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Towards a common approach to the assessment of the environmental status of deep-sea ecosystems in areas beyond national jurisdiction

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ABSTRACT

Many of the marine policy frameworks developed to protect biodiversity in deep-sea areas, including areas beyond national jurisdiction (ABNJ), include indicators to assess policy objectives. These frameworks often have specific guidance on how the indicators should be applied and interpreted. Selection of indicators is an important process and those with strong scientific underpinnings are more likely to produce the expected outcomes. We reviewed three policy and assessment frameworks which include ABNJ regions or were developed specifically for ABNJ: (1) Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) ecosystem assessments, (2) the frameworks adopted to implement the UN General Assembly (UNGA) sustainable fisheries resolutions for the management of bottom fisheries to prevent Significant Adverse Impacts on vulnerable marine ecosystems, and (3) the Aichi Biodiversity Targets adopted by Parties to the Convention on Biological Diversity (CBD). We examined whether an assessment approach based on evaluation of Good Environmental Status (GES) under the European Union's Marine Strategy Framework Directive (MSFD), could be applied to ABNJ. We examined each MSFD descriptor for its applicability to deep-sea habitats considering the work of two European projects concluding that the MSFD could be applied to ABNJ to support OSPAR, UNGA and CBD policy objectives towards a common approach to the assessment of the status of deep-sea ecosystems in ABNJ. In achieving this we also introduce readers outside of Europe to the work conducted within the MSFD.

1. Introduction

Increasing anthropogenic pressures on marine ecosystems can impact their sustainability and provision of ecosystem services. As a result, there has been a growing acknowledgement of the value of Integrated Ecosystem Assessments (IEAs) to monitor such impacts, and of their importance in supporting an Ecosystem Approach to assessing status and trends of marine ecosystems, and informing policy makers and managers of threats and impacts of human activities [1–10]. However, there are many challenges facing the development and implementation of IEAs, especially in the deep sea, including defining objectives, developing targets and indicators, undertaking risk analyses, and creating tools to evaluate management measures for marine anthropogenic activities [11,12]. A number of structured frameworks

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for IEAs have been evaluated in different geographical areas, with varying degrees of comprehensiveness and testing [11,13–16]. Notwithstanding the diversity of possible ways to conduct IEAs, some general properties emerge about their structure, including:

1) the value of explicit policy and management objectives in scoping what to assess;
2) the use of indicators for at least some key part of the assessment, so that changes can be tracked in a consistent manner, interpreted relative to the objectives and allow comparisons between assessed areas;
3) assessments and component indicators that track both structural and functional properties of the ecosystem as well as other aspects now referred to as "ecosystem services";
4) use of the best available information and robust indicators, while recognizing that a weak surrogate is better than leaving the feature out altogether [17]; and
5) adopting an explicit framework for a specific use, applying that framework consistently, so that changes from one assessment to the next reflect changes in the ecosystem and its uses, not just changes in which variables were used and what analyses were done.

To be a useful assessment framework, the assessment outputs should be structured so the results inform decision-makers of biodiversity status and trends in ways relative to the expected outcomes of the various high-level policies and implementation criteria already in place for the protection of biodiversity in Areas Beyond National Jurisdiction [18]. This was indeed the motivation for this manuscript, i.e., to explore the potential usefulness of the existing Marine Strategy Framework Directive (MSFD) as an assessment framework to be applied more broadly to ABNJ. It is also highly relevant to current negotiations on an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine Biological diversity of areas Beyond National Jurisdiction (BBNJ) (General Assembly resolution 72/249), in particular when considering establishing baselines for Environmental Impact Assessment.

Globally, there is a need for a consistent and fit for purpose IEA framework for deep-sea ecosystems (i.e., areas below 200 m depth, below the photic zone and often beyond the edge of the continental shelf) to support the various international policies currently in place and those anticipated in the near future. This may be achievable because a number of those policies have a high degree of commonality in their objectives, and other reviews have concluded that the different sets of criteria developed are complementary and practical to implement [19]. However, although the various criteria that have been adopted do provide a basis for prioritizing conservation efforts, guidance is not consistently available for assessing success of the conservation measures implemented and for establishing baselines for such evaluations as is required for a robust IEA. Availability of guidance on setting baselines and/or thresholds and conducting evaluations for conservation in the deep sea could reduce the likelihood of inconsistent and possibly ineffective practices.

Of the many IEA frameworks available which might provide a basis for an IEA framework for the deep sea, the system developed for the MSFD to assess Good Environmental Status (GES) is particularly promising, for two reasons. First, it is a comprehensive policy framework with objectives for essentially all parts of the marine environment and its uses. Second, European Union (EU) waters encompass a wide variety of deep-sea habitats, including seamounts, vents, seeps, cold-water coral reefs and gardens and deep-sea sponge grounds, from a range of biogeographic realms [20] and most major uses of the deep ocean are currently undertaken in at least parts of EU waters. The aforementioned deep-sea habitats and features are also found in ABNJ, consequently, many of the conditions and pressures likely to be encountered in the waters beyond national jurisdiction are assessed within the MSFD framework. The MSFD IEA framework for assessment of GES is an indicator-based system relying on suites of indicators to capture the complexity of marine ecosystems from the coast to the deep sea within EU waters. Such systems can give insight into the status and trends of the marine environment and their social and economic dimensions, but the suites of indicators must be carefully selected and their links to the policy objectives, their sensitivity to detect change, and their performance characteristics must be evaluated [17]. The MSFD IEA framework is the subject of extensive scientific input by the International Council for the Exploration of the Sea (ICES), and the Joint Research Centre (JRC), the European Commission's science and knowledge service, to develop a complete assessment framework with comprehensive indicators linked to the policy objectives. Together ICES and the JRC provided the background information for the European Commission Decision on criteria and methodological standards on GES of marine waters and on the scientific development, benchmarking, and operationalization of IEAs. The latter was extensively tested for practicality of application and relevance of outputs [14,21,22]. Within the EU, several policy initiatives have also triggered development of other indicator-based frameworks, for example the Natura 2000 framework of the Habitats [23] and Birds [24] Directives, which complement and support the MSFD.

Due to greater data availability, the MSFD IEA framework for assessment of GES, in common with most IEAs, has been applied primarily to coastal waters and shelf seas. However, two recent EU projects funded under the Horizon 2020 programme (ATLAS[2]) and DG Environment (IDEM[3]) have separately applied the MSFD IEA framework in deep-sea areas of the EU to evaluate its effectiveness in these data-limited areas. In particular, the ATLAS project collected new data from a number of deep-sea habitats [25], providing one of the most comprehensive data sets on deep-sea ecosystems, due to their 12 case study areas located across the North Atlantic. In each case study area multidisciplinary research has been carried out for years and in some cases decades, allowing for an evaluation of the performance of the MSFD framework in a wide range of deep-sea habitats over a large geographic scale (see Kazanidis et al. in press and references therein, [25]). This provides the opportunity to evaluate the MSFD IEA framework as a prototype for a global assessment framework for the deep sea. Similarly, in the case of IDEM project a meta-analysis was conducted for all MSFD descriptors, on the deep-sea realm across the Mediterranean Sea, offering an up to date picture on the current status and potential application of the descriptors to the Mediterranean deep-sea based on current knowledge [26].

Despite global data gathering efforts, such as the Global Ocean Observing System and it's set of Essential Ocean Variables [27] and global data repositories such as the Ocean Biodiversity Information System [28], there are no globally agreed policy objectives for the entire deep sea. At this point the available benchmark of outcomes for successful policies and implementation measures are generally taken from meeting components of the United Nations (UN) Sustainable Development Goal (SDG) 14, "Conserve and sustainably use the oceans, seas and marine resources for sustainable development", 2030 agenda [29]. The Aichi Biodiversity Targets [30] (UNEP 2010, UNEP/CBD/COP/10/9) also provide objectives for evaluating success at implementing measures for conserving biodiversity. Currently a global IEA framework does not exist but it could be adopted to support evaluating progress towards these global objectives, as well as objectives of other global and regional policies that may be integrated with the SDGs and successors to the Aichi Biodiversity Targets. A common global assessment framework would

[2] ATLAS is a European Horizon 2020 project "A transatlantic assessment and deep-water ecosystem-based spatial management plan for Europe" grant agreement No 678760.

[3] IDEM is a DG Environment project "Implementation of the MSFD to the deep Mediterranean Sea" grant agreement No 11.0661/2017/750680/SUB/ENV.C2.

ensure harmonised, consistent and comparable environmental assessments. It would also facilitate the development of common and cost-effective monitoring programmes with the potential to allow for a common assessment with multiple reporting for the similar objectives of the policies in force.

In this paper we review three policy and assessment frameworks, which include ABNJ regions or were developed specifically for ABNJ. The three frameworks were selected as concrete examples applicable to the deep sea, with specified indicators linked to defined objectives. For each of these policy frameworks we examine whether an assessment approach based on evaluation of GES under the MSFD for EU waters could be applied more broadly to explore its potential as an IEA framework in ABNJ. We evaluate each of those frameworks, including their indicators, against a set of properties that we feel comprise a robust framework assessment. Further, the evaluation of EU Member States' first MSFD reporting efforts identified a significant gap in deep-sea environmental assessments [31–33]. Accordingly, we review the GES descriptors and their relevance to deep-sea environments, with a focus on benthic ecosystems and demersal species drawing on experiences gained from the ATLAS and IDEM projects. This paper will also introduce readers outside of Europe, such as the UNEP Regional Seas Partnership, to the body of work conducted within the MSFD, for application in other deep-sea areas to address similar policy requirements for indicators.

2. UNGA, CBD and OSPAR policy frameworks and the relevance of the MSFD

In ABNJ, the UN organizations and agencies, as well as regional and/or sectoral regulatory bodies, have adopted sector-specific prioritization criteria, often with accompanying measures, to guide and manage sectoral uses of deep-sea resources. A primary focus has been the protection of areas important for deep-sea biodiversity. For fisheries, UN General Assembly (UNGA) Resolution 61/105 [34] (adopted in 2006) committed States individually and through regional fisheries management organizations (RFMOs) to manage bottom fisheries in ABNJ to prevent Significant Adverse Impacts on vulnerable marine ecosystems (VMEs). The adoption of the resolution triggered the development and adoption of criteria through multilateral negotiations convened under the auspices of the Food and Agricultural Organization of the UN (FAO), which were then subsequently endorsed by the UNGA. The FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO Guidelines) establishes criteria designed to assist States and RFMOs to identify areas where VMEs are known or likely to occur and to select measures appropriate for ensuring these areas do not suffer Significant Adverse Impacts [12,35]. For seabed mining, the International Seabed Authority (ISA) requires that activities by contractors be managed to prevent 'serious harmful effects' on VMEs under the ISA regulations currently in force for the exploration of seabed minerals in ABNJ [e.g. 9,10,36]. The ISA has also adopted an environmental management plan for the Clarion-Clipperton Zone, which features spatial measures to protect representative areas of deep-sea habitats and biodiversity in the region [37]. In parallel and cutting across the sectoral uses, the UN Convention on Biological Diversity (CBD) adopted criteria for identifying Ecologically or Biologically Significant Areas (EBSAs), where, subject to consideration by States and/or competent international authorities, enhanced risk aversion in management may be appropriate (UNEP 2010, CBD-COP Decision IX/20, [38]). There are also Regional Conventions with mandates extending into ABNJ, for example the Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) has a mandate for developing an integrated process for the protection of marine areas in ABNJ within its Maritime Area. OSPAR is following the MSFD Common Implementation Strategy Groups closely and is aligning its assessments with the MSFD requirements. All the frameworks presented in this paragraph are discussed below.

2.1. *The MSFD*

The assessment and achievement of Good Environmental Status (GES) is a cornerstone of the MSFD [39], which was adopted to define a common framework at the EU level for effective management and protection of the marine environment. The MSFD is the first EU legislative instrument related to the protection and maintenance of marine biodiversity in the long-term, containing the environmental objective that "biodiversity is maintained" as the basis for achieving GES. According to the MSFD, environmental status should be evaluated against a benchmark of standard conditions, based not only on abundance and diversity of species, but also on the condition, distribution and diversity of habitats and ecosystems, and their functioning. To achieve this, the European Commission (EC) has produced both a set of detailed criteria and methodological standards [40] to help Member States implement the MSFD (European Commission, 2008, [39]) through 11 descriptors (see Box 1) related to ecosystem features, human drivers and pressures. The MSFD makes specific reference to deep-water environments (European Commission, 2008; paragraph 22, [39]) and so has potential relevance to ABNJ as well as for European waters.

Considerable scientific effort was invested in producing the GES criteria as reflected in the recently repealed GES Commission Decision [40], with organizations such as the ICES and the JRC coordinating that effort. In particular, ICES/JRC led the development of an approach based on the Driver Pressure State Impact Response (DPSIR) framework, including identification of indicators and reference levels [41]. That approach underpins all current actions to implement the MSFD. The revision of the GES Commission Decision [40], based on the evaluation of the EU Member States' first reporting [42–44], enabled further improvement of the criteria, reducing ambiguity and redundancy [41, 45–52], and giving greater potential for consistent and comparable application and interpretation of the framework at appropriate geographic scales [53]. Relative to other comparable environmental initiatives the MSFD has benefited from a very high degree of scientific input for its practical application.

2.2. *The OSPAR policy framework*

OSPAR is comprised of 15 governments and the EU, which formally co-operate through a ratified Convention to protect the marine environment of the northeast Atlantic. OSPAR Region V, the Wider Atlantic, represents the deep waters of the northeast Atlantic and hosts a number of Threatened Endangered and/or Declining species and habitats that also qualify as VMEs (e.g., hydrothermal vents, carbonate mounds, coral water coral reefs and sponge communities). OSPAR has been working to develop methodologies and guidelines relevant to determining GES, focusing on a subset of MSFD descriptors: D1 (Biological diversity is maintained, the quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions), D2 (Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems), D4 (All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity), D5 (Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters), D7 (Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems), D8 (Concentrations of contaminants are at levels not giving rise to pollution effects), D10 (Properties and quantities of marine litter do not cause harm to the coastal and marine environment) and D11 (Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment) and more recently D6 (Seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular,

Box 1
Eleven qualitative descriptors* which describe what the environment will look like when GES has been achieved.

Descriptor 1. Biodiversity is maintained;
Descriptor 2. Non-indigenous species do not adversely alter the ecosystem;
Descriptor 3. The population of commercial fish species is healthy;
Descriptor 4. Elements of food webs ensure long-term abundance and reproduction;
Descriptor 5. Eutrophication is minimised;
Descriptor 6. The sea floor integrity ensures functioning of the ecosystem;
Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem;
Descriptor 8. Concentrations of contaminants give no effects;
Descriptor 9. Contaminants in seafood are below safe levels;
Descriptor 10. Marine litter does not cause harm;
Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem.
* Annex I Directive 2008/56/EC

are not adversely affected), (see Box 1), with several already included in the 2017 OSPAR Intermediate Assessment documents [54,55]. There are strong analogies between the MSFD and OSPAR approaches, for instance a connection has been made between "special habitats", including OSPAR Priority Marine Habitats determined as "threatened and/or declining" under the OSPAR Convention [56], and the achievement of GES in the MSFD framework [57].

OSPAR produced Quality Status Reports (QSRs; [58,59]) in 2000 and 2010, the last being considered a holistic assessment that tracked and evaluated status and trends in the descriptors and drew conclusions on overall ecosystem status, with regional summaries. Assessment reference points and baselines were established for monitoring eutrophication, hazardous substances and radioactive substances (OSPAR 2010 chapt. 11, [59]). Since QSR2010, OSPAR released an Intermediate Assessment [54,55] noted above, that assisted EU Member States in their 2018 updates to the MSFD reporting for the MSFD Initial Assessment, GES determination and target setting. OSPAR's Intermediate Assessment [54] examined new indicators and assessment methodologies, which will be applied in QSR 2023.

Building from QSR 2010 [59], OSPAR plans to assess cumulative impacts, through application of a simple non-quantitative pathway approach to risk assessment referred to as a modified bow-tie analysis [60]. Cumulative impacts will be assessed by combining bow-ties for each selected OSPAR indicator and linking pressures, hazards or effects across different pressure and state indicators to identify potential risks and delineate their scope. Unfortunately, little to no information was available for Region V in OSPAR 2010, but the approach developed by OSPAR for their ecosystem assessments is expected to apply to deep-sea areas.

2.3. The UNGA and CBD policy frameworks

The UNGA under its Sustainable Fisheries Resolutions calls for the prevention of Significant Adverse Impacts of VMEs, in order to protect biodiversity from harmful effects of bottom-contacting fishing gears [34]. The FAO Guidelines to facilitate implementing the resolutions specifies that States should choose indicators for assessing the status of VMEs and the possible occurrence of Significant Adverse Impacts (FAO 2009; paragraph 38; [35]), but does not specify particular indicators for that purpose, nor how they should be applied and interpreted. Similarly, the CBD Aichi Biodiversity Goal A, "Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society", and Goal B, "Reduce the direct pressures on biodiversity and promote sustainable use", introduces the concept of "Safe ecological limits" through Targets 4 and 6 respectively. A small number of potential indicators were developed by the Ad Hoc Technical Expert Group (AHTEG) on indicators for the Strategic Plan for Biodiversity 2011–2020 (CBD 2015, UNEP/CBD/ID/AHTEG/2015/1/3; UNEP/CBD/SBSTTA/19/INF/5 [61]). The indicators were recommended for monitoring global progress towards achieving the Aichi Biodiversity Targets, and some were carried over as relevant to the UN Post-2015 Sustainable Development Agenda (UNGA A/RES/70/1; [62]). The Aichi Biodiversity Goals apply broadly to coastal and marine areas, including deep-sea areas and ABNJ. Again, however, the CBD AHTEG and subsequent meetings of the Conference of Parties did not provide guidance on how to choose targets and limits on the indicators, nor on how to combine the results from individual indicators into overall assessments of deep-sea status called for in CBD 2013 [63]. Only indirect guidance is available to infer the properties intended for benchmarks in the Sustainable Fisheries resolution and CBD Aichi Target framework. The commitment in UNGA Sustainable Fisheries resolution 61/105 [34] to prevent Significant Adverse Impacts to VMEs, was intentionally included in Aichi Target 6 as the benchmark for marine habitats (Box 2), whereas at the same time the MSFD standard for achieving safe ecological limits was taken as the benchmark for the impact of fishing and harvesting pressures on species and ecosystems, requiring that impacts must be kept at levels which "… *do not undermine the long-term sustainability of the ecosystem*". This retains the intent that pressures need to be at or below the level of what ecosystems can sustain while still allowing them to provide ecosystem services.

However, because Target 6 only applies to fisheries, it does not take in the full GES definition within the MSFD: "… *provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable* …", because many pressures other than fisheries can affect progress towards GES. Nevertheless, the similarities between safe ecological limits and GES and convergence of the FAO and CBD approaches to deep-sea conservation and sustainable use, suggest that the MSFD GES assessment framework could be adapted so both Significant Adverse Impacts and safe ecological limits could be assessed using a consistent approach.

3. Current progress on assessment of GES under the MSFD in European waters

Ecosystem variability is widely recognized as one of the critical and challenging issues in the implementation of the MSFD, and in assessments more generally [64]. The work in progress entails open issues related to operationalizing the GES framework within EU waters as, for instance, some of the assessment methods used evaluate the benefits to humans rather than assess the environmental status, or the lack of suitable indicators to be applied at large geographical scale [65 and references therein]. Good Environmental Status of the deep-sea realm was considered in the MSFD first reporting by some EU Member States (in 2012). In all relevant cases the limited information for the deep sea was highlighted [31–33,66], and in most cases assessment of GES in

Box 2
CBD Aichi Biodiversity Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use.

Target 6: By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no Significant Adverse Impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

Possible Indicators:

- Trends in proportion of depleted target and bycatch species with recovery plans
- Trends in area, frequency, and/or intensity of destructive fishing practices
- Trends in catch per unit effort
- Trends in extinction risk of target and bycatch aquatic species
- Trends in fishing effort capacity
- Trends in population of target and bycatch aquatic species
- Trends in proportion of utilized stocks outside safe biological limits

such areas was not attempted or only cursorily addressed. The benchmark for considering a score for "biodiversity status" to meet the MSFD GES standard was commonly set by expert judgement through a qualitative assessment of the criteria and indicators for each of its descriptors. However, recent developments in assessment of GES under MSFD include methods to integrate and weight indicators, criteria and elements to achieve the high-level GES assessment at the appropriate scale [65].

Several tools were developed and reported for GES assessment during the first MSFD cycle in the European waters [31]. Amongst those, models and multi-metric indicators have been presented in the scientific literature as a means to integrate information from multiple sources. In particular, Piroddi et al. [67] reviewed 44 ecological models and about 200 indicators that could potentially be relevant to or helpful for the MSFD assessments. They noted that many of the models examined were created for purposes other than assessing GES and that they required further work to establish thresholds and/or reference values for GES. In addition, multi-metric criteria have been applied to monitor the ecological status of marine waters in relation to the MSFD criteria. The criteria translate the general descriptors of ecological quality into a single value of ecological status by combining, for example, indices of species diversity, species sensitivity and density. Examples include the BEAT tool (HELCOM Biodiversity Assessment Tool: BEAT; [68]), the Benthic Quality Index (BQI) and the Brackish Water Benthic Index (BBI) [69]. The response of some of these multi-metric indices (the Danish Quality Index, DKI, and the Swedish Benthic Quality Index, BQI) to bottom trawling, have been independently tested and demonstrate methods of integrating information to make environmental assessments [70]. All of these approaches require expert judgement to weight values of indicators but offer a less subjective and transparent means of evaluation of GES.

Further, Carstensen and Lindegarth [71] analysed the importance of estimating different sources of indicator uncertainty, especially in frameworks such as the MSFD, that highlight the importance of quantifying the confidence of an assessment. Due to the specific biological and ecological characteristics of the majority of the studied deep-sea species (see Section 4), recovery rates after impacts can be very slow or non-existent. Consequently, the application of precaution is fundamental in any policy uses of assessments of GES in the deep sea, making the quantified indicator uncertainty particularly prominent in decision-making [53].

Other priority issues for improving the IEA for GES, varying across the MSFD descriptors, include standardization of methods to address the criteria, validation of methods to set ecologically consistent thresholds across indicators and to allow comparisons of assessment results among geographical locations. The many indicators and parameters available to address the MSFD descriptors have different degrees of ecological relevance, implementation and operability, which must be considered. One of the tools to address this challenge is the Nested Environmental status Assessment Tool (NEAT; [72]). The NEAT tool has been applied up to now to 10 marine ecosystems to test its applicability and compare biodiversity assessments across four European Regional Seas [73], the Saronikos Gulf (eastern Mediterranean) [5] and to the Caspian Sea [74,75], all with useful results.

The ATLAS project reviewed the GES descriptors, which are briefly described in Box 1, and their relevance to North Atlantic deep-sea benthic ecosystems and demersal fish species within EU waters. ATLAS suggested and reviewed additional indicators for descriptors 1, 3, 4, 6 and 10 (Box 1) and applied the NEAT software to evaluate the status of selected deep-sea ecosystems based on empirical data [25]. The IDEM project tested the implementation of the MSFD in the deep Mediterranean Sea exploiting the scientific database available and attempting to use all of the 11 descriptors but stopping short of undertaking a holistic assessment of GES [26]. In this work we summarize the findings of ATLAS and IDEM in applying the MSFD GES framework to deep-sea areas of the EU as a test ground for a global application of the framework for ABNJ. We first consider aspects of the deep-sea realm that make it different from the ecosystems of coastal waters and shallow seas. The ATLAS findings are more widely present and discussed in Section 5.

4. The special case of deep-sea ecosystems

Three special aspects of the deep sea have a direct impact on GES assessment: 1) the specific biological and ecological characteristics of deep-sea biodiversity and habitats that may increase vulnerability to pressures: for instance, slowdown of many biological processes including growth rates, (e.g., cold-water corals (CWCs), [76]; deep-sea sponges, [77]), presence of long-lived species with episodic recruitment (e.g., deep-sea elasmobranchs, [78]; benthic organisms in cold-seeps, [79]), low resilience of many ecosystems (CWC reefs, [76,80]), unknown and poorly quantified species diversity [81,82]; 2) the technical and financial constraints to monitoring remote deep-sea areas, and consequent need to consider new approaches that dramatically increase the information collected per unit of funding; and 3) lack of long time-series data to evaluate trends, that reduces the context for setting biologically-based benchmarks on indicators and interpreting trends in data series that are available [83,84]. Teixeira et al. [85] noted that the number of indicators assessed decreased noticeably from shallow to deep waters, due among other factors to the lack of data for the latter.

4.1. Applying MSFD descriptors to the deep sea

The first step in evaluating the appropriateness of applying the MSFD approach to the deep sea is to consider how each MSFD Descriptor is expressed in such areas:

Within D1 (see Box 1 for this and subsequent Descriptors), research and commercial data on demersal fish (including deep-sea sharks) is often available for fished and/or surveyed areas and may also record other macro- and mega-invertebrates by-catch species. For non-commercial species, and benthic habitats deeper than 800 m, one-off scientific surveys in specific areas often offer the only available information, and in some cases temporal datasets are rare or short-term (see ICES data portals: vulnerable marine ecosystems; DATRAS, Biodiversity).

Non-indigenous species (D2) can cause impacts in the deep sea as elsewhere. This is true in the case of the red king crab *Paralithodes camtschaticus* intentionally introduced to the Barents Sea [86] and the gastropod *Philine auriformis* in California introduced through ballast water [87]. It is likely that the problem of species invasion in the deep sea will notably expand in the near future, as it is becoming evident in areas, such as the deep Mediterranean Sea, which are subjected to the penetration of several non indigenous species [87,88]. However, given the lack of knowledge on deep-sea biodiversity it is unlikely that D2 can be assessed in ABNJ except for certain ecosystem components which have been well sampled over time (e.g., large pelagic megafauna, phyto- and zooplankton). D3 pertaining to commercial fish species, stipulates the need for fishery-induced mortality yielding (but not exceeding) maximum sustainable yield, and that populations of all commercially exploited species should remain within safe biological limits, which means at least a population age and size distribution indicative of a healthy stock. Data on deep-sea fisheries are generally available, both within the EU waters and in ABNJ. It is worthwhile to mention that few, if any, deep-sea fish stocks are likely to be able to sustainably support any commercial fishery in the long term, as was demonstrated with many Orange Roughy fisheries [89] and other deep-sea fisheries [90]. The EU ban on bottom trawl fishing below 800 m in EU waters bordering the northeast Atlantic was adopted as a precautionary measure to protect VMEs but is also recognized as beneficial to the conservation of deep-sea species that were depleted as a result of past trawl fishing in the region (Regulation (EU) 2016/2336 [91]).

The functional aspects of marine food webs, especially the rates of energy transfer within the system and levels of productivity in key components are addressed in D4. The GES Decision (European Commission, 2017; [53]) sets criteria and methodological standards for monitoring and assessment of GES under the "Ecosystems" theme bridging the content of the D1 in the repealed Decision (European Commission, 2010; [42]) with D4. Selection criteria stipulate that at least one of the three trophic guilds monitored should focus on primary producers. Aside from the few, very localized ecosystems that depend on chemosynthesis (hydrothermal vents, cold seeps, or wood and whale falls), the vast majority of the deep sea depends on surface primary production, and monitoring will have to take into account horizontal and vertical transport of nutrients to the sea floor in order to make the links between production and diversity [92]. The relevance of deep-sea food webs coupled with the challenge of their assessment, determining benchmarks, and the lack of adequate information resulting in poorly resolved and indirectly obtained food-web relationships represent major challenges for the implementation of D4 in the deep sea [21,93,94]. The meta-analysis carried out by the IDEM project for D4 on the Mediterranean deep-sea food webs indicated that, essentially, the system works on four trophic levels, each one encompassing different trophic guilds [26,95]. However, while the food web of some regions could be described in detail, there were still several gaps, mostly related to supra-benthos, meso- and microzooplankton in large areas of the deep Mediterranean Sea [26].

While the concept of eutrophication (D5) is well explored in coastal environments (i.e., nutrient loading causing the increase of primary production), the concept is more difficult to apply to the deep sea. However, an increasing portion of the deep sea is experiencing oxygen depletion and expansion of the minimum oxygen zones [96]. The MSFD implementation of D5 in the deep sea can be further explored in terms of decrease of dissolved oxygen concentration (incidence of hypoxic zones) along with the monitoring of quantity and quality of sedimentary organic matter (in particular of the labile fraction reactive to oxygen; [97–101]).

Deep seafloors are subjected to increasing physical disturbances associated with human activities, due to bottom-contact fisheries and oil and gas exploration and production [102–107]. A set of tools (e.g., high-resolution maps of benthic substrate from the more extended use of remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), manned submersibles and seafloor observatories) is currently available for assessing seafloor integrity (D6). The semi-quantitative analysis performed for D6 revealed that bottom trawling and waste disposal are the two mostly investigated pressures in the deep Mediterranean Sea [108]. Indeed, bottom trawling as having by far the greatest physical impact on the seafloor below 200 m (at least an order of magnitude higher than all other seafloor activities combined) along the continental margin of the NE Atlantic in the OPPAR/NEAFC convention area [109].

Climate-driven events, altering hydrographical conditions (heat and salt content and structure of the water column before the onset of convection), can alter deep-water ecosystem functions. Climate change is a crosscutting issue for the MSFD relevant to all Descriptors. Moreover, permanent alterations of such hydrographical conditions are the basis of D7. Long-term monitoring of basic hydrological parameters (temperature and salinity), collected as time series with appropriate temporal resolution, occur in many parts of the deep sea and ABNJ and offer data to assess D7 over relatively long time periods [110]. The influence on deep-sea ecosystems of altered oceanographic circulation patterns [111] has been demonstrated to have important consequences for the ecosystems [84,112]. The impact of episodic climate driven events on hydrological variables has been well documented in the deep Mediterranean Sea as well as the consequences on the biodiversity and ecosystem functioning [113–115]. This is especially true and increasingly frequent in regions displaying dense shelf water cascading (DSWC) events [116]. Thus, D7 is potentially of great relevance for assessment of deep-sea ecosystems, at least to bathyal depths [117], even if the pressures acting on the deep-sea ecosystems are not exclusively tackled by D7.

Anthropogenic inputs of xenobiotic compounds represent one of the major current threats to the global ocean, including the deep sea [118]. Our knowledge on the concentrations, fluxes, and behaviours of trace elements, radionuclides and organic substances in deep waters and sediments and their toxicological impacts on habitats and organisms is still limited [119,120] and lacking in large portions of the deep sea. In addition, some habitats, such as hydrothermal vents, release toxic compounds through the natural venting activities, thus making it complicated to distinguish between natural and anthropogenically-driven phenomena and so assess D8. The IDEM project concluded that DSWC that occurs in the submarine canyons, is a specific northwestern Mediterranean mechanism for pollutant transfers to deep environments [121]. The DSWC events remove compounds retained in the continental margin to the offshore in a few days. The highest marine deposition fluxes ever described for PCBs, DDTs, HCB, PeCB and PAHs have been observed in association with DSWC [122].

Organochlorine compounds such as PCBs and chlorinated pesticides, constitute a group of persistent organic pollutants of increasing concern in the deep sea due to their toxic effects [123]. Radioactive substances have been reported in the deep sea as result of nuclear fallout due to the Chernobyl accident and historic dumping. These pollutants can accumulate in the biota (D9) causing concern also for human consumption. In the deep Mediterranean Sea, where the presence of toxin compounds has been identified [124], the biota exhibits higher levels of metal accumulation than those of populations inhabiting other areas such as the Atlantic Ocean [125].

The impact of marine litter is addressed in D10. The main sources of marine litter in the deep-sea floor include fishing activities, shipping and direct dumping, and plastics [126–132]. The analysis performed by the IDEM project on marine litter data for D10 revealed that, in the deep Mediterranean Sea, fishing gear such as longlines, trawl nets and ropes dominate litter found, followed by plastics. Similarly, the likely source of microplastic contamination at the Mingulay Reef CWC reef complex west of Scotland was fisheries debris [133].

Lastly, D11 deals with introduction of energy into the marine environment by human activities, including noise. The occurrence of low frequency noise in the deeper part of the basins is particularly important for deep-diving marine mammals, such as beaked whales, that use echolocation to detect prey [134].

Not only can the MFSD indicators and GES assessment help identify individual stressors on deep-sea ecosystems but also cumulative impacts from multiple stressors – an increasingly recognized need for the management of activities across multiple sectors operating in ABNJ to ensure the conservation of biodiversity and sustainable resource use.

5. ATLAS experience in applying MSFD descriptors to the deep sea and assessing GES

The ATLAS project used a case-study (CS) based approach to perform the exercise of assessing the environmental status in deep-sea areas found in the EEZ of 9 European countries (Table 1). ATLAS produced a list of 24 indicators (1 for D1, 1 for D3, 7 for D4, 13 for D6 and 2 for D10) that could be associated with MSFD Descriptors 1, 3, 4, 6 and 10. ATLAS group of experts also suggested some new indicators: (Table 2). ATLAS used the NEAT software [72] to integrate these assessments (see Section 3). Differences in the available data prevented the application of all indicators in each of the 9 case studies. The spatial scale of the ATLAS assessment was highly variable, ranging from 115 km^2 (CS 4, Mingulay Reef Complex, Table 1) to 40,798 km^2 (CS 3, Rockall Bank, Table 1). The large differences not only in extent, but also in geographical location, habitats and features included in the CS areas (e.g., mud volcanoes, seamounts, canyons, ridges), and different types and intensity of human uses, provided a rich basis to test the performance of the NEAT under different deep-sea scenarios. However, we note that only two of the sites extend to bathyal depths (1,000–3,000 m) and the abyssal realm which covers 80% of the ocean is not represented (Table 1). All analysed areas were relatively data poor (in common with most deep-sea areas), and in most cases indicators for D1 and D6 were restricted to VMEs, as these are the most studied benthic ecosystems in the deep sea. Overall, the lack of long-term data series in the CS areas prevented comparisons with baseline data (non-existent for most areas), meaning that in most cases the analyses carried out were based on a "snapshot" provided by the information originating from specific research surveys, although in a few cases relatively long data series were available (e.g., D3 for Rockall Bank). However, in some cases comparisons between periods before and after fisheries closure (e.g. in Condor Seamount in the Azores), or between areas inside and outside MPA (e.g. in the Faroe-Shetland Channel) provided a framework for comparison. The full assessment for each of the CS areas, habitats and ecosystem components is detailed in Kazanidis et al. (in press, [25]).

6. Comparing and contrasting MSFD GES assessment with other environmental frameworks in ABNJ

6.1. Approach used to compare existing assessment frameworks for the deep sea and ABNJ with MSFD

We developed a set of 21 properties for comparing the characteristics of three marine environmental assessment processes (the ecosystem assessments developed by OSPAR, the process for assessing Significant Adverse Impacts of fishing on VMEs developed by the UNGA and FAO implemented by regional fisheries management organizations to regulate deep-sea fisheries in ABNJ, and the CBD evaluation of safe ecological limits) with the MSFD process for assessing GES. For each property we provide a short description elaborating on what aspects of each we were considered when drawing conclusions (Table 3).

6.2. Comparison of four environmental assessment frameworks

All four environmental assessment frameworks were initially examined against the properties outlined in Section 6.1. All show links to both regulatory policies and biodiversity conservation policies and share common over-arching strategic objectives (Table 4). We concluded that there was sufficient similarity among the strategic objectives of the various assessment frameworks that an effective assessment process for any one of them (such as to determine GES within European waters) would be transferable to another and applicable to ABNJ. However, it is worthy to acknowledge the potential limitations of this approach as, for instance, the existence of different regional contexts that might hamper the applicability of this assessment framework.

The details of how each of the strategic objectives is assessed and the characteristics of each assessment framework (as detailed in Table 4), differed markedly (Table 5). The FAO assessment of Significant Adverse Impacts of fishing on VMEs differed from the others in that the framework does not develop indicators *per se*, although it does refer to indicator species and habitats. These function as indicators in the role of identification of areas that are VMEs. However, there are no corresponding pressure or impact indicators. Rather, management of areas considered to be VMEs relies heavily on the precautionary approach for its implementation, with binding regulatory actions linked to areas where VMEs are known or "likely" to occur. The lack of explicit state indicators (see Table 3) and benchmarks within this UNGA/FAO policy framework relates to the intent of the policy to protect particular types of ecosystems from a particular pressure (fisheries), but otherwise had no goals for overall environmental policy (Table 3). Relevance to the resolutions and inclusion of Significant Adverse Impacts on VMEs in Target 6 of the CBD Aichi Biodiversity Goals (Box 2) is comprised of a series of outcomes all already included in existing international agreements on fisheries (target species, bycatches, depleted and endangered species, habitat impacts, ecosystem status). This indirectly links the Target to all the indicators adopted for the agreements contributing to the overall target, including pressure indicators such as "Trends in area, frequency, and/or intensity of destructive fishing practices" which is relevant to Significant Adverse Impacts on VMEs.

There is a great deal of consistency between the OSPAR and MSFD frameworks (Tables 4 and 5) as OSPAR has been working with other Regional Seas Conventions and the European Commission to develop common assessment tools to harmonise the MSFD implementation across the EU Member States. However, although most OSPAR Contracting Parties are also members of the EU, OSPAR integrated assessment values are not equivalent to MSFD criteria threshold values for GES, although they can contribute to reporting [54]. The MSFD framework is more extensive than that of OSPAR, but OSPAR is working on expanding its suite of indicators (31 are under evaluation) and contributed substantially to the development of MSFD descriptors and criteria.

The most challenging assessment framework using our evaluation scheme are the CBD Aichi Biodiversity Targets (Tables 4 and 5). The associated list of potential indicators was based on availability of data, ease of communication, ability to aggregate/disaggregate into national and global reports, and previous use. In the case of Target 6 (see Box 2) only two indicators were deemed ready for use: Trends in fisheries certified by the Marine Stewardship Council, and Red List Index (impacts of fisheries), with most other potential indicators needing additional work, particularly with regard to ability to aggregate data from

Table 1
ATLAS case study areas, total analysed area, Spatial Assessment Units (SAU) dimensions, depth range, human activity/impact/conservation status of the selected SAU, habitat description, NEAT outcome and degree of agreement between NEAT outcome and expert judgement. Abbreviations: NEAFC (North East Atlantic Fisheries Commission), MPA (Marine Protected Area), SAC (Special Area of Conservation).

Study area	Total extension of study area (km^2)	SAUs size (km^2)	Depth range (m)	SAU characteristics related to human pressures/ conservation status (encountered across the study area)	Representativity of SAU(s) for the whole study area	Habitat description	NEAT outcome[a]	Degree of agreement NEAT outcome & expert judgement
LoVe Ocean Observatory (Hola trough, Northern Norway)	3,250	SAU1: 350 SAU2. 2,900	SAU1: 200-260 SAU2: 200-260	Human pressures: fisheries, tourism. Conservation status: MPA.	SAU-1: Good SAU-2: Good	Benthic	0.616 (Good)	Complete agreement
Faroe-Shetland Channel (North-western Scotland)	5,278	SAU1: 2,639 SAU2: 2,639	SAU1: 450-523 SAU2: 497-715	Human pressures: Fisheries, oil and gas, cables, telecommunication, shipping. Conservation status: MPA.	SAU-1: Good SAU-2: Good	Benthic	0.819 (High)	Good agreement
Reykjanes Ridge (Southern Iceland)	34,608	SAU-1: 30,092 SAU-1-1: 14,946 SAU-1-2: 15,146 SAU-2: 4,516	SAU1: 200-500 SAU2: 200-500	Human pressures: fisheries. Conservation status: fisheries closure.	SAU-1: Poor SAU-1-1: Poor SAU-1-2: Poor SAU-2: Poor	Benthic	0.549 (Moderate)	Good agreement
Rockall Bank (North-western Ireland/UK)	40,797	SAU1: 1,274 SAU2: 13,932 SAU3: 7,501 SAU4: 18,091	SAU1: 0-150 SAU2: 151-250 SAU3: 251-350 SAU4: >351	Human pressures: fisheries. Conservation status: Extensive closed areas (NEAFC), SAC.	SAU-1: Good SAU-2: Good SAU-3: Poor SAU-4: Poor	Benthic	0.313 (Poor)	Moderate agreement
Mingulay Reef Complex (South-western Scotland)	115	SAU1: 115 SAU2: 11	SAU1: 120-190 SAU2: 120-190	Human pressures: fisheries, marine litter. Conservation status: SAC	Good	Benthic	0.272 (Poor)	Moderate agreement
Porcupine Seabight (South-western Ireland)	35,500	SAU1: 35,500	SAU1: 1500-2500	Human pressures: fisheries, oil and gas, telecommunications, cables. Conservation status: SAC.	Moderate	Benthic	0.980 (High)	Good agreement
Bay of Biscay (Northern Spain-western France)	20,308	SAU1: 4,118 SAU2: 10,654 SAU3: 5,536	SAU1: 368 SAU2: 1,194 SAU3: 1,100 (average depths)	Human pressures: fisheries, marine litter. Conservation status: Natura 2000 network.	Poor	Benthic *(Lophelia pertusa (now known as Desmophyllum pertusum)/ Madrepora oculata* on hard and soft sediments, sea pens/alcyonaceans on soft sediments, antipatharians/ alcyonaceans on hard substrates.)	0.717 (Good)	Judgement not expressed
Gulf of Cádiz (South-western Spain, Atlantic)	1,810	SAU-1:1,059 SAU-2: 751	SAU-1: 258-900 SAU-2: 450-700	Human pressures: fisheries, shipping. Conservation status: Natura 2000 network (Site of Community Importance).	SAU1: Good SAU2: Good	Benthic (rocky, sedimentary.)	0.477 (Moderate)	Moderate agreement
Condor seamount Azores (Central North Atlantic)	280	SAU1: 280	SAU1: 250-600	Human pressures: fisheries. Conservation status: MPA.	Good	Benthic	0.510 (Moderate – Before fisheries closure) 0.683 (Good – After fisheries closure)	Moderate agreement

[a] Full NEAT results are in Kazanidis et al. (in press, [25]).

Table 2
List of indicators to assess the status of deep-sea ecosystems for Descriptors D1, D3, D4, D6 and D10 (see Box 1). Indicators included in the table were already considered in the NEAT software indicators database, which were based on the indicators considered in the MSFD Directive. The indicators generated within ATLAS, specific for the deep sea are highlighted in **bold**.

D1	D3	D4	D6	D10
Abundance of non-commercial demersal fish and cephalopods	Body length distribution of fish	**Species richness of non-commercial fish**	Fishing effort	**Areal extent of litter: Type (e.g. plastic, glass)/abundance/density/weight**[a]
		Species richness of corals[a]	Areal extent of human affected area[a]	**Density of abandoned fishing gear (e.g. lines, nets, etc.)**[a]
		Species richness of benthos	Areal extent of protected sea areas[a]	
		Species diversity (Shannon index) of non-commercial fish	Number of size cohorts within a population	
		Abundance of commercial fish	Areal extent of biogenic/vulnerable habitats (type, abundance, biomass, condition and areal extent of relevant biogenic substrata)[a]	
		Biomass of demersal fish	Areal extent of rocky seafloor/vulnerable habitats (type, abundance, biomass, condition and areal extent of relevant sedimentary communities)	
		Biomass of selected fish species	**Areal extent of sedimentary seafloor/vulnerable habitats (type, abundance, biomass, condition and areal extent of relevant sedimentary communities)**[a]	
			Distribution and condition of habitat forming species[a]	
			VMEs and VME indicator taxa (status, areal extent, size-frequency distribution)[a]	
			Abundance of coral colonies alive[a]	
			Abundance of corals (excluding reef building corals)	
			Density of biogenic reef forming species (type, abundance, biomass and areal extent of relevant biogenic substratum per habitat type)[a]	
			Ratio of live versus dead/overgrown coral cover[a]	

[a] Measurement units were not specified due to the different sampling tools applied.

national to global scales or disaggregate from global to national ones. These scaling challenges are always present but become particularly problematic for the CBD Targets because they apply to *all* countries, which have vastly different capacities for scientific assessments, and Target 6 applies to *all* biodiversity and habitats in the ocean, and not just VMEs, or endangered species. Although global inferences about status of marine biodiversity relative to Target 6 would be most direct and robust if all Parties used the same suite of indicators for assessments, Target 6 is not alone among Aichi Targets in not all countries being equally able to meet that global ideal. Rather, Target 6 is explicit about the necessary outcome for each component of biodiversity, so jurisdictions can select indicators feasible with their capacities and diversity of ecosystems and set reference benchmarks consistent with the outcomes specified in the Target. Consequently, in being most ambitious in aspiration (all biodiversity globally) it must be most flexible in implementation (Table 4).

7. Discussion

Our comparison of the frameworks that address the conservation and protection of biodiversity in the deep-sea ABNJ (OSPAR Ecosystem Assessments, UNGA Significant Adverse Impacts, and CBD Safe Ecological Limits) with the EU MSFD [39], has highlighted the commonality in their overarching objectives. Many of the concepts and approaches used by the MSFD, such as the ecosystem approach, were drawn from other international agreements and commitments, including the UN Convention on the Law of the Sea, the 1995 UN Fish Stocks Agreement, the FAO Code of Conduct for Responsible Fishing and the CBD. Consequently, if shown to be useful within the deep-sea areas of the EU, the MSFD and its GES descriptors could be a useful assessment approach to fill the gaps in tested assessment methodologies for ABNJ identified above (see Section 6; Tables 3 and 5). A particularly strong aspect of the MSFD is the DPSIR framework endorsed by the MSFD assessment of GES. A DPSIR framework is readily adaptable to the UNGA Sustainable Fisheries Policy framework [34], and to the protection of VMEs from Significant Adverse Impacts in particular. The inclusion of drivers and pressures in the framework focuses attention on key management priorities. Adopting that framework more broadly in the frameworks that address the conservation and protection of biodiversity in the deep-sea ABNJ may lead to more direct management responses as seen in the implementation of UNGA resolutions related to fishing and VMEs.

However, as we have summarized (Section 5), many of the GES descriptors have issues when applied to the deep sea (Table 5). Nevertheless, there is scope for further development of new indicators that take into account the special case of deep-sea areas (Section 4). For example, ATLAS identified additional indicators for some descriptors (Table 2) that may be appropriate for the deep sea, partially addressing this deficiency. Further, assessment of GES/safe ecological limits in ABNJ may have to be assessed at large spatial and temporal scales when compared to the shallower waters of the European Seas [137]. If it does turn out that the special ecological and logistical circumstances of the deep sea (Section 4) mean that the type of indicators to be used have to be simplified, or be based on high-level analyses related to traits, pressures/risks, and habitat/ecosystem resilience, substantial efforts at calibrating the loss of sensitivity and robustness of the assessments will be necessary, including applying similar simplifications to the same indicators from more data-rich shallower systems, and comparing the resultant assessments with assessments of the same areas using the full information.

The ATLAS work on nine strategically selected case studies in the northeast Atlantic, highlighted the scarcity of available information across spatial and temporal scales, and showed induced effects such as challenges associated with the establishment of baselines against which the assessment of environmental status could be conducted [25]. Nevertheless, ATLAS results also demonstrate that for deep-sea areas in EU waters, and therefore appropriate in ABNJ, it is possible to apply the MSFD framework and to make holistic assessments (Section 3). The ATLAS project applied one of the assessment tools (NEAT, see Section 3 and 5) developed to assess the state of the environmental status, to deep-sea areas [25]. It concluded that overall for any given case study area the NEAT integrated assessment tool performed well in that it was

Table 3
Characteristics used for comparing assessment frameworks supporting marine environmental policies with a focus on the deep sea.

Assessment Framework Property	Description
Link to marine regulatory policies	Framework directly links to regulatory policies for ocean economic sectors (i.e., fisheries, extractive industries etc.) and was developed to inform regulatory decisions.
Link to marine policies for the conservation of biodiversity	Framework directly links to policies for the conservation of biodiversity and was developed to inform such policies.
Strategic objective(s)	Over-arching objective is clear and measurable.
Terms used in objectives defined	Information is publicly available defining the terms used in the objectives, with examples.
Sub-objectives for achieving overall objective	Sub-objectives when achieved will collectively meet the over-arching objective; operational objectives.
Indicators for achieving objectives	A specific, observable, and measurable characteristic or change that when a target is met will represent achievement of the objective alone or in combination with other indicators. In some cases decision rules are articulated.
Rationale behind indicator selection	Framework identifies a rationale that was followed to derive indicators. For example, the DPSIR (drivers, pressures, state, impact and response model of intervention) is a causal framework for describing the interactions between humans and the environment.
Indicators appropriately linked to objectives	Indicators when evaluated will result in the desired outcomes detailed in the objectives.
Indicators meet criteria for good indicators	Rice & Rochet [17] developed a framework for developing indicators to ensure that they are relevant and not redundant. That guidance is used herein to establish whether the indicators are "good" or otherwise.
Data available for the deep sea to assess indicators	Is the appropriate data available to evaluate the indicator? This includes spatial, temporal and data quality aspects. Also information on environmental factors, drivers, natural and anthropogenic sources of variability.
Indicators appropriate for the deep sea	Indicators have relevance to what is known of deep-sea biology and ecology.
Indicator thresholds justified	Thresholds, tipping points or similar decision points have a scientific foundation based on theory or empirical data; or justified based on socio-economic or precautionary criteria.
State indicators	An indicator that measures the state of the ecosystem or its components, e.g., fish spawning stock biomass.
Pressure indicators	An indicator that measures the human pressures imposed on an ecosystem and/or its components, e.g., contaminants, fishing activities.
Alternatives to indicator-based assessment in place	Alternatives to indicator-based assessments for reaching objectives in data-poor regions are provided.
Methodological standardisation to measure indicators/ Cumulative assessments are comparable	Guidance to practitioners on standard protocols to measure indicators and make results comparable. This may not be possible due to different data availability, or desirable if flexibility is needed to operationalize objectives.
Guidance on spatial and temporal scale of assessment	Guidance to practitioners on spatial and temporal scale of assessment is attached to each indicator/objective.
Methods for assessing cumulative impacts	Methods for assessing cumulative impacts and/or multiple indicators are developed/proposed within the framework.
Clear guidance documents to undertake evaluations	Guideline documents for practitioners are available to enable users to apply the framework, including clear examples, lessons-learned, etc.
Assessments are repeatable/Monitoring	The process producing the assessments is repeatable with updated information sources; monitoring is discussed.
Assessments consider uncertainty	Qualitative and/or quantitative measures of uncertainty are incorporated in the assessment framework.

able to detect differences in the environmental status between areas under different levels of pressures (see Table 1) and there was generally a moderate/good agreement between the outcome of the NEAT analyses and expert judgement - which was expressed as the deep knowledge from each ATLAS expert responsible for a specific case study area they were responsible for- (see Kazanidis et al. in press [25], for each of the ATLAS case studies (Table 1)). For example, improvements in status score were detected for assessments on the status of two fish species conducted considering data prior to and after a fisheries closure (e.g., D3, Condor Seamount (Azores); [25], Table 1). However, NEAT assessments were shown to be very dependent on the dimensions of the spatial assessment unit (SAU) considered in each case study area ([25], Table 1). Typically, ATLAS experts responsible for the case study areas of the project, felt that the results could not be generalized to the whole of each case study area due to the 1) data-driven influence of VMEs on SAU selection, 2) low confidence in the set up of the boundary values for each class of environmental status as required by NEAT [25] and 3) limited knowledge on natural variability of ecosystem components across space and time. Consequently, at the present time, insights for policy and management are limited by data availability and habitat type in deep-water areas.

However, even with limited data this approach was able to draw attention to which habitat types are more vulnerable to degradation and/or recover more slowly, and/or which pressures need most effective management to keep environmental status in good condition. In general, standardization of integrated assessment methods and measurements are needed to provide the necessary basis for a proper comparative analysis, taking into account the singular characteristics of each area and specific pressures. This will be a key consideration for ABNJ as there is a need to aggregate data from national to international scales (see Section 6.2).

Assessment tools such as NEAT provide a flexibility in the use of indicators which would meet the challenge of uneven data distribution in ABNJ globally. The use of multi-metric indicators and models could be incorporated into such an assessment in areas where the appropriate data exist. Further testing and development of such integration tools are needed before any one approach can be endorsed.

The experience gathered from the IDEM project on the implementation of the MSFD in the deep Mediterranean Sea, indicates that the MSFD can be effectively applied almost entirely on the deep sea. At the same time, there is not only an urgent need to expand the monitoring of deep-sea habitats, but also to feed the open access databases [28,133,138], define common procedures for data sharing and rigorous and standard protocols for data acquisition (e.g. [139]). The development of innovative tools, the implementation of new technologies (e.g. [140]), together with the optimization of the monitoring strategies (spatial resolution, long-term monitoring positions, data sharing) (e.g. [141]) are crucial to provide a holistic assessment of the environmental status in the deep sea [137].

8. Conclusions

We conclude that the EU MSFD framework for assessing environmental status would serve as a useful assessment approach to support the policy objectives of the UNGA with respect to conservation of VMEs and avoidance of Significant Adverse Impacts, and achievement of CBD Aichi Biodiversity Targets safe ecological limits. The substantial body of scientific advice and investigation, including lessons learned, supporting the development of the MSFD, could be transferred to the ABNJ to improve current frameworks for the conservation and protection of marine biodiversity. However, application of the MSFD framework for assessment of GES in ABNJ should be expanded to include guidance on: incorporation of new indicators (or adaptation of the existing ones) of relevance to the conservation and protection of biodiversity in the deep sea; the spatial and temporal scales of assessment; assessing cumulative impacts of pressures and drivers; incorporation of uncertainty

Table 4
Comparison of each of four marine environmental assessment frameworks illustrating their links to policy and commonalities in their strategic objectives. Convention on Biological Diversity: CBD, Marine Strategy Framework Directive: MSFD, Good Environmental Status: GES.

Assessment Framework Property	OSPAR Ecosystem Assessments	UNGA Significant Adverse Impacts	CBD Aichi Biodiversity Targets Safe Ecological Limits	MSFD Good Environmental Status (GES)
Link to marine regulatory policies	CBD Network of Marine Protected Areas; MSFD 2008/56/EC of the European Parliament	UNCLOS; UNGA Sustainable Fisheries Resolutions	CBD Network of Marine Protected Areas; UNGA Sustainable Fisheries Resolutions (Significant Adverse Impacts)	MSFD 2008/56/EC of the European Parliament; Common Fisheries Policy; Framework for Maritime Spatial Planning 2014/89/EU [135]; World Summit on Sustainable Development
Link to marine policies for the conservation of biodiversity	CBD; MSFD 2008/56/EC of the European Parliament	UNGA Sustainable Fisheries Resolutions	CBD	MSFD 2008/56/EC of the European Parliament [135]; CBD [58]; Water Framework Directive 2000/60/EC; Habitats Directive 92/43/EC [136]; Natura 2000
Strategic objective(s)	To understand and assess the interactions between and among the different species and populations of biota, the non-living environment and humans.	To assess, on the basis of the best available scientific information, whether individual bottom fishing activities would have Significant Adverse Impacts on vulnerable marine ecosystems, and to ensure that if it is assessed that these activities would have Significant Adverse Impacts, they are managed to prevent such impacts, or not authorized to proceed.	Take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. [a]	To achieve GES of EU marine waters by 2020, which is the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations.

[a] To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach (CBD).

Table 5
Comparison of the characteristics of three marine environmental assessment frameworks with a focus in the deep sea (OSPAR Ecosystem Assessments, UNGA Significant Adverse Impacts, and CBD Safe Ecological Limits) with the EU MSFD Good Environmental Status (shaded column). See Table 3 for explanation of framework properties used in this summary. ● Indicates property present; X Indicates property not present; ○ Indicates property partially addressed, perhaps indirectly.

Framework Property	OSPAR Ecosystem Assessments	UNGA Significant Adverse Impacts	CBD Aichi Biodiversity Targets Safe Ecological Limits	MSFD Good Environmental Status (GES)
Terms used in objectives defined	●	●	●	●
Sub-objectives for achieving overall objective	Ecological Quality Objectives (EcoQO); e.g., Safe Fish Stocks: To achieve safe levels of defined commercial fish stocks.	X	Aichi Biodiversity Goals and Targets	GES Descriptors and Criteria
Indicators/criteria for achieving objectives	●	X	○	●
Rationale behind indicator selection	●	X	○	●
Indicators appropriately linked to objectives	●	X	●	●
Indicators meet criteria for good indicators	●	X	○	●
Data available for the deep sea to assess indicators	○	●	○	○
Indicators appropriate for the deep sea	○	X	○	○
Indicator thresholds justified	○	X	X	○
State indicators	●	X	●	●
Pressure indicators	●	X	●	●
Alternatives to indicator-based assessment in place	X	●	X	X
Methodological standardisation/ Assessments are comparable	●	X	X	○
Guidance on spatial and temporal scale of assessment	●	●	X	●
Methods for assessing cumulative impacts	●	X	X	X
Clear guidance documents to undertake evaluations	●	○	●	●
Assessments are repeatable/ Monitoring plans	●	○	●	●
Assessments consider uncertainty	●	●	X	●

agreement on methods to be followed for the set up of boundary values linked to GES (Table 5). This rationalization of assessment approaches has already been recognized explicitly by OSPAR in relation to the MSFD, and in the language of the CBD Aichi Biodiversity Targets concept of safe ecological limits, itself embracing UNGA avoidance of Significant Adverse Impacts. Uniting the scientific support for the assessment of human impacts in ABNJ would focus limited scientific capacity on improving such assessments and is directly relevant to aspects of the Biodiversity Beyond National Jurisdiction (BBNJ) negotiations, in particular measures such as area-based management tools including marine protected areas and environmental impact assessments, and the CBD post 2020 global biodiversity framework [142] as a follow-up to the current Strategic Plan for Biodiversity 2011–2020 with a view to achieving the 2050 Vision for Biodiversity [143].

Author contribution

Covadonga Orejas, Ellen Kenchington and Jake Rice: Conceptualization; Covadonga Orejas, Ellen Kenchington, Jake Rice, Georgios Kazanidis: Data curation, Writing - original draft; J.Murray Roberts, Roberto Danovaro, Ellen Kenchington: Funding acquisition; All co-authors: Writing- Reviewing and Editing.

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Appendix A. Supplementary data

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