an IROPI, for 'imperative reasons of overriding public interest'.

9. Concluding remarks

Despite the plethora of management organizations, governance instruments and management approaches, the marine environment is arguably still deteriorating, and is certainly not recovering from all past

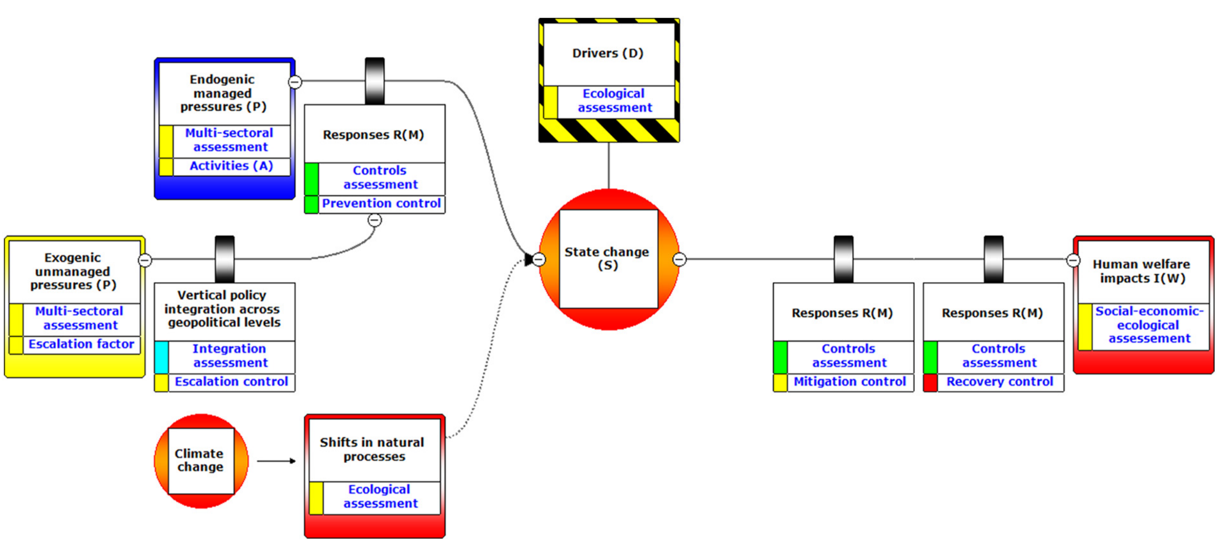

Fig. 7. Structuring the knowledge generated by various assessment.

disturbances. There are many activities and pressures which are changing the natural state and impacting human welfare related to the seas. The state of the environment and changes to ecosystem features and functions indicate that existing legislation and policies are not adequately effective at achieving environmental objectives and societal goals. Even if the only problem with current effectiveness of sector legislation, regulations and standards is that they are being undermined by the sheer number of activities and the intensity of their pressures that are being generated at ecosystem scales, better tools for integrating the information and structuring the choices are still necessary. Most of these regulatory requirements were developed for localized point-source effects rather than non-point source ecosystem scale effects and cumulative impacts across multi-use sea areas.

The aspects identified here may appear as a very intimidating list of integration demands, but, in fact, such integration occurs *de facto* every time a decision on ocean use is made. The argument here is that often the full integration is not done systematically within a structured framework, and often key parts are done subjectively and intuitively (and often with less-than-good knowledge, understanding or data) as the decision-makers consider how the elements of information are linked and used. A structured process of integration does not pre-empt or nullify the prerogative of the decision-makers to decide what trade-offs are most acceptable given the overarching policy objectives. It just informs them of what choices are available, what trade-offs must be confronted, how costs and benefits could be distributed, and the extent to which each can be described and quantified (Börger et al., 2016). Wherever formal compromises are made within the governance process, the integration of relevant information is still required, perhaps even to ensure a legally-defendable decision.

In order to provide these policy benefits, the framework for organizing information and supporting advice has to accommodate uncertainty, and therefore be risk-based in a consistent and defendable way across social, economic and ecological outcomes of the management decisions. If this is not the case, the traded-off compromises being discussed may incompletely consider both costs and benefits of the alternatives. Clearly, something more than a categorical triage-based risk framework is needed. Managers and stakeholders must be able to understand and explain the interconnectedness of the risk elements during management controls processes and deliberations. This may be regarded as a Utopian view of accommodating the complexity of policy and decision making but our argument here is that this is a complex system and that a fully-structured and rigorous approach to decision-making is manageable, defendable and possible. It should aim to avoid unintentionally (or intentionally) overlooking key risk elements that would have made a significant difference in the decision.

We consider here that it is necessary to acknowledge and emphasise the complexity of marine uses, users, managers and societal demands. Therefore, we have not attempted to simplify the complexity of these contributing elements but rather argue for a structured framework within a risk management context so that we can identify the courses of action needed to make progress more effectively, and hopefully with fewer impediments and delays. Risk management is about reducing the uncertainties of achieving objectives by implementing the necessary management and operational controls. The selection of the courses of action still requires that the risks are identified, analysed and evaluated by focussing on the policy objectives set by management processes as directed by the governance. The risk assessment does not assess risks because they are popular, interesting or easy to do but rather because good decisions require an understanding of what is known and not known regarding the risks perceived by managers and stakeholders given the policy context. It is emphasised that decisions still have to be taken irrespective of the availability of data and understanding.

Within the policy context, the Bow-tie analysis of the responses in terms of operational and management controls is conducted for the relevant drivers, their activities and resulting pressures that may cause an ecosystem state change and the resulting impacts on human welfare. The Bow-tie, therefore, uses spatial and temporal pathways risks for the analysis. Although the socio-ecological system may be driven by multiple feedback processes operating within several systems, management has to focus on an underlying cause-to-consequence hierarchical approach. Legislation, regulations, policies, standards and guidelines used in sector operations have to be integrated so that they do not only deal with one pressure-state-consequences pathway without considering multiple activities that collectively contribute to the pressures. In such a context, adaptive management may only occur through changes to existing legislative and regulatory regimes.

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