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Managing Marine Resources Sustainably – The 'Management Response-Footprint Pyramid' Covering Policy, Plans and Technical Measures

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The plethora of human activities and their pressures and impacts in the oceans require managing at local, national, regional and international scales. This requires management responses in a programme of measures to determine (a) the area in which the human activities take place, (b) the area covered by the pressures generated by the activities on the prevailing habitats and species in which pressures are defined as the mechanisms of change, and (c) the area over which any adverse effects (and even benefits) occur on both the natural and human systems. The spatial and temporal scales of these leads to the concepts of activity-, pressures-, effects- and management responses-footprints, defined here. These footprints cover areas from tens of m^2 to millions of km^2, and, in the case of management responses, from a large number of local instruments to a few global instruments thereby giving rise to what is termed the management response-footprint pyramids. This may operate from either bottom-up or top-down directions, whether as the result of local societal demands for clean, healthy, productive and diverse seas or by diktat from national, supranational and global bodies such as the United Nations. These concepts are explained and illustrated using marine examples based on experience from many jurisdictions.

Keywords: DAPSI(W)R(M), UNCLOS, European Directives, technical measures, policy performance, regulatory equivalency

INTRODUCTION

Marine management, as with all environmental management, is implicitly or explicitly based on a cause-consequence-response framework whereby human activities then lead to consequences, as effects on both the natural system and the way society uses the natural system, which then need management actions to alleviate, reduce or remove those consequences. As a manifestation of this approach, Driver-Pressure-State-Impact-Response (DPSIR) frameworks have long existed to

integrate the relationship between development and their pressures and impacts to the environment (Wascher, 1962). Over time, DPSIR has also been modified and refined into the most recent, and arguably a more complete, approach such as the DAPSI(W)R(M) (pronounced *dap-see-worm*) framework (Cooper, 2013; Patrício et al., 2016; Elliott et al., 2017). In this, **D**rivers of basic human needs and values (such as the need for food and recreation) need to be fulfilled by **A**ctivities (e.g. fishing, tourism) that create **P**ressures (e.g. seabed abrasion, pollution); in turn, those **P**ressures, as the mechanisms of change lead to **S**tate changes on the natural system (e.g. turbidity increase, oxygen depletion) and **I**mpacts (on human **W**elfare) for the human system (e.g. biodiversity loss, ecosystem services provision depletion). The **R**esponse (using management **M**easures), i.e. a policy response, then implies that society responds to those environmental and societal consequences (Elliott et al., 2017).

A policy response is very dependent on the context of a policy and the goals and objectives established by its governance processes; here we define governance as the combination of policies, politics, administration and legislation. The use of the term "policy response" may express the intent of international and national agreements such as United Nations agreements that are ratified by their member States and legislation enacted by national governments. A policy response may also express very specific procedures to be followed in emergencies such as marine accidents and oil spills as well as the prevention, reduction and control of pollution and other hazards to the marine environment. Currently, the interpretation of response (R) varies somewhat in the literature expressed as environmental policy goals and visions, marine plans objectives or the outcomes of technical measures (Cormier et al., 2017). A policy response as conventions and legislation is not the same as the implementation of a marine plan by a competent authority nor the conditions of licences and permits by a regulator. The term policy responses therefore is an integrated system of policies, plans and measures to address goals and objectives established by national governance structures and implemented through management and regulatory processes (Elliott et al., 2020b).

The management of maritime activities is the integration of environmental and development objectives generated through marine planning processes across sector management of their respective activities which should also integrate protection and conservation strategies (Stephenson et al., 2019). In contrast, marine planning processes is the vertical integration of environmental and socio-economic policies as mandated by the national governance structures (Cormier et al., 2019). However, national public policymaking processes also have to integrate obligations established through regional and global governance processes such as European directives and United Nations conventions. The complexity of the marine environment and its management requires horizontal and vertical integration – horizontal integration is across all of the various activities (e.g. fishing, aquaculture, navigation, etc.) whereas vertical integration goes from local and immediate to global and long-lasting. Vertical integration between policies, plans, and technical measures from the local to the global is key to achieving policy objectives and sustainability goals with the understanding that these are achieved through effective and reliable technical measures dealing with the specific activities and their impacts (Stephenson et al., 2019). Therefore, this system of global, regional and national policies, plans and technical measures implemented through treaties, conventions, agreements legislation and regulatory frameworks were developed within the scope of different organizations that framed the context of their policies (Elliott et al., 2020b). It is contended here that there is a poor understanding of the vertical integration of global, regional, and national policy responses and the links to their implementation through marine plans and technical measures. Therefore, here we explore the need for a clear link between the different levels of policy responses to ensure that marine plans and the technical measures used to manage maritime activities are effective and informed by relevant and fit-for-purpose natural and social sciences (Elliott et al., 2020b). For example, this is where a regulator establishes conditions as part of a project approval process to address the natural and societal effects identified in an Environmental Impact Assessment (EIA).

Previously, we proposed that an activity in the marine environment and its contribution to pressures and effects (both on the natural and human systems, i.e. both the S and the I(W) in the DAPSI(W)R(M) framework) could be organized in terms of their 'footprints', i.e. the area and/or time covered by the activity, pressures and effects (Elliott et al., 2020a). We consider that this structure provides a more practical understanding that management actions within the activity-footprint are most effective at addressing pressures that are the root causes of effects. Activities, pressures and effects have overlapping footprints but that because of the dynamic nature of the marine environment then the pressures-footprints will be larger than the activity-footprint and the effects footprint will be larger and longer-lasting still. Therefore, such a structure also helps understand the spatial and temporal causal scales of activity-pressure-effects and in turn is needed to decide what management responses are required to address the activity, pressures and effects. In turn, those management responses are needed to address hazards from anthropogenic and natural sources which occur in the marine environment and that can become risks to nature, property, human health and livelihoods (Cormier et al., 2019; Elliott et al., 2019). Hence, those hazards and their risks need to be addressed through technical measures that avoid and control their causes or mitigate and compensate their consequences.

Policies regarding resource sustainability and conservation most often are developed to address environmental effects out of concerns for human well-being, such as providing sustainable and safe sea foodstuffs (Elliott et al., 2017). From such policies, the administrations and statutory bodies, i.e. those implementing legislative instruments and agreements, develop marine plans with objectives to reduce the risks of such effects from the pressures generated by activities in the marine environment which are then integrated in regulatory and non-regulatory tools used to manage those activities (Cormier et al., 2017; Gorjanc et al., 2022). Therefore, here we explore the contention that the management response measures also have

a spatial extent and/or temporal duration that can be described as a footprint – i.e. the compound term the management response-footprint. The footprints of these management responses (the R(M) in the DAPSI(W)R(M) framework), by necessity, have to reflect the footprints of the activities, pressures and effects (Elliott et al., 2020a). However, the footprint of the responses are also constrained by jurisdictional boundaries and even the areas beyond such jurisdiction but because of the dynamic marine nature, they do not necessarily align with the footprints of the effects and pressures that can be addressed through measures on the activity that then generate them (Verlaan, 2021; Cormier and Minkiewicz, 2022).

Hence, we aim to show firstly, that responses in terms of policies, marine plans, and technical responses do not necessarily have the same footprint. Secondly, the lack of a clear understanding of the hierarchy of management response-footprints that are developed and implemented by different actors are thereby creating a fragmented system of marine management. Based on the insights from the activity-, pressures- and effects-footprint definitions (Elliott et al., 2020a), we define the management response-footprint and demonstrate the importance for understanding the hierarchy of policy, marine plans and technical measures responses from a global, regional, national and local footprint perspective. Finally, we emphasise the summary of these ideas using the concept of two related 'management response-footprint pyramids' as the underlying framework and hierarchy of marine management; a spatial management response-footprint pyramid reflects management responses from very local scales to global scales and a pyramid reflecting the very large number of local management instruments (indeed, for example, one for each activity) feeding through a hierarchy to very few global instruments. By presenting an understanding of the complexities and differences in terms of policymaking approaches and capacities across national jurisdictions, we hope that this response-footprint concept will help to improve our understanding of the hierarchy between policies, marine plans and technical measures in relation to global, regional and national footprints. Here we put more emphasis on the spatial nature of these footprints than their temporal nature given that the spatial coverage is the precursor to long-term marine management.

DEFINITIONS OF FOOTPRINTS

As a starting point and to place this discussion in context, it is necessary to suggest definitions of the various types of footprints; note that those for the activity-, pressures- and effects- are modified as shown in **Table 1**.

UNDERSTANDING THE FOOTPRINTS OF POLICIES, MARINE PLANS AND TECHNICAL MEASURES

Marine policies and management measures can be derived either top-down, from international, regional, or national diktats, or bottom-up by demands from those being managed or from the different groups of stakeholders (Newton and Elliott, 2016). For example, these can range from international agreements such as the United Nations (UN) Sustainable Development Goals (SDGs) (UN, 2016) to the requirement by regulators, local communities and pressure groups for management measures on new marine industrial development such as an offshore wind-farm. The footprints of policies, marine plans, and technical measures are closely linked to the boundaries and mandates of their respective governance processes (**Figure 1**). Here, we propose five management response-footprints reflecting different governance, administration and regulatory processes showing the importance of top-down vertical integration from the global policy response-footprint that is needed to ensure an effective bottom-up vertical integration at the technical response-footprint to ultimately achieve global policy objectives (Cormier et al., 2017; Cormier et al., 2019; Stephenson et al., 2019).

TABLE 1 | Definitions for activity, pressures and effects footprints (adapted from Elliott et al., 2020a).

Activity-footprint	The area and/or time, based on the duration, intensity and frequency of an activity which ideally has been legally sanctioned by a regulator in an authorisation, licence, permit or consent, and which should be so clearly defined and mapped in order to be legally-defendable; it should be both easily observed and monitored and attributable to the proponent of the activity.
Pressures-footprint	The area and time covered by the mechanism(s) of change resulting from a given activity or all the activities in an area once avoidance and mitigation measures have been employed (the endogenic managed pressures). It does not necessarily coincide with the activity-footprint and may usually be larger but could be smaller. It also needs to include the influence and consequences of pressures emanating from outside the management area (the exogenic unmanaged pressures); given that these are caused by wide-scale events (and even global developments) then these are likely to have larger scale (spatial and temporal) consequences.
Effects-footprint	The spatial (extent), temporal (duration), intensity, persistence and frequency characteristics resulting from (a) a single pressure from a marine activity, (b) all the pressures from that activity, (c) all the pressures from all activities in an area, or (d) all pressures from all activities in an area or emanating from outside the management area. They include both the adverse and positive consequences on the natural ecosystem components and on the ecosystem services and societal goods and benefits. They need to include the near-field and far-field effects and near- and far-time effects because of the dynamics and characteristics of marine areas and the uses and users of the area. They may be larger in extent and more persistent than the causing activity-footprint and the resulting pressures-footprints. They also need to encompass the effects of both endogenic and exogenic pressures operating in that area.
Response-footprints	The area and time covered by the governance means of monitoring, assessing and controlling the causes and consequences involved in the use of the marine environment through public policy-making, marine planning and regulatory processes. The policies, marine plans and technical measures produced by these processes indicate the means of determining if legal controls are satisfied, and of providing information and data to national and supra-national bodies. They focus on the area and/or time covered by the marine management actions and measures (e.g. programme of measures), including the distribution and range of a species.

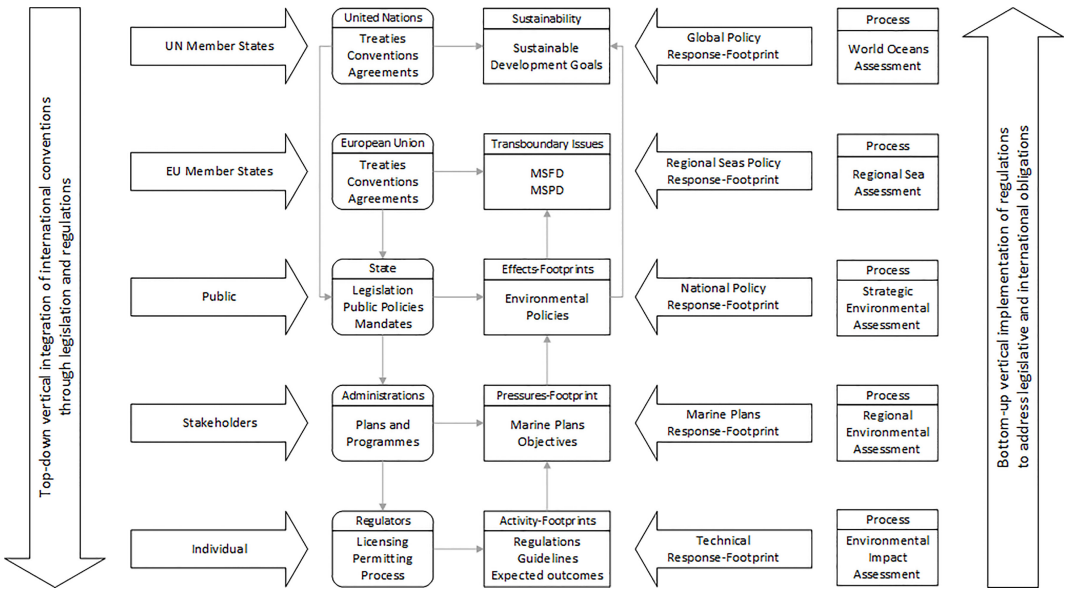

FIGURE 1 | The vertical link between policies, plans and technical response-footprints. Key for examples provided: MSFD, Marine Strategy Framework Directive; MSPD, Maritime Spatial Planning Directive; UN, United Nations; EU, European Union.

- ***Global policy response-footprints*** are the goals and objectives outlined in treaties, conventions and agreements such as those that are ratified and implemented by UN Member States legislation to fulfil in good faith their obligations. Within the spirit of international peace and sovereign equality, territorial integrity and political independence of its members under the UN Charter (UN, 1945), the role of the organizations and agencies of the United Nations is to coordinate and facilitate the negotiations and drafting of treaties, conventions, and agreements as directed by the UN Member States. In the marine environment, the United Nations Convention on the Law of the Sea (UNCLOS) (UN, 1996) defines the spatial boundaries of the sovereignty of Coastal States regarding the physical and biological resources as well as the right of innocent passage of any State Party to UNCLOS that does not have a coast - State Parties are those that have ratified the UNCLOS. UNCLOS also establishes the accountabilities of any State Parties regarding marine activities in the high seas from vessels flying their respective flags. UNCLOS is highlighted here because it ultimately frames the footprints of global policy responses of many other UN environmental instruments such as the Convention on Biological Diversity (CBD) (UN, 1992) as well as the International Convention for the Safety of Life at Sea (SOLAS) (UN, 1974) and the International Convention for the Prevention of Pollution from Ships (MARPOL) (UN, 1973). Although there are many assessments and scientific panels involved throughout these UN organizations and agencies, the World Oceans Assessment II (UN, 2021) is listed here as an example of the type of assessment that informs such global governance processes.
- ***Regional seas policy response-footprints*** are similar to the goals and objectives outlined for the global policy response-footprint. However, their treaties, conventions and agreements are applicable to specific and often designated regional marine areas even though these are still signed by member States as contracting parties. In the marine environment, the European Union (EU) directives are examples of regional seas governance processes that are legally-binding for the EU Member States. In the marine environment, directives such as the Marine Strategy Framework Directive (MSFD) (European Union, 2008; European Union, 2017) and the Maritime Spatial Planning Directive (MSPD) (European Union, 2014) are to be implemented within the context of the Regional Seas Conventions (RSC). Similar to ratification and implementation of UN instruments discussed above for UN Member States, such EU regional responses require the transposition of directives into national regulations for EU Member States and Acts of Parliament in non-EU States framing the regional seas policy response-footprint. The MSFD requires that EU Member States undertake an initial assessment of their marine waters to ultimately identify the programmes of measures which need to be taken in order to achieve or maintain good environmental status (Borja et al., 2013). In a wider European context, these regional instruments also include the Oslo and Paris (OSPAR), Helsinki (HELCOM), Barcelona (UNEP-MAP) and Bucharest Regional Seas Conventions (RSC) for the North-East Atlantic Ocean, the Baltic Sea, the Mediterranean and the Black Seas, respectively. As an indication of the reach of the regional agreements, the UNEP (UN Environment

Programme) Regional Seas Programme encompasses 3 types of Regional Seas Conventions and Action Plans (RSCAPs) (https://www.unep.org/explore-topics/oceans-seas/what-we-do/regional-seas-programme). This includes 18 different regions and other action plans: the UNEP-administered ones established and administered by UNEP include: the Caribbean Region, East Asian Seas, Eastern Africa Region, Mediterranean Region (Barcelona), North-West Pacific Region, Western Africa Region (with Regional Office for Europe administering the Tehran Convention for the Caspian Sea); the Non-UNEP administered ones were established by UNEP but have different secretariat bodies, including the: Black Sea Region (Bucharest), North-East Pacific Region, Red Sea and Gulf of Aden, ROPME Sea Area, South Asian Seas, South-East Pacific Region, Pacific Region, and thirdly the Independent ones not established by UNEP but cooperating with the RSC: Arctic Region, Antarctic Region, Baltic Sea (HELCOM), North-East Atlantic Region (OSPAR). These include both developed and developing countries and those with long and short histories of managing their sea region (for example the Baltic and North-East Atlantic RSC were established in the early 1970s) and therefore they give the more recent ones and those areas with a lesser capacity the chance to learn from the other RSCAPs. Most importantly, the RSC requires signatories to carry out the monitoring, assessment and reporting of the status of their marine environments. While the RSC requirements are not legally binding, the signatories have agreed to their implementation and there is an arbitration process for disputes between country signatories. Again, they require to be implemented through the national regulations and instruments of a signatory country. The regional Quality Status Reports produced by the RSC such as OSPAR and HELCOM give excellent examples of integrated marine assessments.

- ***National policy response-footprints*** are reflected by the legislation and policies that are developed through national policymaking processes within established jurisdictional boundaries of a State. Coastal States that have ratified and implemented UNCLOS may have different jurisdictional configuration that may typically start from the normal baseline up to the 12 nm for territorial seas and may include another 24 nm for the contiguous zone and outwards to the 200 nm (or the mid-line between adjacent states) for the exclusive economic zone (EEZ) that may be extended to the continental shelf. In the high sea, the jurisdiction of any State extends to any vessel or infrastructure flying their flag. For example, the United Kingdom (UK) has different jurisdictions and competent authorities that can take management actions within different boundaries such as the areas from 3, 6 or 200 nautical miles (nm) (Boyes and Elliott, 2015). National policy responses reflect public values and objectives expressed through policymaking processes that can follow very different national governance structures and are limited to the activities that occur within the boundaries of their jurisdictions. National legislation and policies are also needed to fulfil the obligations of global and regional policies. National policy response-footprints tend to be influenced by a wide range of concerns such as water quality, productivity or cumulative effects which can be more or less aligned with the effects-footprint (Elliott et al., 2020a). Within the context of regional seas policy response footprints, any transboundary issues between two jurisdictions would ultimately need some form of agreement to resolve these issues within their respective legislative authorities and policies. At this level, there are many examples of strategic environmental assessments used to assess the wider effects of plans and programmes on the environment (Weiland, 2010; Noble and Nwanekezie, 2017; Rehhausen et al., 2018). Indeed, as shown by the European Strategic Environmental Assessment Directive, SEAs are processes covering a regional area and designed to inform policy decisions in contrast to EIA that are processes to inform regulatory decisions. As indicated below, regulatory decisions include technical measures to address the impacts of the activities both singly and cumulatively.
- ***Marine plans response-footprints*** are the plans and programmes that are developed and implemented by administrations having received a mandate from their governments. These plans may outline strategies for new maritime activities, spatial allocation for many maritime activities including protection and conservation strategies for the marine environment. In consultation with relevant stakeholders, their planning and management processes are conducted within jurisdictional boundaries that frame the marine plans response-footprints established by their legislation within the national policy response-footprint. For example, in England, the Inshore Nature Conservation and Fisheries Authorities (IFCAs) cover fisheries to 6 nm whereas the Marine Management Organisation operates to 200 nm, and Natural England manages conservation to 12 nm whereas the Joint Nature Conservation Committee covers to 200 nm. Maritime spatial planning and integrated coastal and oceans management are also examples of marine plans response-footprints legislation (Scotland, 2012; Canada, 2019). Marine plans response-footprints may but not necessarily overlap in whole or in part with the pressures-footprints (Elliott et al., 2020a). There is a wide variety of regional environmental assessments produced to inform these processes for different purposes and environmental contexts such as ecosystem overviews and assessment reports (DFO, 2005), integrated ecosystem assessments (Diekmann and Möllmann, 2010), or the State of marine ecosystem reports (Bernier et al., 2018; Devlin et al., 2019).
- ***Technical response-footprints*** are the technical measures that are implemented through regulatory and non-regulatory frameworks to manage specific operations of an activity undertaken by an individual or a corporate entity. As part of a regulatory framework, technical measures are implemented as regulations, standards, standardized operating procedures that regulate and control a variety of impacts from individual activities (e.g. physical changes to

habitats, contaminants to mitigate pollution effects, biological disturbance to species life cycle, etc.). Technical measures dealing with continuous, often daily, tasks such as inspections and maintenance, monitoring and reporting, incident response plans and corrective actions are implemented through non-regulatory frameworks such as guidelines, codes of practice, good industry practices, etc. These response-footprint are also tightly linked (and of the same size and duration) to the activity-footprint that has been sanctioned by a regulator and regulatory approval processes including certifications (Elliott et al., 2020a). Such footprints are typically informed by an environmental impact assessment (EIA) and its environmental statement that scope the ecological, cultural, social and economic impacts for which the individual or corporate entity is accountable to address through their regulatory approvals issued by regulators (Elliott et al., 2020b). An EIA is very prescriptive being tied to the impacts of a particular development, at a specified time and place, performed in a given way with certain mitigation and communicated widely. Although an EIA must be carried out as part of the regulatory approval process, the identified impacts are then used by regulators to establish the technical measures as conditions for licensing or permitting how, where and when, for example, a land-based discharge, a sea-based dumping site or a marine oil and gas operation is to be undertaken (Lonsdale et al., 2015; Lonsdale et al., 2017). Each technical measure is designed to produce a specific expected outcomes to avoid, reduce, compensate or offset impacts within a mitigation hierarchy (Arlidge et al., 2018; Duarte and Sánchez, 2020). For example, technical measures would be implemented to fulfil the expected outcomes of the input controls, the spatial and temporal distribution controls and the output controls of the programmes of measures of the MSFD.

VERTICAL COHERENCE OF POLICY INTEGRATION VERSUS EQUIVALENCY OF REGULATORY IMPLEMENTATION

As a management system, policies are conditional on the performance of plans and programs that are in turn conditional on the effectiveness and reliability of the technical measures implemented for specific activities and their impacts (Cormier et al., 2018; Elliott et al., 2020b). Vertical and horizontal policy integration is imperative to implement local to global ecosystem management strategies in the marine environment (Rosendo et al., 2018; Kidd et al., 2020; Winther et al., 2020). Vertical integration encompasses policy and management responses from the global to the local whereas horizontal policy integration operates and integrates across the sectors and activities (fishing, aquaculture, navigation, recreation, etc.) (Boyes and Elliott, 2014). Although maritime spatial planning is considered as a key to policy integration, integration, in practice, depends on the context of the policy objectives involved such as sustainable development, ecosystem-based management or marine protected areas (Zaucha and Gee, 2019). Integration may be applied to decision-making and planning processes, risk assessments and management or stakeholder consultation and participation (Lombard et al., 2019). Thus, vertical and horizontal integration is still necessary but difficult to achieve because of capacities needed for planning processes including the governance structures and decision-making processes in a given national context (Cormier et al., 2019; Stelzenmüller et al., 2021).

Top-down vertical policy integration across the response-footprints implies that global and regional policy responses have to be integrated in the development of national policy responses (**Figure 2**). After the treaties, conventions or agreements have been ratified and signed, it is up to the member States or contracting parties to take the *actions* necessary to implement these as their national

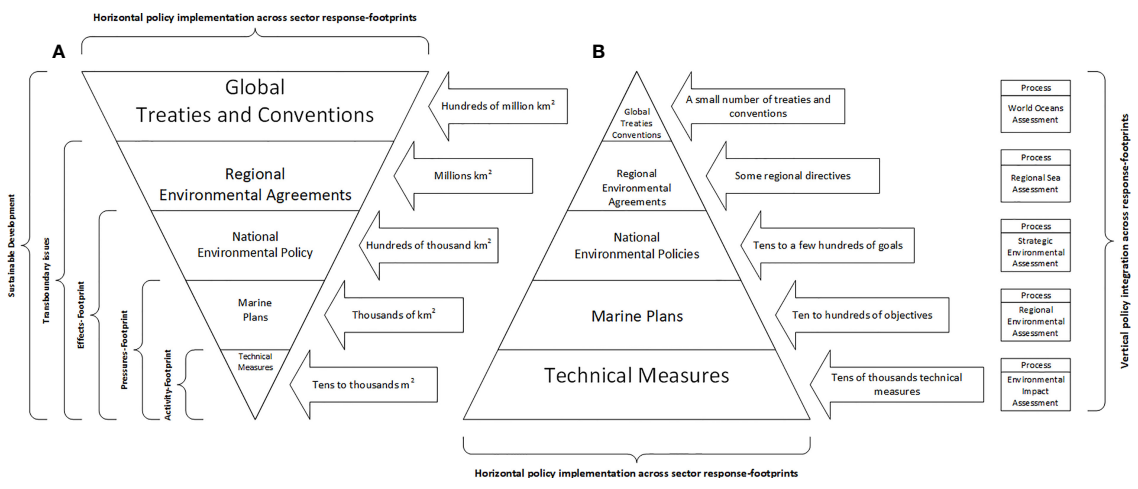

FIGURE 2 | The 'management response-footprint pyramid' – showing both **(A)** the areas covered by management response-footprints and **(B)** the number of policy instruments; horizontal and vertical policy integration is also denoted.

policy responses. It is subsequently the administrations that have to take the necessary *actions* to initiate marine planning processes to develop marine plans to address their respective national policy responses. The ultimate *action* is taken by the regulator to identify the technical measures to address the objectives of marine plans that start the bottom-up policy implementation across response-footprints (Stephenson et al., 2017).

Therefore, the linking and illustration of the size of the management response-footprints takes the form of a pyramid which can be presented in either the inverted or standard form (**Figure 2**) but which respectively indicate that (a) local management initiatives (such as an EIA) may cover a small area or a short timeline whereas regional and then international/global initiatives cover larger areas and timelines, and (b) that there are many statutory instruments or agreements at local levels leading up to a few global agreements. We have termed this 'the management response-footprint pyramid' (Ruini et al., 2015). As discussed above, **Figure 2** also indicates that marine management responses have to be integrated horizontally (across the width of the pyramid) and vertically (up the height of the pyramid). Whether the pyramid is then being used to determine top-down or bottom-up management results in the pyramid being inverted or the usual way around, one would expect that the footprints of these responses are spatially integrated into one another to ensure coherence across the responses by each level of governance (Inverted pyramid **Figure 2A**).

In essence, global and regional treaties, conventions and agreements have a response-footprint that can span millions km^2 of global oceans to achieve the UN SDG 14 "Life below water" (Cormier and Elliott, 2017). These overlap with or encompass in whole or in part hundreds of thousands km^2 of national policy responses-footprints such as the EEZ of a State or the territorial waters. This is further exacerbated by the footprint of marine plans that can span thousands of km^2 such as the maritime spatial plan for the southern North Sea or the Belgian Shelf area (Elliott et al., 2020a). At the smallest scale and much more locally there is the footprint of the technical responses that deal with tens to thousands m^2 such as the conditions established in licences and permits that are informed by an EIA (e.g. for an offshore windfarm or an aggregate extraction area).

The integration challenges of each footprint are also influenced by the individual governance, management and regulatory processes involved in each footprint that are not conducted by the same authorities and within the same time frame. Most if not all maritime States have a plethora of marine management organisations and statutory bodies, often with overlapping mandates and competences (Boyes and Elliott, 2015). Based on the premise that sustainable development and transboundary issues are ultimately addressed through national policy responses within the footprint of their jurisdictions (ICES, 2021; Cormier and Minkiewicz, 2022), any given State can only address global and regional policies within the footprints of their legislative, policymaking, marine planning and regulatory processes. Without the collaboration of multiple coastal States within a regional sea, a State can only address the environmental impacts, pressures and effects that occur within their national policy response-footprints (Elliott et al., 2020a). In cases where pressures- and effects-footprints overlap across Coastal State boundaries, horizontal integration of policies is dependent on the level of policy coherence across national policy response-footprints (Elliott et al., 2020b).

A large number of technical measures implemented through regulatory and non-regulatory frameworks are used to reduce the impacts within a specific activity-footprint (**Figure 2B**). As discussed above, an EIA identifies the impacts to subsequently identify the technical measures needed to minimise the size and duration of their impacts and, ultimately, the pressures and effects they may collectively generate. Given that operating licences, authorisations and permits are based on sector planning permissions, the technical measures relate mainly to the activity itself while the pressures and effects they generate often disperse across jurisdictional boundaries and persist for as long as the activity operates (Trendall et al., 2011; Borgwardt et al., 2019). For example, an individual dredging programme requires a permit that is issued by a national competent authority to the dredging company. The Member State of this competent authority is then required to report this under the relevant RSC giving the contaminant levels in the dredged material, the quantities of sediment moved and the ability to meet quality standards (Alvarez-Guerra et al., 2007). Even though there might be very good coherence in the vertical integration of policies across global, regional and national footprints as well as in the horizontal integration across marine plans, there might not be any equivalencies of the technical measures used across national regulatory and non-regulatory frameworks for the impacts of an activity within the context of transboundary pressures and effects (Cormier et al., 2017). Continuing with this example, the RSC and the UN Member State that ratified the London Convention and Protocol for dumping at sea may not be able to ensure effective control of marine pollution from dumping of wastes and other matter and ultimately address the targets outlined for the United Nations SDG14 (life below water) (UN, 2016).

While the technical response-footprints may only apply to tens to thousands of m^2, there are many technical measures that are implemented through regulatory and non-regulatory frameworks across jurisdictions (**Table 2**). In addition, the performance of marine plans and the success of national policies depend on the implementation of effective and reliable technical measures that provide equivalent levels of protection across their respective activity-footprints (Cormier et al., 2018; Murillas-Maza et al., 2020). Given the challenges of technical equivalencies across jurisdictions, the global and regional governance processes would require effective collaboration to promote equivalency of technical measures to address transboundary issues as dedicated by global and regional policy responses such as the case for MARPOL and SOLAS (Cavallo et al., 2018).

VERTICAL INTEGRATION OF ENVIRONMENTAL ASSESSMENTS ACROSS RESPONSE-FOOTPRINTS

In recent decades, policies in the form of treaties, conventions, agreements, legislation, plans and programmes have evolved into a

TABLE 2 | Examples of regulations, codes of practice, and guidelines as technical response-footprints.

Technical responses	Type of response	Authority
Wastewater Systems Effluent Regulations	Deleterious effect to fish regulations	*Fisheries Act* https://laws-lois.justice.gc.ca/eng/acts/f-14/
Potato processing plant liquid effluent regulations	Deleterious effect to fish regulations	*Fisheries Act* https://laws-lois.justice.gc.ca/eng/acts/f-14/
Disposal at sea regulations	Pollution prevention regulations	*Canadian Environmental Protection Act* https://laws-lois.justice.gc.ca/eng/acts/c-15.31/
Persistence and bioaccumulation regulations	Pollution prevention regulations	*Canadian Environmental Protection Act* https://laws-lois.justice.gc.ca/eng/acts/c-15.31/
Environmental code of practice for metal mines	Complete life cycle of mining	Environment and Climate Change Canada https://www.ec.gc.ca/lcpe-cepa/documents/codes/mm/mm-eng.pdf
Canadian environmental quality guidelines	Quality of aquatic and terrestrial ecosystems	Canadian Council of Ministers for the Environment https://ccme.ca/en/summary-table
New-Brunswick watercourse and wetland alteration regulations and guidelines	Manage the operations of an activity	*New Brunswick Clear Water Act* https://www.canlii.org/en/nb/laws/regu/nb-reg-90-80/latest/nb-reg-90-80.html https://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/Water-Eau/WatercourseWetlandAlterationTechnicalGuidelines.pdf

complex structure of instruments that reflect global, cultural, social, economic, and environmental concerns (as in the horrendogram given in Boyes and Elliott, 2014). Having been developed independently, policies have become issue- and concern-centric that have likely contributed to the so-called *fragmentation* of policy responses to broader environmental issues (Raakjaer et al., 2014; Michanek et al., 2018). Given the need for scientific knowledge and advice, these issue- and concern-centric policies have also framed the science produced to inform those policymaking processes independently for each response-footprint. There are many forms of environmental assessments (**Table 3**) but this leads to what may be called the environment assessment paradox – 'that there are more and more environmental initiatives requiring assessments but there is less funding for achieving them (or the funding is put onto industry)' (Borja and Elliott, 2013; Strong and Elliott, 2017; Borja and Elliott, 2021).

The performance of policy responses and their footprints span significant spatial and temporal scales (**Figure 3**). Based on the premise that societal goals and objectives, and indeed the vision for our seas, rely on regulatory frameworks (Elliott et al., 2020b), the performance of global, regional, national marine policy and management responses ultimately rely on the technical measures of the regulatory frameworks to approve and regulate activities within their technical response-footprints. For example, defining and controlling the footprint of an offshore windfarm and considering its pressures and effects based on national legislation are only as good as our ability to (a) carry out the EIA, (b) ensure that there are effective and reliable technical measures to mitigate and/or compensate the impacts on nature and society, and (c) check *a posteriori* that the predictions of impact and the effectiveness of the technical measures were accurate (i.e. the management measures really did address the impacts which occurred). Paired with fragmented scientific advice related to management and operational implementation (DFO, 2014), ineffective and unreliable technical measures used to regulate the root-causes of environmental pressures and effects contribute to the uncertainties of achieving national, regional and global goals and objectives and ultimately, the performance of their policy response-footprints (Cormier et al., 2018). Given that risk is defined as the effect of uncertainty on objectives (ISO, 2018;

TABLE 3 | Examples of Environmental Status Assessments.

Intent of the instrument	Instruments
Catchment quality	• EU Water Framework Directive • US Clean Water Act
Habitat and species conditions	• EU Habitats Directive • Canada National Marine Conservation Act
Marine regional quality	• EU Marine Strategy Framework Directive • US Oceans Act • Canadian Ocean Act
Cumulative impacts and effects assessments	• EU Cumulative Impact Assessment Directive • Canadian Impact Assessment Act • Canadian Fisheries Act
Strategic environmental assessments	• EU Strategic Environmental Assessment Directive • Canadian Impact Assessment Act
Environmental impact assessment	• Environmental impact assessment legislation worldwide
Regulations and codes of practice for industry and marine activities	• Canadian Environmental Protection Act regulations • Fisheries Act regulations

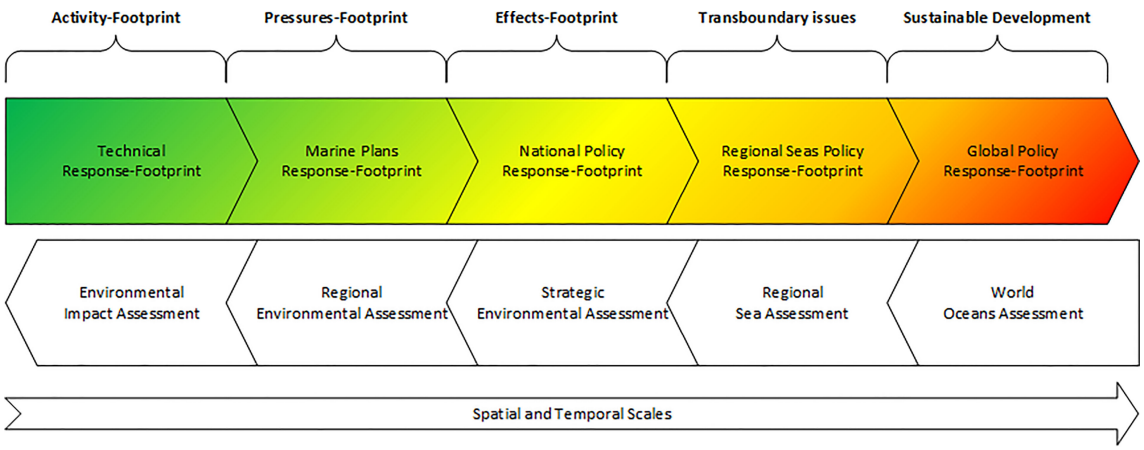

FIGURE 3 | Vertical integration of assessments.

IEC/ISO, 2019), a preventive risk management strategy of the root-causes of risk carries the least uncertainty in achieving objectives while a reactive risk management strategy of the consequences of risk carries the most uncertainty in achieving objectives. Thus, effective and reliable technical measures implemented within the technical response-footprint for an activity carries the least uncertainties in achieving objectives of national, regional and global policy responses (Green to red colour in **Figure 3**). However, relying on global, regional and even national policy responses in reaction to issues and concerns carries the most uncertainties in achieving objectives (Red to yellow transition in **Figure 3**). In risk management, controls are implement to prevent the causes of risk and mitigate the consequences of risk effectively reducing the uncertainty of achieving objectives.

As discussed above and illustrated in **Figure 2** for vertical policy implementation across response-footprints, this also requires top-down vertical integration of the science and knowledge generated across the assessments to ultimately provide the context for an EIA at the technical response-footprint level (**Figure 3**). An assessment conducted for a given policy response should inform the responses that are and can be implemented for the specific footprint. Thus, there is as much need for top-down vertical integration of the scientific knowledge as there is advice generated by the assessments within each response-footprint. For example, there is an increasing number of methods for ocean status assessments (Borja et al., 2016). One would expect that a world oceans assessment conducted for a global policy response could inform the context for regional sea assessments to integrate the relevant global knowledge in such assessments (as in UN, 2021). Not all global pressures and effects can be dealt with at a given regional policy response; for example, climate change adaptation requires global initiatives such as Paris COP but as the coordination of national initiatives with global science. The same can be said of a regional sea assessment where regional pressures and effects cannot necessarily be dealt with one national policy and marine plan responses, as happens in the case of the MSFD in the different regional and sub-regional seas (Borja et al., 2019).

FACTORS AFFECTING THE RESPONSE-FOOTPRINTS

There are many factors that can facilitate as well as impede the integration of the response-footprints (**Figure 4**). For example, global policy response-footprints in the high seas depend on the cooperation of UN Member States that are parties to UN conventions and agreements to find solutions (Blaustein, 2016). In essence those States need to coordinate their activities to protect and preserve the marine environment and its biological diversity as well as address demands from their constituents (UNCLOS and CBD). These goals especially depend on the coherence of marine policies and plans within the boundaries of regional sea and the capacity of coastal States to ratify and transpose such policies into national legislation and/or regional legislation as in the case of EU Directives. Even when UN conventions and agreements are ratified and implemented by UN Member States through their legislation, the performance of national plans and programmes depends on the mandates and the complexities of national competent authorities to lead and facilitate marine planning processes across internal jurisdictions. It also requires that stakeholders have the capacity to deal with the collective pressures generated by multiple marine activities. Ultimately, the success of global and regional policy responses depends on the performance of national policy responses, the integration of marine plans and the equivalency of technical measures implemented across national jurisdictions including the high seas. As discussed for **Figure 3**, it is the equivalency of technical measures implemented across the technical response footprints of multiple jurisdictions that carries the least uncertainty in achieving global goals and objectives such as the UN Sustainable Development Goals shown as an example in **Figure 4**.

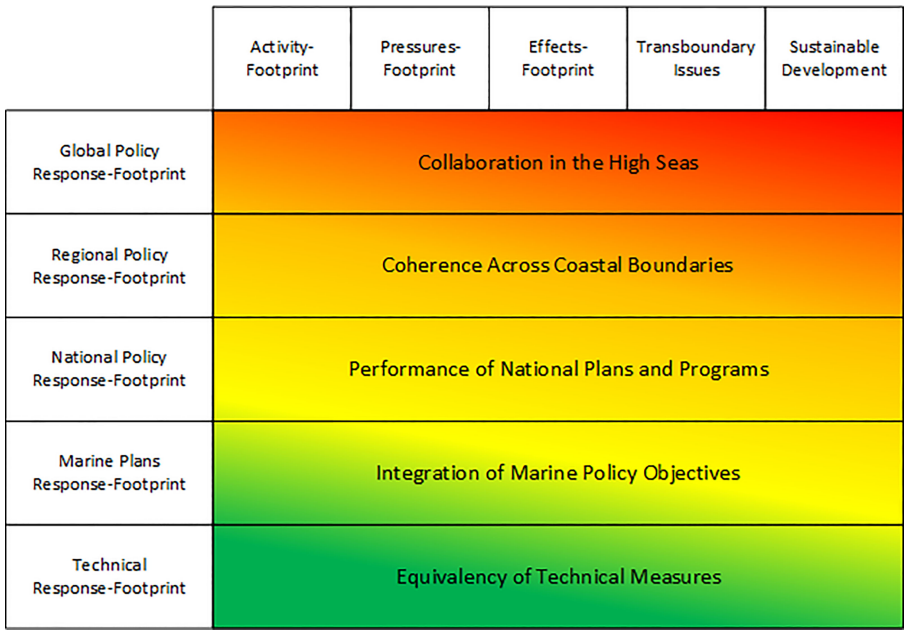

FIGURE 4 | Factors affecting the efficacy of the response-footprints.

Although the response-footprint framework discussed here is primarily focused on a structured governance processes of policymaking, marine planning and regulatory approval, the capacity of the governance and administrative systems of States have to be acknowledged. Following the principles of sovereign equality, territorial integrity and political independence of UN Member States (UN, 1945), we have to recognize that States have inherently different political and policymaking processes, legal and administrative systems that may or may not reflect the structure of the framework discussed here.

As examples, **Table 4** links activity-, pressures- and effects-footprints with the management response-footprints according to the specific technical measures implemented to address marine plans objectives and ultimately national, regional and global policy responses. A technical response-footprint is much more specific compared to broader goals established for regional and global response-footprints. For example, a national law may only control sea dumping of dredged material whereas the global goal may be to protect the whole marine system and, under the principle of subsidiarity, whereby decisions should be taken as close to the population as possible, devolving decisions to the lowest practical political level, leave the precise mechanism of achieving this to the State. At a lower level, this is analogous to the EU setting a framework directive, such as the MSFD, and then leaving the precise implementation to an EU Member State.

DISCUSSION

The residual impacts of each activity generate pressures that are specifically tied to its precise, often daily operations and ultimately contribute to the effects on the natural and societal systems (respectively the State change and Impacts (on human Welfare) under DAPSI(W)R(M)). The activity-footprint may be located on land, in rivers and lakes and still generate pressures in these adjacent estuarine, coastal and marine environments (Borgwardt et al., 2019). For example, agriculture, urban and industrial developments create diffuse and point source emissions which then create pressures and effects far from their source. As such, the amount of pressures to estuaries, coastal zones and the seas are highest from land-based, estuarine, and coastal activities. Some of these pressures ultimately disperse to the marine environment causing effects at multiple ecosystem scales (Borgwardt et al., 2019). It is axiomatic that in developed countries, and many developing countries, any activity that has the potential to adversely affect the environment needs legally-enforced conditions of approvals issued through authorisations, licences, permits or consents. As conditions of approval, technical measures are typically used to regulate human activities and the impacts within their individual footprints wherever they are located. As regulations impose compliance requirements on an individual or a corporate entity, regulations are implemented through the authority of national legislation that also establishes the footprint of their internal jurisdictions (Cormier and Minkiewicz, 2022). In the case of supra-national bodies, such as the EU, sanctions to the Member State for infraction proceedings for non-compliance of EU legislation can be actioned by the European Court of Justice while compliance for individuals or corporate bodies remain with the competencies of that EU Member State and its judicial system (De Santo, 2011).

Marine management responses are a means to integrate the technical responses and national legislation from multiple internal jurisdictions. Hence, the plethora of bodies with a

TABLE 4 | Examples of linkages between the different types of footprints (Elliott et al., 2020a).

Environmental Footprints			Management Response-Footprints				
Activity	**Pressures**	**Effects**	**Technical Measures**	**Marine Plans**	**National Policy**	**Regional Seas Policy**	**Global Policy**
Land-based undertakings and activities such as urban development, agriculture, and forestry	Catchment input of nutrient and organic matter	Eutrophication and anoxia of estuaries and coasts	Catchment regulations and environmental quality guidelines to control the sources nutrients	Catchment planning of activities and assessment of their collective pressures	Territorial and coastal development and environmental protection legislation and policies	EU Water Framework Directive	UN Sustainable Development Goals and Targets for oceans (14) and for land (15)
Estuarine works and infrastructure such as crossing and ports	Barriers to hydrological flows and flushing	Change in migration patterns of species and fragmentation of species populations	Regulations and guidelines for the location and design of works and infrastructure	Coastal and estuarine integrated plans	Territorial and coastal development and environmental protection legislation and policies	EU Marine Strategy Framework Directive	UN Convention on the Law of the Sea Part XII Protection and Preservation of the Marine Environment
Marine transportation and shipping	Input of contaminants	Pollutions effects in the estuarine, coastal and marine environments	Implementation of IMO MARPOL Codes and recommendations into maritime shipping regulations	Maritime spatial plans	Ratification MARPOL and transposition of EU MSPD into legislation	EU Maritime Spatial Planning Directive	MARPOL codes, guidelines and recommended practices
Marine fisheries	Fishing mortality of targeted and non-targeted species and gear impacts to seafloor	Decreased fishery productivity and changes to the integrity of the seafloor	Fisheries regulatory conditions of licence	Integrated fisheries management planning processes	Fisheries sector development and environmental protection legislation and policies	EU Common Fisheries Policies	UN Convention on Biological Diversity and Code of Conduct for Responsible Fisheries

marine management competency, as shown for one country within the UK by Boyes and Elliott (Boyes and Elliott, 2015), require their response-footprints to be formally or at least informally coordinated. Using that example from the UK, the different bodies in England responsible for managing inshore and offshore fisheries (the Inshore Fisheries and Conservation Authorities (IFCAs) and the Marine Management Organisation (MMO) respectively) have to ensure compatibility in their response footprints. Hence, marine management planning processes have to provide a more holistic approach as an overall response-footprint bringing together managers, regulators and stakeholders to determine how best to manage multiple activities within the marine plan response-footprint while implementing and complying with existing regulatory and non-regulatory requirements. As an overall national policy response-footprint (for example to ensure that a State fulfils the SDG14 to protect its marine waters (Cormier and Elliott, 2017), national legislation establishes both the territorial boundaries of sovereignty to natural resources and the authority to regulate activities. In turn, regional and global policy responses ultimately rely on the national ratification or transposition to achieve their policy goals and objectives.

Technical responses indicate how, where and when an activity can take place while reducing, mitigating and controlling impacts to address the objectives to be achieved in marine plans (Murillas-Maza et al., 2020). National policy responses reflect the societal values of the people living within the boundaries of their States providing the reasons why actions regarding development and sustainability are to be taken which are expressed as legislation, policies and priorities. Global and regional policy responses reflect the transboundary issues that Member States or Contracting Parties have identified as priorities to be addressed through international collaboration and coordination (Cavallo et al., 2018). Regardless of the treaties, conventions and agreements established as global or regional policy responses, current governance structures still require the State to legislate any actions on its individuals and corporate bodies. The principle of subsidiarity is important especially at the level of supranational bodies such as the United Nations and European Union, thereby allowing (or requiring) Member States to take action (Koivurova, 2009). Therefore, these organizations play a major role to ensure coherence across the policies and equivalencies of the management strategies of their Member States to achieve common goals and objectives.

As shown here, the management response-footprint pyramids operates both in a bottom-up and a top-down manner and shows the clearly delimited size (and duration) of the response-footprint for an individual development such as an offshore oil extraction platform. The activity-footprint is well-known in both space and time (i.e. the area occupied by an oil platform and the length of time it is being constructed, operated and been decommissioned are easily determined) and hence so would be the management response-footprint for the activity; in contrast, the management response-footprints for the pressures

and the effects on the natural and social systems are less easily defined given the dynamic nature of the marine environment, the dispersion properties of materials emanating from the site and the often highly mobile nature of the organisms affected by the development. At larger scales, the management response-footprints for multiple activities, cumulative and strategic effects, including maritime spatial planning become much harder to define and quantify. In addition, these often require consideration of transboundary consequences, given that the pressures and effects emanating from an activity in the waters of one country can extend to the waters of other adjacent countries (European Commission, 2020).

At the highest level, the current configuration of the governance, management and regulation of maritime activities are framed by the key principles of the United Nations Charter (UN, 1945) that recognizes sovereign equality of all its Members and to refrain from threats or force to their territorial integrity and political independence. UNCLOS simply transposes these principles to the sea in terms of territorial seas and contiguous zones (Part II), straits used for international navigation (Part III), archipelagic States (Part IV), exclusive economic zones (Part V), the continental shelf (Part VI), the high seas (Part VII), regime of islands (Part VIII), enclosed or semi-enclosed seas (Part IX), and the right of access of land-locked States to and from the sea and freedom of transit (Part X). Only the Area (Part XI) curtails the sovereignty of the Members regarding the physical resources and beneath the seabed, including polymetallic nodules which fall under the authority of the International Seabed Authority. Although above we provide generic definitions for the types of the response-footprints, the boundaries of the national policy response-footprints in the marine environment and the marine management and regulations of their maritime activities will ultimately reflect their sovereignty to physical and biological resources within their jurisdictional boundaries as defined by UNCLOS as listed above.

Currently, top-down vertical integration loosely integrates the policy responses from global, to regional, to national and their implementation through marine plans and technical responses (Stelzenmüller et al., 2021). Therefore, an evaluation of the level of integration of marine plans can seldom be linked to the performance of national plans and programs as well as issues surrounding the coherence of global and regional policy responses regarding the management of maritime activities. Global, regional and national policymaking processes most often leave the implementation of such policies to future national regulatory programmes (Marsden, 1998). For example, States Parties to UNCLOS dedicated considerable efforts to ratify UNCLOS to establish their boundaries in the marine environment since coming into effect in the 1990s (e.g., Part II to Part X). Although some have ratified the provisions for the protection and preservation of the marine environment within their jurisdictional boundaries (Part XII) (Cormier and Minkiewicz, 2022), State Parties to UNCLOS have yet to extend these provisions to the high seas to address transboundary issues globally (Verlaan, 2021). Because of the fragmentation of policies, it is also difficult to infer that legislation and policies *carry into effect* the goals and objectives they were set to achieve even though considerable scientific knowledge and stakeholder inputs were brought to bear (Pearl, 2014; Cormier et al., 2017; Korkea-aho, 2022).

We acknowledge that our analysis is written largely from the perspective of the developed countries, principally in Western Europe, North America and Australasia, but also including considerations from the developing and less-developed countries (e.g. Dunstan et al., 2021). It is emphasised here that countries have different capabilities and capacities for marine management and those countries may be regarded as separated into capability, data and skills rich and capability, data and skills poor. It is expected that those with lesser histories of marine management can learn from more-experienced countries and regions and implement marine management policies suited to their particular circumstances. We consider that it is notable that many governance measures and legal instruments can be adopted and often verbatim by other countries without 're-inventing-the-wheel'. Indeed, although outwith the current analysis, given that most if not all maritime states have similar governance structures, it is suggested that the 'law of diminishing returns' applies here in that some marine management initiatives, such as the coordination of ministries and legal instruments related to the marine can be achieved for less-developed maritime states. While we have not attempted a discussion of the financial means of implementing the management response-footprints, we acknowledge that the different measures differ in their cost-effectiveness. For example, the costs of the activity-based measures will be placed upon the developer and industry rather than the state, under the polluter-pays principle. Multiple UN conventions and agreements, such as UNCLOS, have provisions for scientific and technical assistance regarding global and regional rules, standards and recommended practices to address marine pollution and environmental concerns. Examples of international scientific and technical assistance are the international standards, codes of practices and guidelines from the International Maritimes Organization for security and marine pollution including a broad range of other concerns such as the World Health Organization for human health (https://www.who.int/), the Codex Alimentarius for food safety (https://www.fao.org/fao-who-codexalimentarius/en/), the World Organization for Animal Health (https://www.oie.int/en/home/), and the work of the International Plant Protection Convention (https://www.ippc.int/en/). These international organizations have a long history of collaboration in the development of technical measures that can be used by any country.

The capability and capacity of a state to enact the management response-footprints described here also relate to the past or current nature of the state. It is of note that many post-colonial countries have administrative and legal systems derived from their past colonial powers in Western Europe and so may already have an appropriate governance framework. It is expected that as, for example, the UNEP Regional Seas Programmes expand to include states with lesser histories of

marine management that can learn from other programmes then good practice in marine management can be transposed to more areas. Despite this, it is also realised that those countries with current or recent unstable geopolitical systems will have priorities other than the integrated management of their seas.

We further acknowledge that we have placed more emphasis on the spatial element of management response-footprints and that the temporal element is of equal importance. This has partly been due to the space available in the manuscript but we also take the view that the temporal aspect cannot be addressed in detail until the spatial element is defined but also that the temporal aspect is even more dependent on the capacity and capability of a country than is the spatial element.

CONCLUSIONS

Marine management implies that the spatial and temporal scales of management are understood and built into prevailing legislation and administrative structures. Those temporal and spatial scales are needed to embody the footprints of activities, their pressures and effects on the marine natural and human systems. However, given that the dynamic nature of the seas requires actions not just at the national level but also the regional and supranational and global levels, those management actions and responses all have their own footprints, even if some of these are overlapping. It is emphasised here that the sustainable management of the seas and their resources requires that the different types and magnitudes of footprints to be understood, quantified and integrated into a holistic marine management approach.

AUTHOR CONTRIBUTIONS

RC, ME, and AB conceived the paper and contributed in an equal manner to the preparation of the paper. All authors contributed to the article and approved the submitted version.

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