Big Insights From a Small Country: The Added Value of Integrated Assessment in the Marine Environmental Status Evaluation of Malta

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In the last few years, the concept of ecosystem-based approach has led to the need for developing integrative assessments that consider the different ecosystem components all together. In Europe, the Marine Strategy Framework Directive (MSFD) aims at achieving the Good Environmental Status for all regional seas. This requires Member States (MS) to implement monitoring networks and assess the status in 6-years management cycles, based on 11 qualitative descriptors, ranging from biodiversity to noise. For that assessment MS must apply criteria and methodological standards, following certain specifications. However, the number of MS which have undertaken quantitative assessments, or aggregated the different criteria and/or descriptors in holistic assessments, remains low. This is probably due to the few available tools that enable the aggregation of information at different scales (spatial and temporal) and the integration of a diverse range of indicators. In order to identify the main constraints tied to the integration of data from different indicators, criteria and descriptors, this study involved a comparative analysis of a national assessment of official marine data reported by Malta with the integrative Nested Environmental status Assessment Tool (NEAT). In total, we have used 282 indicators, 24 criteria, seven descriptors, and 12 ecosystem components. The results showed a good agreement in the assessment at the indicator level (as applied in the national assessment) and threw light on the advantages of integrating the information at criteria, descriptor or ecosystem component levels, when using NEAT. Such integration allows for a global assessment of status of Malta's marine waters whilst allowing for the identification of management measures at different spatial levels and for different ecosystem components. Lessons learnt from this case study are applicable to remaining assessments for other European MS.

Keywords: marine strategy framework directive, ecosystem-based approach, NEAT, ocean status, integrative assessment

INTRODUCTION

Although the oceans cover 71% of the Earth's surface, the list of human activities at sea has been relatively limited until recently, including amongst others fishing, shipping, and oil/gas exploitation. However, in the last two decades, some activities such as aquaculture, tourism and recreation, biotechnology applications or seabed mining have shown dramatic increases at a global level, constituting the so-called blue economy or blue growth (Eikeset et al., 2018). All these activities, either traditional or new, can result in multiple pressures on marine ecosystems and their services (Dailianis et al., 2018; Korpinen et al., 2019), which can be monitored through their impacts or footprints (Elliott et al., 2020).

In the past, such monitoring was used to assess the status of aquatic systems through individual ecosystem components (i.e., phytoplankton, macroalgae, fish, etc.) (Birk et al., 2012; Poikane et al., 2020). However, in the last few years, the emerging concept of the ecosystem-based approach (Kirkfeldt, 2019), has led to the need for integrative assessments that consider the different ecosystem components all together (Inniss et al., 2016; Reker et al., 2019). The ecosystem-based approach explicitly recognizes social-ecological systems interactions within environmental management contexts, including humans and their activities as part of the marine ecosystem components (O'Higgins et al., 2020). Nevertheless, the tools for performing such integration are still very limited (Personnic et al., 2014; Borja et al., 2016).

In general, developments of marine legislation of the different countries, such as Canada, United States, South Africa, Australia, or China; have been a main driver for the development of integrative assessments (Borja et al., 2008). In the case of Europe, the Marine Strategy Framework Directive (MSFD; European Commission, 2008), which applies to all European Union countries, created a new vision for achieving clean, healthy, and productive seas throughout the implementation of the ecosystem-based approach, in which humans are part of the marine ecosystem. This means that any human activity at sea must be managed at sustainable levels (Borja et al., 2010; Reker et al., 2019).

The MSFD aims at achieving the Good Environmental Status for all seas by 2020 or 2026, for which it requires Member States (MS) to carry out the implementation of marine monitoring networks, the assessment of the seas' environmental status, and the definition of programs of measures to minimize human impacts, all in 6-years management cycles (European Commission, 2008). The environmental status is based upon 11 qualitative descriptors (D), which includes: D1-Biodiversity, D2-Non-indigenous Species, D3-Commercial fish, D4-Foodwebs, D5-Eutrophication, D6-Seafloor integrity, D7-Hydrography, D8-Contaminants in the environment, D9-Contaminants in seafood, D10-Litter, and D11-Noise/energy.

Following the first MSFD management cycle, assessment and reporting inconsistencies amongst MS, which led to the revision of the methodological standards to determine the environmental status in the European Commission (2010) decision (2010/477/EU), revealed that there was insufficient detail and clarity to support the determination of the environmental status (Palialexis et al., 2014). This resulted in the revised 2017 Commission Decision (2017/848/EU); presenting a more developed framework -including revised criteria and methodological standards—for MS to undertake the assessment during the second management cycle (European Commission, 2018b, 2019). This framework includes the (i) species groups (i.e., seabirds, mammals, reptiles, fish, and cephalopods); (ii) habitat types; (iii) ecosystem structure, functions, and processes, i.e., physical, hydrological, chemical, and biological; and (iv) anthropogenic pressures (i.e., biological, physical, contaminants, litter, and energy/noise), to be considered when determining/assessing the environmental status.

Within the framework of the MSFD, good environmental status has been progressively refined from its high-level definition in Art. 3(5), *via* the Descriptors of MSFD (Annex I), the defined characteristics, pressures/impacts in the marine environment (Annex III), and the outlined requirement for criteria and methodological standards for assessment as per Art. 9(3). In line with Art. 9(3), the revised Commission Decision (European Commission, 2017) sets criteria (i.e., "distinctive technical features that are closely linked to qualitative descriptors") and methodological standards for MS to follow "to ensure consistency and to allow for comparison between marine regions or subregions of the extent to which good environmental status is being achieved." Within this context, MS were to define good environmental status in their marine waters and select the most relevant elements to be included for their second assessment cycle (European Commission, 2020).

Furthermore, MS must follow certain specifications/requirements in the environmental status assessment (European Commission, 2017, 2018b, 2019, 2020), including: (i) elements for assessment and indication of whether good status has been achieved for those; (ii) criteria for assessment of the elements, including parameters to be used; (iii) threshold values for assessing quality and trends (including distinguishing good from non-good status); (iv) assessment scales (through so-called Marine Reporting Units); (v) approaches to express the extent to which good status is achieved; (vi) approaches/methods for data collection and monitoring; (vii) aggregation methods for the data (spatial and temporal) (Walmsley et al., 2017; European Commission, 2018b); and (viii) units of measurement for the criteria.

In both the first and the second cycle assessments, the number of MS which have undertaken quantitative assessments (i.e., using quantitative thresholds), or aggregated the different criteria and/or descriptors in holistic assessments, remains low (Palialexis et al., 2014; European Commission, 2020). In fact, most countries are assessing the environmental status at the level of criterion (aggregating species or habitats) and very few at the level of descriptor (European Commission, 2020). This is probably due to the few available tools that enable the aggregation of information at different scales (spatial and temporal) and the integration of indicators of different nature (Borja et al., 2016), but also because the discussions on the pros and cons of aggregating information at different levels are still in development (Ojaveer and Eero,

2011; Langhans et al., 2014; Palialexis et al., 2014; Probst and Lynam, 2016).

Amongst the tools available for integrated assessment is the Nested Environmental status Assessment Tool (NEAT; Borja et al., 2016), which allows the quantitative aggregation of selected indicators/criteria. The tool is designed to accommodate the Ecosystem-Based management approach (as described in O'Higgins et al., 2020); its interface incorporating multiple socio-ecological aspects including human activities and pressures (e.g., fishing, contaminants, litter, etc.), a variety of ecosystem components (from phytoplankton to mammals, from pelagic to benthic habitats), all defined according to the different criteria and descriptors applied within the MSFD framework. NEAT has been tested and validated in many locations around Europe (Uusitalo et al., 2016; Pavlidou et al., 2019), outside Europe (Nemati et al., 2017) and covering large regional seas (Kazanidis et al., 2020) or even the whole Europe (Borja et al., 2019c).

In order to demonstrate the possibilities and advantages of integrating indicators, criteria, and descriptors, the official MSFD data from a small Mediterranean country, Malta (ERA, 2020a,b) has been used within the NEAT framework. Since this country has quantitative data and adequate information from a relatively small number of reporting units, it constitutes a good candidate to compare the results obtained through an integrative assessment using NEAT with those of the official national assessment (wherein the integrated assessment of status was based on both qualitative and quantitative data/approaches). This research outlines the comparison of both approaches, highlighting the main differences in their outcomes, and their potential implications in management, thus providing insight for other MS when undertaking their assessments in upcoming MSFD implementation cycles.

MATERIALS AND METHODS

Adaptations of NEAT for Comparability to Malta's Official Assessment

Malta submitted the initial assessment of environmental status of its marine waters in October 2013[1], as part of the first MSFD implementation cycle. At that time, the report did not fully address the criteria as stipulated by the first MSFD Commission Decision (European Commission, 2010). Shortcomings of such assessment were particularly related to the qualitative nature of the good environmental status definitions, the limited ambition of the environmental targets and the limited reporting of impacts from pressures. Under the second implementation cycle, Malta implemented a monitoring and assessment program, through a European Union funded project, during the period 2017–2019 (Borja et al., 2019a,b). This project provided updated datasets that enabled a revised assessment in accordance with the new MSFD requirements (European Commission, 2017). Such targeted data collection process facilitated the application of the criteria laid down by the European Commission (2017). In addition, data and information robustness and updated environmental targets,

focusing on the main pressures that are considered to put achievement of good status at risk, resulted in an improvement in terms of the degree of quantitative assessment involved (ERA, 2020a,b).

Malta officially reported data on all 11 descriptors. Whilst quantitative assessment was undertaken for most of the descriptors, in some cases—D2 (Non-indigenous Species) and D11 (Noise/energy)—the assessment was based on qualitative information. Meanwhile possibilities for assessment of D4 (Food webs) and D7 (Hydrography), are pending further developments of essential aspects such as indicators and baseline data. Within this context, for the purpose of the comparison between the official and the NEAT assessment, descriptors 2, 4, 7, and 11 have been excluded from this study (**Supplementary Table 1**). Further, 19 out of the 52 criteria[2] applied within NEAT's framework lacked data for Malta; and for another nine criteria, Malta's official assessment lacked assessment methods or thresholds of good/non-good status (ERA, 2020a). In order to facilitate comparability these criteria were also omitted from this study. Further, not all secondary criteria (as defined in European Commission, 2017) were applied in view of their non-mandatory nature.

Following such conditions, the quantitative assessment in NEAT was finally based upon 24 criteria, covering seven descriptors (D1, D3, D5, D6, D8, D9, and D10), and including birds, mammals, reptiles, fish, cephalopods, and pelagic and benthic habitats as ecosystem components (**Supplementary Table 1**). The 24 criteria were assessed through 336 indicators, these indicators having also been applied within the national assessment reported to the European Commission [**Supplementary Table 2**, information obtained from ERA (2020a,b)].

Requirements of NEAT

The NEAT is a flexible and user-friendly software, which allows the hierarchical integration of multiple indicators and ecosystem components, represented by data collected from different monitoring sources at different spatial scales, for a robust assessment. To assess the status of any area, NEAT needs:

- Indicators: these are the basis of calculations in NEAT. For each indicator, the mean and standard error values for each assessed area are calculated.
- Marine reporting units: these are the areas to which the indicators are attributed. Their hierarchical, nested structure allows for the weighting of indicators in the assessment that is based on the reporting units' surface areas.
- Normalization of indicators: in order to aggregate results for all indicators, their values are normalized along a scale of 0 (worst environmental status) to 1 (best environmental status). Specific thresholds of the indicators

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[1]https://era.org.mt/en/Pages/MSFD-Initial-Assessment.aspx

[2]It should be noted that the number of criteria quoted here (52) is higher than what is enlisted in the revised European Commission Decision (European Commission, 2017); in view of differences in the application of criteria for D1 (biodiversity) – mammals, seabirds, fish, and cephalopods, within the NEAT approach.

are also normalized e.g., good/non-good environmental status boundary is normalized at 0.6 in all indicators.

- Aggregation rules: By default, aggregation is done across all indicators belonging to a reporting unit, with options to visualize the status of the separate ecosystem components of the reporting unit.
- NEAT value: the outcomes of the aggregation are represented by a number and a color, which corresponds to the status. This NEAT value is obtained for the whole assessed area, but can be visualized at different spatial scales, descriptors, ecosystem components (e.g., fish, phytoplankton, etc.), or habitat types.
- Confidence on assessment values: each NEAT value is accompanied by its quantitative estimate of the confidence of the result, based on Carstensen and Lindegarth (2016). This estimate is performed on the basis of the standard error, and the performance of Monte-Carlo simulations, as a means to understand how this error propagates throughout the assessment.

The NEAT version 1.4[3] was applied in this study. Additional information on the software can be consulted in Borja et al. (2016, 2019c) and Berg et al. (2017).

Marine Reporting Units as Applied in the NEAT

The reporting units applied within the scope of the MSFD assessment and making up the Maltese waters are shown in **Figure 1**. These comprise:

- Nine coastal water bodies of sizes ranging between 13 and 97 km^2 and covering a total area of 400 km^2. These are referred to as the Water Framework Directive (WFD) waterbodies noting original designation under this directive.
- Territorial waters and internal waters, extending from the low-water coastline to the 12 nm (nautical mile) limit, and covering a total of 4,028 km^2.
- The Fisheries Management Zone (FMZ) and internal waters, extending from the low-water coastline to the 25 nm limit, and covering a total of 11,678 km^2.
- The designated area for hydrocarbon exploration and exploitation (referred to and HCexp within the scope of this study) and extending from the low water coastline to the outer limit of the continental shelf, and covering a total of 75,475 km^2.

Indicators are associated to specific reporting units and then these are aggregated hierarchically, as indicated in **Figure 2**.

Adaptations Within the NEAT Reflecting MSFD Criteria and Ecosystem Components

The default setting of the NEAT software originally allowed for the hierarchical integration of data at the reporting units

and habitat levels (Berg et al., 2017). As an example, habitats were classified as pelagic and benthic, benthic habitats were re-classified as rocky and soft-bottom substrata, soft-bottoms were re-classified as sandy, muddy and mixed substrata, and so on. For the purpose of this study, the NEAT software was manually adapted, to allow integration at other required levels or for other components of the marine environment. Following the hierarchical structure for habitats, similar hierarchies were re-defined considering relevant species groups, habitat types, ecosystems and pressures, as well as criteria, as in the European Commission (2019) Decision. As an example, for the "Species" category, the following categories were created: birds, mammals, reptiles, fish, and cephalopods; each of which was further defined reflecting MSFD requirements e.g., for birds, the included groups were surface feeding birds, pelagic feeding birds, etc. Further, each of these groups was associated with the relevant MSFD criteria, which were coded as DXCY_name (e.g., Descriptor 1, Criteria 2_BirdsPelagicFeeding Population Abundance). **Supplementary Figure 1** provides a NEAT screenshot illustrating such hierarchical adaptations. Additional components were manually included as appropriate, reflecting available data (e.g., crustaceans, seagrasses).

Further, the NEAT assessment was carried on the basis of a total of 12 ecosystem components and associated criteria/indicators: (1) water column (associated with nutrients, oxygen, contaminants in water, or floating litter); (2) seafloor (associated to loss or disturbance of the seabed, and litter); (3) sediment (contaminants); (4) macroalgae, including quality indices such as CARLIT (Ballesteros et al., 2007) or species such as *Lythophyllum*; (5) seagrasses, the *Posidonia* Rapid Evaluation Index (PREI) (Gobert et al., 2009); (6) macroinvertebrates, the Bentix quality index (Simboura and Zenetos, 2002); (7) Crustacea (indicators of quality, contaminants); (8) cephalopods (indicators of quality, contaminants); (9) fish (indicators of quality, contaminants); (10) reptiles; (11) birds; and (12) mammals. Such grouping was adopted and tested under the NEAT approach here and was not considered a complete reflection of the revised Commission Decision (European Commission, 2017).

Further detail on these adaptations to the NEAT tool can be consulted in the NEAT database for which a direct link (MEDREGPROTO_prototype-Malta.db) is provided as **Supplementary Material**, accessible through the use of the NEAT software[4]. As this file contains all the original information used, it ensures the replicability of the study by any interested researcher.

Indicators and Threshold Setting Within the NEAT

To select the indicators, the criteria of the European Commission (2017) decision were followed as indicated in **Supplementary Table 1**. The use of primary criteria is mandatory to ensure consistency across the EU, whereas the use of secondary criteria should be decided by MS, where necessary, to complement a primary criterion or when, for a particular criterion, the marine environment is at risk of not achieving or not maintaining good environmental status.

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[3]www.devotes-project.eu/neat

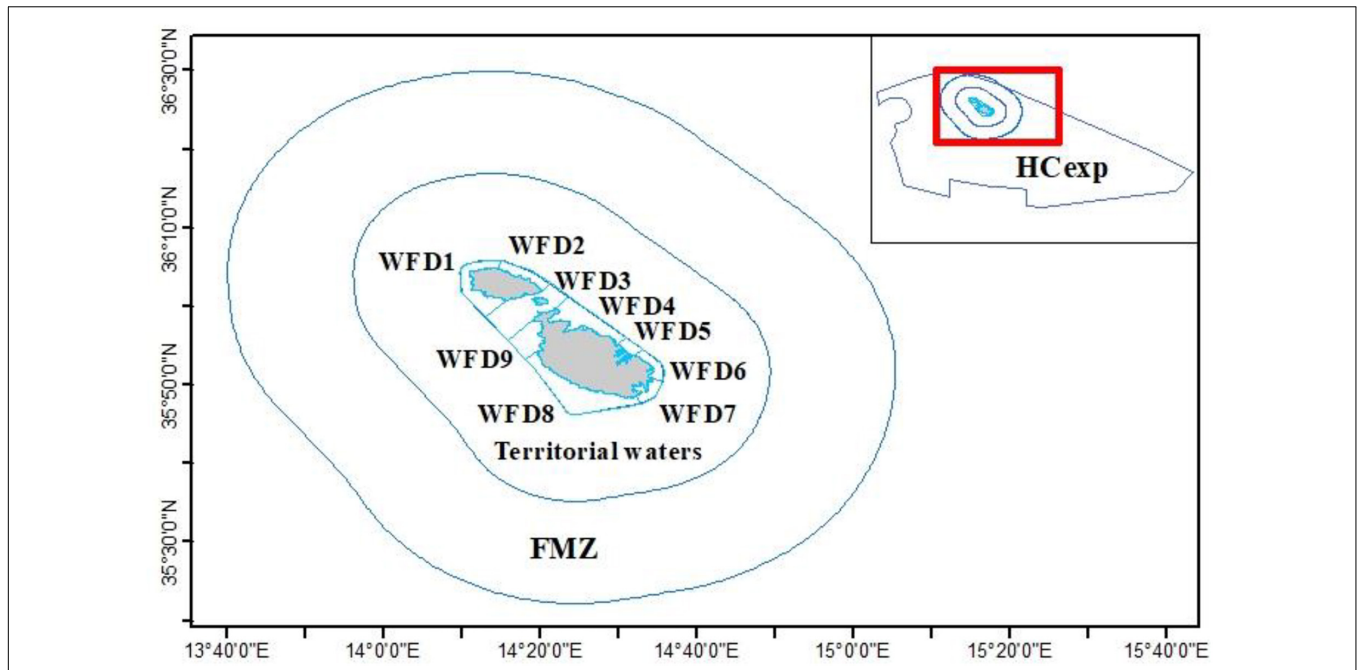[4]http://www.devotes-project.eu/neat/

FIGURE 1 | Map showing the Maltese Marine Reporting Units, including nine coastal water bodies as designated under the Water Framework Directive (WFD 1 to WFD 9), Territorial waters and internal waters, the Fisheries Management Zone (FMZ) and internal waters, and the area designated for hydrocarbon exploration and exploitation (HCexp). The given acronyms are solely used within the scope of this study, for the benefit of legibility.
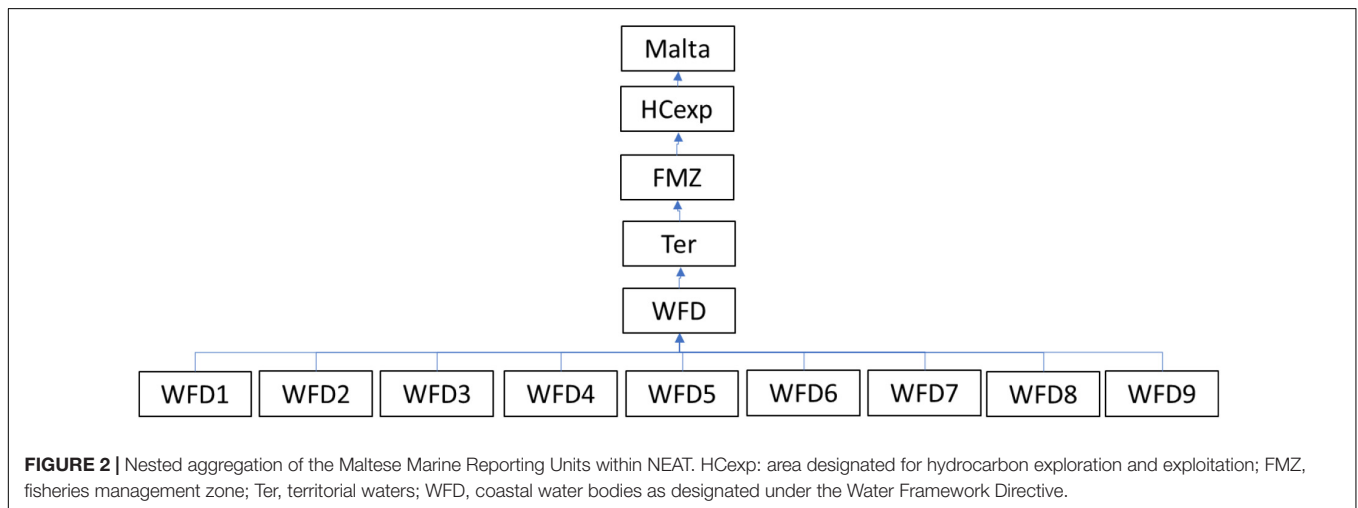

FIGURE 2 | Nested aggregation of the Maltese Marine Reporting Units within NEAT. HCexp: area designated for hydrocarbon exploration and exploitation; FMZ, fisheries management zone; Ter, territorial waters; WFD, coastal water bodies as designated under the Water Framework Directive.

From the 336 indicators applied within the national assessment, 282 indicators were used in the NEAT analyses (see **Supplementary Table 2**). The remaining 54 were omitted in view of the absence of quantitative data or quantitative threshold values for the definition of status (**Supplementary Table 2**). The dependence on quantitative data and thresholds can be considered as a shortcoming of NEAT approach, noting that the absence of such information for all criteria is common for many of the European Union Member States, preventing the application of this tool in its entirety. The generic indicators used, the associated descriptors, criteria and other details can be consulted in **Table 1**.

For the NEAT analyses, each of the used indicators has a range of variation (from worst to best values, i.e., reference conditions), and at least a threshold between good/not good (i.e., moderate) environmental status. In most cases (257 out of the 282 indicators used), the threshold values included in the NEAT calculations were those also applied in Malta's official assessment (**Supplementary Table 2**; ERA, 2020a). The origin of those thresholds is varied, including national thresholds intercalibrated with other MS (European Commission, 2018a); regional thresholds for nutrients and baselines for litter as set for the Mediterranean; or European thresholds for contaminants in the environment or in seafood (**Supplementary Table 2**, columns

K and L). In a few cases thresholds were taken from relevant literature e.g., for D6, for habitat loss and habitat disturbance, thresholds from Kazanidis et al. (2020) were applied. Finally, in 15 cases, referred mostly to incidental bycatch and population abundance of seabirds and mammals, the thresholds were based on expert judgment, but supported on information and data from ERA (2020a) and the Habitats and Birds Directive. In some cases (e.g., indicators intercalibrated as per WFD requirements, such as chlorophyll, Bentix, PREI, CARLIT, etc.; European Commission, 2018a), threshold levels for other boundaries were available (e.g., High/Good, Good/Moderate, Moderate/Poor, Poor/Bad), and used in the calculations. When these intermediate thresholds were absent, they were generated through interpolations in NEAT (Berg et al., 2017). Such interpolations were strictly applied in the NEAT tool, but were not part of the official assessment.

Assessment of the Environmental Status in the NEAT

Data for the applied indicators was obtained from Malta's marine environment database containing data collected through monitoring carried out under the EMFF 8.3.1 project, for the period June 2017 to June 2019. For each indicator, mean and standard error values for stations associated to the different reporting units, were generated. For indicators that were not covered by the said monitoring program, such as those associated
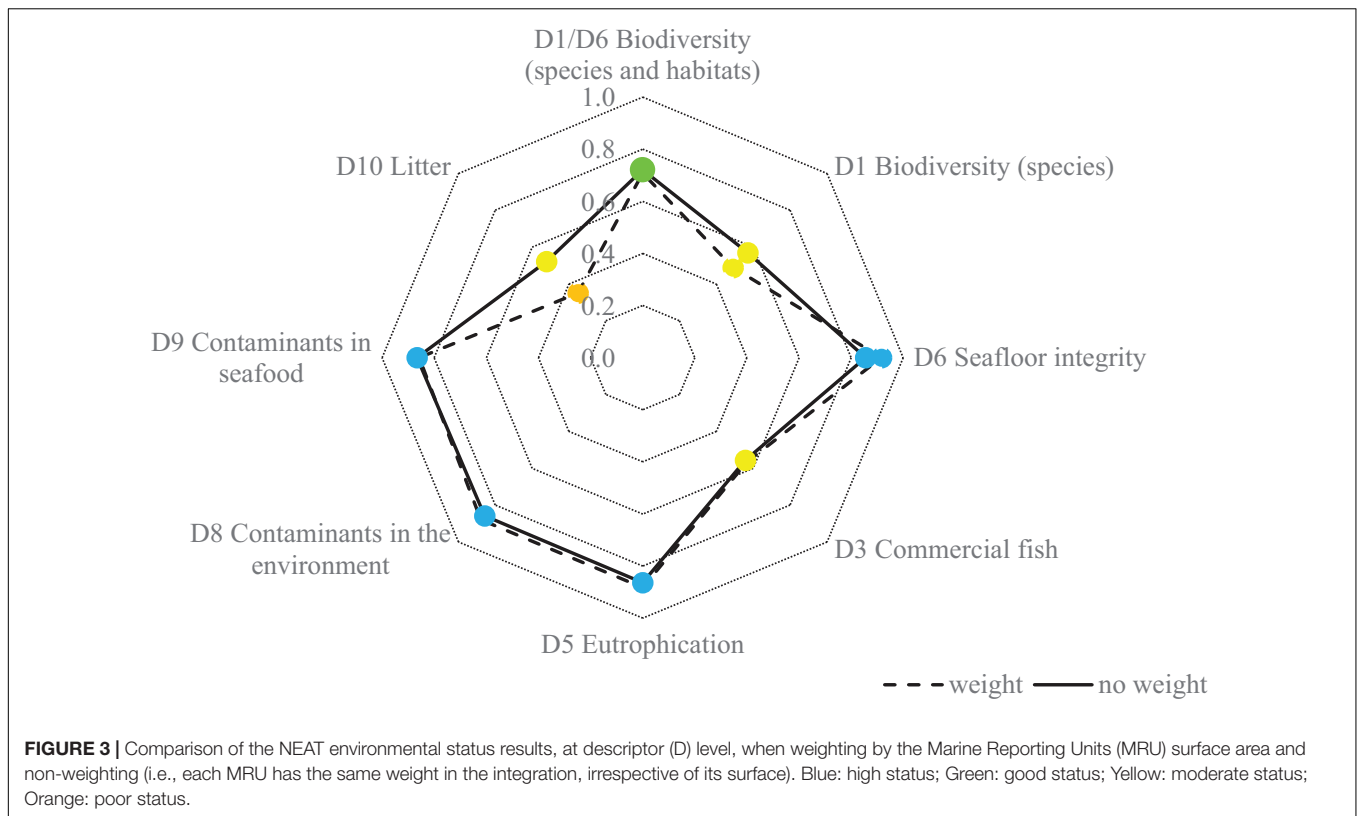
to D1 (biodiversity of birds, reptiles, mammals, fish, and cephalopods) and D3 (commercial fish), the information was extracted from Malta's MSFD assessment report (ERA, 2020a,b) with mean and standard error calculations undertaken following the same procedure. The mean and standard error of each indicator were included in the NEAT, with each indicator associated to a descriptor, a type of species/habitat, an ecosystem component, a criterion of those in **Table 1**, and a reporting unit (see details in **Supplementary Table 2**).

The indicator values were then normalized and aggregated across ecosystem component level (as defined in section "Adaptations Within the NEAT Reflecting MSFD Criteria and Ecosystem Components"), at the descriptor level and by aggregating all descriptors under (i) the option of weighting by reporting unit surface area, and (ii) without applying such weighting. The NEAT interface further allows one to visualize integration results across ecosystem components and the different spatial scales applied, allowing the tracing of the origin of low assessment values. The confidence associated to each assessment and scale is also presented, based on 1,000 Monte-Carlo iterations.

All the information included in the NEAT software (indicators, criteria, thresholds, mean and standard error values, by descriptor and reporting unit) is available in the database provided as **Supplementary Material**, that can be opened using NEAT (MEDREGPROTO_prototype-Malta.db).

TABLE 1 | Number of indicators used/not-used in the NEAT analysis, to assess the environmental status in Malta, related to the seven qualitative descriptors of the Marine Strategy Framework Directive, the criteria (see **Supplementary Table 1** for description), type of criterion (P, primary; S, secondary), and number of species, habitats or matrices associated to each indicator.

Descriptor	Criteria	Type	Indicators	Used	Not used	Species/habitats
D1-Birds	D1C1	P	Incidental bycatch	3	0	3 seabirds
	D1C2	P	Population abundance	3	0	3 seabirds
	D1C3	S	Population demographics	2	0	2 seabirds
	D1C4	S	Distributional range	0	3	3 seabirds
D1-Mammals/reptiles	D1C1	P	Incidental bycatch	3	0	3 mammals
	D1C2	P	Population abundance	4	0	2 mammals, 1 reptile
	D1C4	P	Distributional range	1	0	1 reptile
	D1C5	P	Habitat extent	0	1	1 reptile
D1 – Fish/Cephalopods	D1C2	P	Population abundance	36	16	30 fish, 9 cephalopods
	D1C3	P	Population demographics	10	4	9 fish, 2 cephalopods
	D1C4	S	Distributional range	1	24	16 fish, 8 cephalopods
D1 – Pelagic habitats	D1C6	P	Composition and abundance	0	2	coastal and shelf
D1/D6 –Benthic habitats	D6C4	P	Habitat loss	7	0	7 habitats
	D6C5	P	Habitat disturbance	6	0	6 habitats
D3 – Commercial fish	D3C1	P	Fishing mortality	30	0	23 fish, 4 crustacea, 3 cephalopods
	D3C2	P	Spawning Stock Biomass	63	1	39 fish, 4 crustacea, 4 cephalopods
	D3C3	P	Size distribution	30	0	11 fish, 3 crustacea, 1 cephalopod
D5 – Eutrophication	D5C1	P	Nutrient concentration	4	0	4 nutrients
	D5C2	P	Chlorophyll a concentration	1	0	
	D5C4	S	Transparency	1	0	
	D5C5	P	Oxygen saturation	1	0	
D8 – Pollutants	D8C1	P	Concentration of contaminants	47	3	22 in water, 13 sediments, 15 biota
D9 – Pollutants in seafood	D9C1	P	Concentration of contaminants	25	0	15 in fish, 6 crustacea, 4 cephalopods
D10 – Litter	D10C1	P	Amount of litter	4	0	beach, floating, seabed (shallow, deep)
			TOTAL	282	54	

FIGURE 3 | Comparison of the NEAT environmental status results, at descriptor (D) level, when weighting by the Marine Reporting Units (MRU) surface area and non-weighting (i.e., each MRU has the same weight in the integration, irrespective of its surface). Blue: high status; Green: good status; Yellow: moderate status; Orange: poor status.

RESULTS

All the calculation results of NEAT assessment can be consulted in the **Supplementary Material** including: the outcomes of the weighting and non-weighting by reporting unit area (**Supplementary Tables 3, 4**, respectively); weighting and non-weighting by reporting unit area and sorted by ecosystem components (**Supplementary Tables 5, 6**, respectively); and weighting by reporting unit area and sorted by each descriptor (D1/D6: biodiversity and seafloor integrity in **Supplementary Table 7**; D1: biodiversity in **Supplementary Table 8**; D3: commercial fish in **Supplementary Table 9**; D5: eutrophication in **Supplementary Table 10**; D6: seafloor integrity in **Supplementary Table 11**; D8: contaminants in **Supplementary Table 12**; D9: contaminants in seafood in **Supplementary Table 13**; and D10: marine litter in **Supplementary Table 14**). The information from **Supplementary Tables 3–14** has been summarized in **Supplementary Table 15**, showing the results by weighting and non-weighting by reporting unit area, and for each of the descriptors, criteria, and ecosystem components.

Comparison of Weighting (by Reporting Unit) and Non-weighting Scenarios in the NEAT Analysis

Taking into account the surface area of each reporting unit when nesting the results at the level of the WFD areas, territorial waters, FMZ and HCexp, and integrating to the whole Malta waters, filters for weighting and non-weighting by reporting unit
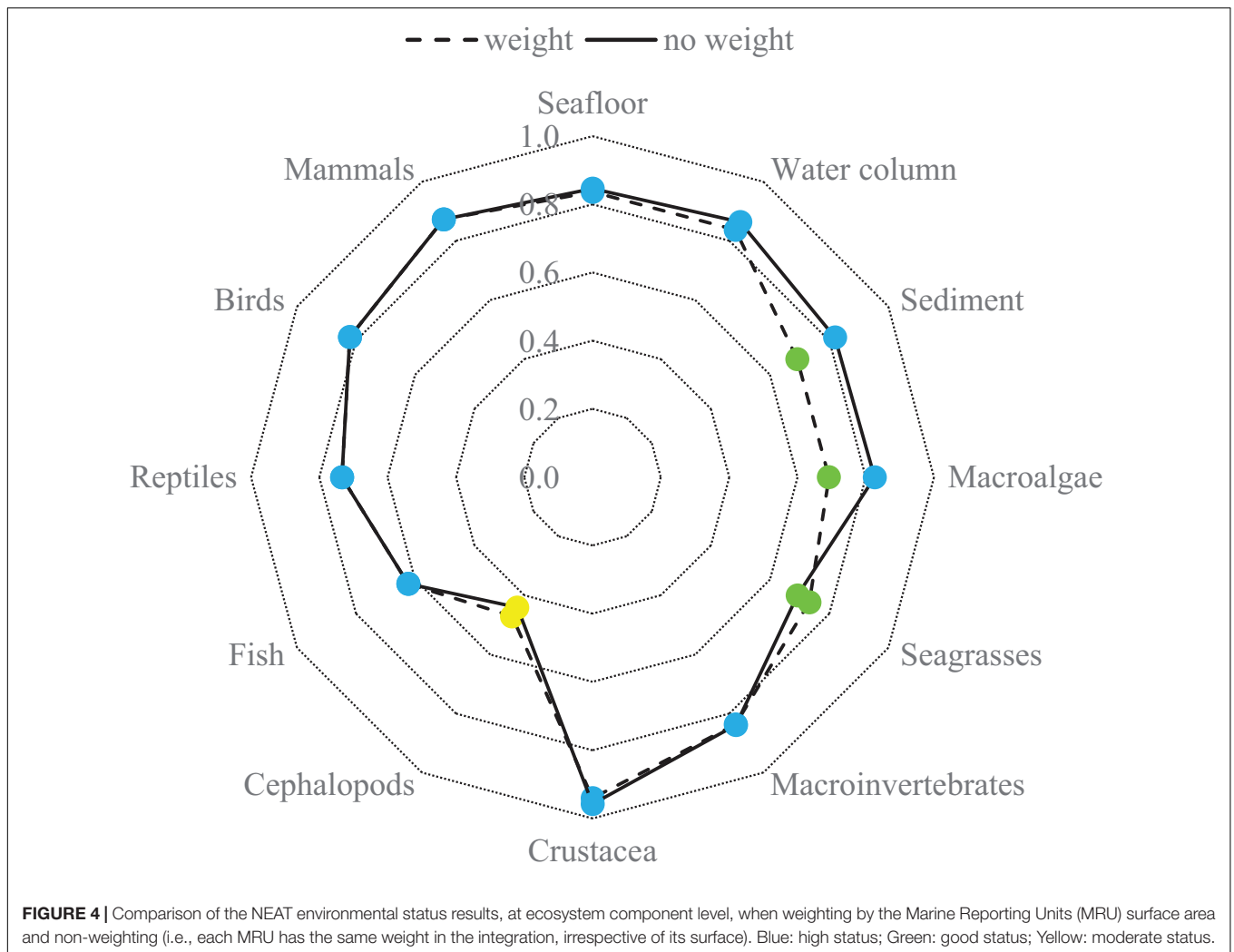
area were applied through the NEAT interface. A comparison of outcomes indicated a similar status assessment for all descriptors except for the Biodiversity and Marine litter descriptors (D1 and D10) (**Figure 3**).

Similarly, when comparing the two assessments at the ecosystem component level, the outputs are highly similar, with some differences (including a difference in quality class) for the sediments and macroalgae components (**Figure 4**).

Global Results for Malta's Marine Waters When Weighting by Marine Reporting Unit in NEAT

Taking into account the results from previous section, the results after weighting by reporting unit surface were further investigated. Under such an option, the larger the spatial cover of a reporting unit the greater the weight given to any associated indicator value. Thus, the overall assessment of Malta's marine waters is a weighted average of indicators. **Table 2** provides an overview of the outcomes of an integrated assessment of all reporting units, including criteria and descriptors (shown in columns) and an integrated assessment for criteria and descriptors, for each reporting unit (shown in rows).

Malta's marine waters achieve an overall "good" status, mainly reflecting the "good" environmental status of the HCexp reporting unit, which represents Malta's overall marine area. Most of the other contained reporting units achieve "high" status (**Table 2**). The confidence of the results is near 100% in all cases,

FIGURE 4 | Comparison of the NEAT environmental status results, at ecosystem component level, when weighting by the Marine Reporting Units (MRU) surface area and non-weighting (i.e., each MRU has the same weight in the integration, irrespective of its surface). Blue: high status; Green: good status; Yellow: moderate status.

with the exception of FMZ reporting unit, with a confidence level of 61.1% (**Table 2**).

Generally, NEAT results at coastal water (WFD) level are better than integrations at a larger scale, such a result also reflecting the larger number of indicators considered for the larger reporting units from NEAT results, and the status of these (**Table 2**). However, relatively low NEAT values were also noted for some criteria and ecosystem components at coastal reporting unit level e.g., for WFD5 and WFD6, such as habitat condition based on *Posidonia oceanica* (D6C5), chlorophyll concentration (D5C2), and sediments, which achieved "moderate" status (**Table 2**).

In spite of the overall "good" status achieved for Malta's water though the NEAT application, a lower status was observed for some descriptor level integrations. For example, D1 (biodiversity) is in moderate status reflecting status for cephalopods and fish in coastal waters and/or deep seas under D1C2 (population abundance), D1C3 (population demographic characteristics), and D1C4 (population distribution range) criteria (**Table 2**).

Meanwhile, whilst the D6 (seafloor integrity) achieved "high" environmental status, a deeper look into its component

criteria indicated the benthic habitat condition (D6C5) for circalittoral coarse sediments in "poor" status (**Table 2**), based on the indicator for extent of disturbed seafloor. Meanwhile an overall "moderate" status is achieved for commercial fish and shellfish (D3), reflecting the "moderate" status for the spawning stock biomass (D3C2) and population age/size distribution (D3C3), and fishing mortality rate (D3C1) in "good" status this being based on a NEAT value close to the good/moderate threshold (**Table 2**).

On the other hand, D5 (eutrophication), D8 (contaminants in the environment), and D9 (contaminants in seafood) are in "high" environmental status for the overall Maltese waters and in most of the contained reporting units (**Table 2**).

As for the "poor" environmental status of D10 (marine litter), detected by NEAT, this is reflection of floating and seafloor litter pressures in the HCexp reporting unit (as reflected by the "poor" status under these criteria), in contrast to the "high" status when assessed for coastal waters (WFD) (**Table 2**).

Finally, looking at integrations for elements representing ecosystem components (bottom of **Table 2**), good or high status is achieved in most cases. However, the detailed breakdown of

TABLE 2 | Environmental status values, using NEAT (Nested Environmental status Assessment Tool), weighted by Marine Reporting Units (MRU) area, for each MRU, criterion (C) and descriptor (D) of the Marine Strategy Framework Directive, as well as for each ecosystem component.

MRU	Malta	HCexp	FMZ	TER	WFD	WFD1	WFD2	WFD3	WFD4	WFD5	WFD6	WFD7	WFD8	WFD9
Area (km^2)	75,475	75,475	11,678	4,028	400	50.1	22.9	86.1	57.9	13.3	16.8	17.6	97.4	38.3
Total MRU weight	0	0.825	0.127	0.044	0.002	0	0	0.001	0	0	0	0	0.001	0
NEAT value	0.733	0.714	0.810	0.851	0.827	0.844	0.849	0.863	0.850	0.765	0.819	0.840	0.857	0.833
Confidence (%)	100	100	61.1	100	100	100	100	100	100	98.7	93.2	100	100	94.6
D1/D6 Biodiversity (species and habitats)	0.709	0.712	0.662		0.721	0.805	0.801	0.857	0.853	0.821	0.765	0.789	0.850	0.767
D1 Biodiversity (species)	0.495	0.466	0.662											
D1C1 Birds Pelagic-Feeding bycatch	1.000		1.000											
D1C1 Cetacean Small bycatch	1.000		1.000											
D1C2 Birds Pelagic-feeding Pop abun	0.816		0.816											
D1C2 Cephalopods Coast Shelf Pop abun	0.434	0.436	0.358											
D1C2 Cephalopods Deep sea Pop abun	0.425	0.433	0.283											
D1C2 Fish Coastal Pop abun	0.393		0.393											
D1C2 Fish Deep sea Pop abun	0.504	0.502	0.544											
D1C2 Fish Demersal Shelf Pop abun	0.392	0.388	0.486											
D1C2 Cetacean Small Pop abun	0.744		0.744											
D1C2 Turtles Pop abun	0.794		0.794											
D1C3 Birds Pelagic-feeding Pop demo	0.647		0.647											
D1C3 Cephalopods Coast Shelf Pop demo	0.467		0.467											
D1C3 Fish Deep sea Pop demo	0.581	0.580	0.616											
D1C3 Fish Demersal Shelf Pop demo	0.582	0.584	0.544											
D1C4 Cephalopods Coast Shelf Pop distr	0.383		0.383											
D1C4 Turtles Pop distr	0.674		0.674											
D6 Seafloor integrity	0.916	0.917			0.721	0.805	0.801	0.857	0.853	0.821	0.765	0.789	0.850	0.767
D6C4 Bathyal Upper Rock habitat extent	0.996	0.996												
D6C4 Circalittoral Coarse Sed habitat Extent	1.000	1.000												
D6C4 Infralit Mixed Sed habitat extent	0.996	0.996												
D6C4 Infralit Rock Benthic habitat extent	0.996	0.996												
D6C4 Littoral Biogenic Rock habitat extent	1.000	1.000												
D6C4 Littoral Rock habitat extent	0.957	0.957												
D6C4 Other Benthic habitat extent	0.998	0.998												
D6C5 Benthic habitat condition	0.912				0.912	0.944	1.000	0.888	0.928	0.832	0.872	0.747	0.960	0.840
D6C5 Bathyal Upper Rock habitat condition	0.632	0.632												
D6C5 Circalittoral Coarse Sed habitat cond	0.322	0.322												
D6C5 Infralit Mixed Sed habitat condition	0.837				0.837		0.773	0.875	0.953	0.810	0.838	0.963	0.767	0.747

(Continued)

TABLE 2 | Continued

MRU	Malta	HCexp	FMZ	TER	WFD	WFD1	WFD2	WFD3	WFD4	WFD5	WFD6	WFD7	WFD8	WFD9
D6C5 Infralittoral Rock habitat condition	0.613				0.613									
D6C5 Other Benthic habitat condition	0.733				0.733	0.666	0.630	0.809	0.676		0.584	0.657	0.824	0.714
D3 Commercial fish	0.566	0.568	0.524											
D3C1 Mortality rate	0.632	0.633	0.618											
D3C2 Spawning stock biomass	0.466	0.470	0.382											
D3C3 Population age/size distribution	0.576	0.576	0.573											
D5 Eutrophication	0.883		0.888	0.871	0.827	0.819	0.832	0.813	0.816	0.737	0.815	0.816	0.835	0.810
D5C1 Nutrient concentrations	0.972		0.973	0.972	0.957									
D5C2 Chlorophyll-a concentration	0.860		0.850	0.937	0.867	0.908	0.920	0.873	0.859	0.525	0.838	0.808	0.894	0.877
D5C4 Transparency	0.914		0.954	0.843	0.723									
D5C5 Oxygen saturation	0.803		0.823	0.763	0.803	0.790	0.802	0.798	0.801	0.807	0.807	0.818	0.816	0.787
D8 Contaminants in the environment	0.880	0.887		0.792	0.929	0.951	0.954	0.952	0.914	0.737	0.909	0.967	0.909	0.977
D8C1 Non-UPBTs Contaminants	0.985	0.988		0.947	0.935	0.949	0.935	0.948	0.939	0.787	0.908	0.952	0.923	0.973
D8C1 UPBTs Contaminants	0.775	0.785		0.637	0.923	0.953	0.973	0.957	0.888	0.687	0.910	0.981	0.895	0.982
D9 Contaminants in seafood	0.858	0.857		0.865	0.958			0.958						
D9C1 Contaminants Seafood	0.858	0.857		0.865	0.958			0.958						
D10 Litter	0.350	0.343			0.968									
D10C1 Litter (excluding micro litter)	0.350	0.343			0.968									
Ecosystem components														
Seafloor	0.836	0.836			0.968									
Water column	0.842	0.775	0.888	0.874	0.841	0.850	0.850	0.840	0.837	0.772	0.844	0.842	0.852	0.838
Sediment	0.689			0.666	0.924	0.986	0.986	0.987	0.902	0.556	0.865	0.989	0.898	0.992
Macroalgae	0.692				0.692	0.944	1.000	0.888	0.928	0.832	0.872	0.747	0.960	0.840
Seagrasses	0.733				0.733	0.666	0.630	0.809	0.676		0.584	0.657	0.824	0.714
Macroinvertebrates	0.837				0.837		0.773	0.875	0.953	0.810	0.838	0.963	0.767	0.747
Crustacea	0.940	0.939	0.507	0.978	0.963			0.963						
Cephalopods	0.469	0.476	0.344											
Fish	0.623	0.626	0.503	0.665	0.950					0.950				
Reptiles	0.734		0.734											
Birds	0.821		0.821											
Mammals	0.872		0.872											

HCexp, hydrocarbon exploration; FMZ, fisheries management zone; Ter, territorial waters; WFD, Water Framework Directive water bodies; UPBT, Ubiquitous, Persistent, Bioaccumulative and Toxic substances. Blue: high status; Green: good status; Yellow: moderate status; and Orange: poor status.

the assessment outcome also indicates "poor/moderate" levels for fish, cephalopods and crustaceans assessed at the larger area assessment scales (HCexp and/or FMZ), as well as "moderate" levels for seagrasses in WFD6 and sediments in WFD5.

A Comparative Analysis of the NEAT Assessment Outcomes and Malta's Official MSFD Assessment

Malta official national assessment reporting was carried out by integrating quantitative outcomes for indicators/criteria per descriptor where possible, and complementing with qualitative evaluation where necessary. A comparison of the results obtained through the use of NEAT and the results reported by Malta in its official assessment report, was therefore mostly possible at lower levels on the integration hierarchy i.e., for indicators and criteria. The comparative analysis is summarized in **Table 3**, in which the results (NEAT values) for the integrated assessment done using NEAT (per criterion, per descriptor and considering all descriptors), is shown aside the classification of the status of the indicators (good vs. not good vs. not assessed) as per the NEAT assessment, and as per Malta's official assessment[5].

The reporting units applied in the NEAT approach for the specific indicators reflect the reporting units applied within the national assessment, with some exceptions. Within Malta's national assessment, species under D1 (Fish) and D3 (Commercial fish and shellfish) were assessed at the FMZ scale and also at the scale of the General Fisheries Commission for the Mediterranean (GFCM) and geographical sub-area (GSA) 15, the latter reflecting the regional scale for fisheries data collection. Meanwhile within the NEAT approach, in addition to assessment at FMZ, indicators for these descriptors were instead assessed at HCexp scale. In doing so it was assumed that data for the GSA 15 area, was also representative for the HCexp area.

The achievement of "good" status (0.733) when integrating the NEAT values of all seven descriptors for all of Malta's waters, is a good reflection of the classification of indicators under both assessments, with 56% of indicators in good status in both cases (159 indicators in "good" status out of 282 indicators assessed in NEAT, and 175 indicators in "good" status out of out of 310 indicators assessed in the official assessment; see **Table 3**).

Meanwhile, for the majority of descriptors the high NEAT values were also reflected by the high proportion of indicators in "good" status under both the NEAT assessment and Malta's official assessment (**Table 3**).

When comparing the different criteria, in 38 out of 40 cases from D1, D3, D5, D6, D8, D9, and D10, NEAT values mirror the classification of indicators in both the NEAT and the official assessment i.e., where NEAT values indicates "good" status, the proportion of indicators in "good" status is also high (92–100%) (based on proportions indicated in **Table 3**) and vice-versa. Such results may mask issues noted when looking at the assessment at indicator level e.g., for D9 (contaminants in seafood) mercury in *Xiphias gladius* and *Merluccius merluccius* is present at levels

above established by the environmental quality standards; and for D8 (contaminants in the environment) mercury levels in fish and benzo(a)pyrene and fluoranthene in sediments are also above established standards (**Supplementary Table 2**). Meanwhile for criteria resulting in non-good NEAT values, the percentage of indicators in non-good status, in both the NEAT assessment and the official assessment varies from 59 to 100% (based on proportions indicated in **Table 3**). In the case of D1 (biodiversity), this reflects the numerous indicators not achieving good status including species from several genera, such as e.g., *Diplodus, Epinephelus, Mustelus, Chimaera, Coelorinchus*, or *Etmopterus*, in fish, and *Illex, Octopus, Eledone, Scaeurgus, Sepia*, or *Todarodes,* in cephalopods (**Supplementary Table 2**).

However, disagreements are also noted between the classification of indicator values from both the NEAT assessment and Malta's official assessment (**Table 3**):

- When integrating D1 and D6 (species and habitats) disagreement was noted between the NEAT value indicating "good" status (0.71), and the higher proportion of indicators in non-good status for both assessments (**Table 3**), but with a high level of confidence (100%, **Supplementary Table 7**). Such a case exemplifies cases where integrated values coupled with weighting effects can mask differing scenarios/values evident at lower scales/levels.
- For population abundance of demersal fish in the shelf area (D1C2), low NEAT value (0.39) reflects the number of indicators in non-good status under the NEAT assessment. In contrast under the official assessment, the number of indicators in good status is higher (10) than those in non-good status (8). This difference is however explained by the fact that 10 indicators were excluded from the NEAT assessment due to the absence of quantitative thresholds.
- For population demography in deep-sea fish (D1C3) the non-good status (0.58, close to the threshold of 0.6), calculated with NEAT, does not provide a complete picture of the 50:50 ratio of indicators in good status (*Chimaera monstruosa* and *Galeus melastomus*, in FMZ) and non-good status (*Etmopterus spinax* and *Galeus melastomus*, in HCexp) in both NEAT and official assessments (**Supplementary Table 2**); and
- In the case of fishing mortality (D3C1), the "good" status (close to the 0.6 threshold) calculated using NEAT, contrasts with a 63% of the indicators in "not good" status in both NEAT and official assessments, once again reflecting the loss of detail when integrating values.

DISCUSSION

Despite the progress made in the integrated assessment of the marine environment (Borja et al., 2016; Inniss et al., 2016), a number of challenges persist (Borja et al., 2019b; European Commission, 2020): absence of suitable indicators; absence of suitable reference conditions or thresholds; difficulty in aggregating/integrating indicator outcomes (e.g., challenges with

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[5]For both classifications, these numbers reflect indicators considered within the scope of this study (as reflected in **Supplementary Table 2**) and do not represent the national assessment in its entirety.

TABLE 3 | Malta environmental status values, using NEAT (Nested Environmental status Assessment Tool), for each criterion (C) and descriptor (D) of the Marine Strategy Framework Directive; and a comparison of the classification of indicators as per results in NEAT vs. classification of indicators as per results in the official assessment.

Descriptors and criteria	NEAT values	Classification of selected indicators as per results in NEAT (nr)			Classification of selected indicators as per results in Malta's official assessment (nr)		
		Good	Not good	NA	Good	Not good	NA
Status in Malta, based on all descriptors=	0.733	159	123	31	175	135	3
D1/D6 Biodiversity (species and habitats)	0.709	36	39	28	49	51	3
D1 Biodiversity (species)	0.495	24	38	28	38	51	1
D1C1 Birds Pelagic-Feeding Mortality rate from bycatch	1.000	3			3		
D1C1 Cetacean Small Mortality rate from bycatch	1.000	3			3		
D1C2 Birds Pelagic-feeding Population abundance	0.816	3			3		
D1C2 Cephalopods Coastal Shelf Population abundance	0.434	1	10	1	2	10	
D1C2 Cephalopods Deepsea Population abundance	0.425		2			2	
D1C2 Fish Coastal Population abundance	0.393		2	2	1	3	
D1C2 Fish Deepsea Population abundance	0.504	3	10	3	6	10	
D1C2 Fish Demersal Shelf Population abundance	0.392	3	5	10	10	8	
D1C2 Cetacean Small Population abundance	0.744	2		1	2		1
D1C2 Turtles Population abundance	0.794	1			1		
D1C3 Birds Pelagic-feeding Population demography characteristics	0.647	2			2		
D1C3 Cephalopods Coastal Shelf Population demography characteristics	0.467		1	1		2	
D1C3 Fish Deepsea Population demography characteristics	0.581	2	2		2	2	
D1C3 Fish Demersal Shelf Population demography characteristics	0.582		5	3		8	
D1C4 Cephalopods Coastal Shelf Population distributional range and pattern	0.383		1	7	2	6	
D1C4 Turtles Population distributional range and pattern	0.674	1			1		
D6 Seafloor integrity	0.916	12	1		11		2
D6C4 Bathyal Upper Rock Benthic habitat extent	0.996	1			1		
D6C4 Circalittoral Coarse Sediment Benthic Habitat Extent	1.000	1			1		
D6C4 Infralittoral Mixed Sediments Benthic habitat extent	0.996	1			1		
D6C4 Infralittoral Rock Benthic habitat extent	0.996	1			1		
D6C4 Littoral Biogenic Rock Benthic habitat extent	1.000	1			1		
D6C4 Littoral Rock Benthic habitat extent	0.957	1			1		
D6C4 Other Benthic habitat extent	0.998	1			1		
D6C5 Benthic habitat condition	0.912	1			1		
D6C5 Bathyal Upper Rock Benthic Habitat Condition	0.632	1					1
D6C5 Circalittoral Coarse Sediment Benthic Habitat Condition	0.322		1				1
D6C5 Infralittoral Mixed Sediment Benthic habitat condition	0.837	1			1		
D6C5 Infralittoral Rock Benthic habitat condition	0.613	1			1		
D6C5 Other Benthic habitat condition	0.733	1			1		
D3 Commercial fish	0.566	47	76	1	48	76	
D3C1 Fish Commercial Fishing mortality rate	0.632	11	19		11	19	
D3C2 Fish Commercial Spawning stock biomass	0.466	25	38	1	26	38	
D3C3 Fish Commercial Population age/size distribution	0.576	11	19		11	19	
D5 Eutrophication	0.883	7			7		
D5C1 Nutrient concentrations	0.972	4			4		
D5C2 Chlorophyll-a concentration	0.860	1			1		
D5C4 Transparency	0.914	1			1		
D5C5 Oxygen saturation	0.803	1			1		
D8 Contaminants in the environment	0.880	45	3	2	47	3	

(Continued)

TABLE 3 | Continued

Descriptors and criteria	NEAT values	Classification of selected indicators as per results in NEAT (nr)			Classification of selected indicators as per results in Malta's official assessment (nr)		
		Good	Not good	NA	Good	Not good	NA
D8C1 Non-UPBTs Contaminants in environment	0.985	22	1	1	23	1	
D8C1 UPBTs Contaminants in environment	0.775	23	2	1	24	2	
D9 Contaminants in seafood	0.858	23	2		23	2	
D9C1 Contaminants in Seafood	0.858	23	2		23	2	
D10 Litter	0.350	1	3		1	3	
D10C1 Litter (excluding micro litter)	0.350	1	3		1	3	

Indicators "Not assessed" in the NEAT assessment represent those omitted in view of the absence of quantitative data or quantitative threshold values.
*For indicators listed as "Not assessed" in Malta's official assessment, a proper assessment was not possible in view of data limitations. For both classifications, these numbers reflect indicators considered within the scope of this study (as reflected in **Supplementary Table 2**) and do not represent the national assessment in its entirety.*
NEAT values: Green- good status, Red-not good; Classification of indicators: Green: highest number of indicators in good status, Red: highest number of indicators in "not good" status, Yellow: equal numbers of indicators in good/not good status OR indicators not assessed.
UPBT, Ubiquitous, Persistent, Bioaccumulative, and Toxic substances; NA, not assessed.

approaches such as the OOAO—One Out All Out—principle); lack of guidance on the number of indicators to be used; and lack of traceability when integrating indicators or criteria (Borja and Rodríguez, 2010).

When assessing environmental status, the selection of indicators remains one of the most critical and limiting factors (Hummel et al., 2015; Teixeira et al., 2016; Uusitalo et al., 2016; Thibaut et al., 2017). There are different criteria for selecting suitable indicators, including ecological significance, sensitivity to pressures and measurability, among others (Shin et al., 2010; Queiros et al., 2016; Rossberg et al., 2017).

For Malta's national official assessment of the status of the marine waters, as required under MSFD processes (ERA, 2020a), well-known indicators and criteria were used by Maltese authorities, together with legally binding thresholds, based upon international decisions, e.g., intercalibration exercises under the WFD (European Commission, 2017, 2018a), Environmental Quality Standards (European Commission, 2013), etc. In the absence of suitable reference conditions and thresholds values, it is not possible to undertake quantitative environmental assessments (Borja et al., 2012). Hence, when those binding thresholds were not available, Malta authorities used other sources for thresholds/boundaries of status as accepted by the scientific community (e.g., thresholds for fish and shellfish stocks – Froese et al., 2018) or under regional/sub-regional bodies (e.g., UNEP/MAP baselines for marine litter). Most of the threshold values employed within Malta's official assessment was also used within the NEAT assessment.

Furthermore, the NEAT assessment was complemented with additional threshold values, referred to from academic sources (e.g., habitat loss and habitat disturbance thresholds from Kazanidis et al., 2020), or based on expert judgment. However, for other indicators, threshold values were deemed unavailable. Noting that the use of such values is a requirement of the NEAT software, such indicators were excluded from the

NEAT assessment, giving rise to discrepancies when comparing outcomes to those of Malta's official assessment (e.g., exclusion of indicators for criterion D1C2—fish demersal shelf population abundance, as shown in **Table 3**). This throws light on the importance of discussion and agreement on threshold values amongst countries implementing MSFD processes and sharing the same (sub)regional sea. Such values play a role in ensuring comparability of assessments across MS, especially in states sharing similar pressures, and facilitating the design of common management measures to achieve good status (Gorjanc et al., 2020; Murillas-Maza et al., 2020).

In spite of the mentioned challenges, taking into account experience in applying NEAT in the Mediterranean (Borja et al., 2019c; Pavlidou et al., 2019), and based on the available data and thresholds, the application of NEAT to Malta's waters was still possible. An integrative assessment for Malta was performed, with a high confidence in the final result (from 61 to 100% in confidence), suggesting an overall achievement of good environmental status in Maltese marine waters.

In addition to assessing the overall status, the NEAT interface allows for the review of status at smaller geographical scales (reporting units) or at lower levels in the integration hierarchy. As an example, it was possible to note a lower NEAT value (albeit good) for reporting unit WFD5, wherein the capital (Valletta) and its harbor are located, based on the moderate status for some criteria (e.g., chlorophyll) and ecosystem components (e.g., sediments), and others with status values close to the good/non-good threshold e.g., descriptors D5 (eutrophication) and D8 (contaminants). All these observations reflect the intensive urban and harbor activities (e.g., discharges, shipping, dredging, etc.) downgrading the quality of this reporting unit, as also confirmed in previous studies (Romeo et al., 2015). With specific components of the marine environment failing to achieve good status, specific management measures are required (ERA, 2020a).

Furthermore, whilst good status is also achieved for the largest reporting units, FMZ and HCexp, the NEAT interface highlighted cases of non-achievement of good status) for specific criteria and descriptors. A number of such criteria (e.g., spawning stock biomass and population age/size distribution in descriptor D3 of commercial fish) are linked to fishing pressure, which is a general concern in the Mediterranean, with many stocks under the sustainable exploitation limits (de Juan et al., 2011; Raicevich et al., 2017; Froese et al., 2018; Borja et al., 2019c; Reker et al., 2019). With respect to criteria reflecting the status of fish stocks, the shortcomings of assessing such stocks at the scales referred to in section "A Comparative Analysis of the NEAT Assessment Outcomes and Malta's Official MSFD Assessment" must be noted, whilst highlighting the importance of complimenting assessments and measures of stocks at the regional scale, as highlighted by Maltese authorities (ERA, 2020a).

Fishing pressure (from D3) is also known to affect other components of the Mediterranean ecosystem (Coll et al., 2006, 2009), as indicated by the NEAT assessment for several other biodiversity components (in D1), especially fish and cephalopods, under criteria such as population abundance, population demography, and population distribution, for coastal, shelf, and deep-sea areas. In addition, the circalittoral sediments reflect a poor status, reflecting 62.4% of this type of benthic habitat exposed to trawling activity to a lesser or a greater degree (ERA, 2020a), as in other Mediterranean areas (de Juan et al., 2011; Reker et al., 2019). Such quantification is, however, a reflection of the pressure exerted by such activities, and is considered an overestimation of extent of the actual impact on the seabed. This is due to the fact that the intensity with which trawling occurs is highly variable across the reported areas, cumulative dynamics with other pressures may exist and there is no data based on which pressure to impact extrapolations can be made (ERA, 2020a). This example illustrates the challenges encountered when integrating data from different sources to assess the status of large areas, including issues of scale, data accuracy, and knowledge gaps.

Marine litter is another descriptor failing to achieve good status under the NEAT assessment as shown for circalittoral and deep bottoms. Although an attempt was made to correlate its presence with fishing activities and environmental variables, no interpretable correlations were found (Mifsud et al., 2013), implying that litter abundance and distribution depends on factors others than those considered, which could include land-based sources and littering from shipping outside Malta, as shown in other Mediterranean areas (Arcangeli et al., 2018).

In the case of contaminants (D8 and D9), among 68 indicators, benzo(a)pyrene, fluoranthene, and mercury in matrices such as sediments, biota (fish) and seafood failed achievement of good status. Mercury is a substance of concern in the whole Europe (Višnjevec et al., 2014; Kuenen et al., 2018) in water, sediment, biota, as well as in seafood. There is a chronic contamination by this metal in many European locations indicating the need for solutions at the European level (Kuenen et al., 2018). As for the remaining contaminants,

some of them could be related to the bunkering activities (ERA, 2020a), but this should be proven with additional sampling in future applications of the monitoring network (Borja et al., 2019b). Further, such results shed light on the need to ensure representative sampling of fish and cephalopods for future assessments under D9.

According to **Table 3**, 93.3% of the contaminant indicators achieved good status for D8, and 91.3% achieved good status for D9, using NEAT. However, had the OOAO principle been opted for (as suggested by some MS), these descriptors would have failed to achieve good status, on the basis of three out of 45 contaminants in D8, and two out of 23 in D9 failing to achieve the quality objectives. The use of the OOAO principle has been repeatedly criticized (Moss et al., 2003; Moss, 2008; Caroni et al., 2013; Langhans et al., 2014), because it tends to downgrade the quality of assessed locations unjustifiably, depending on the number of indicators included in the assessment, as demonstrated elsewhere (Borja and Rodríguez, 2010; Borja et al., 2019c). Although this principle is consistent with the precautionary principle, such as in cases all the indicators are considered as essential in the assessment; it tends to inflate Type I errors (concluding that the assessed area is below good status, even if the real status is good). Further, it has been demonstrated that in contrast to the OOAO, integrative assessments are more suitable in showing improvements/trends in the quality of marine areas after applying management measures (Borja and Rodríguez, 2010). The inability for the OOAO approach to demonstrate changes in status implies the risk of miscalculating the need for management measures where they are not really needed (Borja and Rodríguez, 2010). Therefore, OOAO principle increases the likelihood of misclassifying to a lower status class by sheer randomness (Hering et al., 2010) and increasing the number of indicators, ecosystem components or descriptors for the MSFD, the possibility of downgrading the quality status in the assessment increases exponentially (Borja et al., 2019c). In contrast, the NEAT represents an alternative approach allowing to trace back low environmental status to underlying indicators, and as a result the proposal of targeted management measures. Finally, under all circumstances, the appropriate choice of representative indicators is as important a factor as the choice of the approach chosen to integrate results.

Despite the human activities and pressures identified in Malta (e.g., high population density, massive tourism in summer, fishing, shipping, bunkering, aquaculture, etc.) (ERA, 2020a), only some reporting units and descriptors can be considered as affected, with some areas which can be considered near pristine and with most of the marine surface as highly oligotrophic (Farrugia et al., 2016).

The study offers an exemplary approach for an effective integrative assessment in spite of widely discussed challenges (Borja et al., 2014; Langhans et al., 2014; Link and Browman, 2014; Probst and Lynam, 2016). The NEAT offers flexibility through customization possibilities, as shown in a number of studies (Uusitalo et al., 2016; Nemati et al., 2017; Borja et al., 2019c; Pavlidou et al., 2019; Kazanidis et al., 2020), and once again here whereby the software was adapted to accommodate MSFD

criteria, whilst allowing for assessments at the levels required by the European Commission (2017, 2018b).

Following the European Commission (2018b) guidelines, quantitative assessments in Malta's official assessment for the MSFD were mainly performed at indicator level, with limitations in relation to integration process especially where quantitative data was not available. Such an assessment represents important progress when compared to the previous absence of marine environmental assessments in Europe, excepting those at sectoral levels e.g., fish stocks (Froese et al., 2018). Meanwhile the NEAT assessment moves quantitative integration to other levels, applying a transparent process whilst doing so. Its relevance within the scope of the ecosystem-based integrated assessment (O'Higgins et al., 2020) is to be acknowledged, allowing the incorporation of human activities and pressures (fishing, contaminants, litter, etc.), different ecosystem components (phytoplankton, macroalgae, macroinvertebrates, seagrasses, fish, cephalopods, seabirds, and mammals), habitats (pelagic, benthic), all under the framework of criteria and descriptors required by the MSFD. Such an integrated approach offers advantages of an easier communication of issues to society, providing an overall picture of the status without losing the traceability of each pressure-impact relationship.

This study is a lesson learnt based on adequate data from a small country like Malta, but this could be extended to remaining European Union Member States. Such an example provides the required insight for supporting countries in the process of choosing between different approaches for assessment also based on their management implications, for example when linking pressures and impacts, and allowing the identification of appropriate measures to achieve good environmental status (Cavallo et al., 2018; Murillas-Maza et al., 2020).

DATA AVAILABILITY STATEMENT

The data analyzed in this study was obtained from ERA, any restriction of use, as well as requests to access these datasets should be directed to SC at ERA, email sarah.f.camilleri@era.org.mt.

AUTHOR CONTRIBUTIONS

AB developed the idea, wrote the first draft, and coordinated the works. YSc, RG, and RA participated in the monitoring and gathering data as part of the EMFF 8.3.1 project (see section "Funding" below). The project was carried out by the M3C consortium, integrated by AIS-Environment and AZTI, for ERA. TM and SC represented ERA as data provider and ensured that the contents reflect the MT official assessment. MU adapted NEAT for the assessment. IM, JG, AU, MU, and AB included all data in NEAT. These authors and JF, JL, YSa, and OS assessed each descriptor in NEAT. All authors made insights into the first drafts and contributed equally to the discussion and in writing the final manuscript.

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SUPPLEMENTARY MATERIAL

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