Section 4

Subchapter 6D

Cumulative effects

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Key points

- Cumulative effects assessments, also known as cumulative impact assessments, have been applied continuously since the publication of the second *World Ocean Assessment*.
- These assessments are being used within national jurisdictions to inform decision-making.
- Lessons learned from the application of cumulative effects assessment can guide further development of assessment approaches.

1. Introduction

Approaches to cumulative effects assessments were reviewed in the second *World Ocean Assessment*. In the development of such assessments, consideration needs to be given to the scale and resolution at which the assessment is being conducted, the values being assessed, the data available, the uncertainties associated with the data and the management objective. The conclusions reached in the second *Assessment* included that expert knowledge and qualitative data were moderately used across assessments, that geographic information systems were commonly used, that uncertainty was rarely evaluated and that integrative methods were increasingly being developed.

According to the second *World Ocean Assessment*, a cumulative effects assessment consists of the following key functional steps:

- Definition of the values of the marine system being assessed
- Definition of the activities that place pressures on the marine system (stressors)
- Conceptual linking of pressures and values
- Assessment of risk and uncertainty
- Validation

In the second *World Ocean Assessment*, attention was drawn to the following key areas where improvements to cumulative effects assessments were needed:

- Incorporation of the extent and spatial and temporal variability of data and their associated uncertainty

- Enhancement of experiment-based and observation-based methods for assessing the sensitivity of ecosystem components to the impacts of stressors
- Incorporation of repeated temporal studies
- Strengthening of connections between cumulative effects assessments and the management measures designed to regulate pressure-inducing activities
- Consideration of the spatial separation between the activity location and the pressure effect
- Clearer definition of the causes and consequences of harmful effects
- Development of approaches that can be applied in developing economies

2. Changes since the second *World Ocean Assessment*

Since the publication of the second *World Oceans Assessment*, there has been increasing acceptance of cumulative effects assessments and cumulative impacts assessments as structured processes (Piet and others, 2021) that serve to specify the functional relationships between human activities, the associated pressures and the state of the ecosystem (Stelzenmüller and others, 2020). Only recently have linkages been drawn between the ecosystem components assessed in a cumulative effects assessment and their contribution to ecosystem services (Ruskule and others, 2023; Simeoni and others, 2023). Particularly in European seas, there is increasing recognition of the need to align the boundaries of cumulative effects assessments with the areas where the operational modes of human activities are regulated through marine spatial planning processes (Hammar and others, 2020; Kirkfeldt and Andersen, 2021). Nevertheless, there is rarely any exploration of future trajectories of human activities and marine spatial planning and how those trajectories might influence outcomes of such assessments in the future (Stelzenmüller and others, 2024). In many regions, cumulative effects assessments have not yet been integrated into management frameworks.

In transboundary settings such as Europe (Mackelworth and others, 2024) and the Yellow Sea (Ma and others, 2023), socioeconomic interests are confined to national boundaries, but ecosystem health and resilience depend on ecosystem processes and exposure to human pressures at multiple spatial and temporal scales (Elliott and others, 2023). Some marine spatial planning processes require international consultations, which increases the complexity of determining effective management responses to mitigate unwanted adverse effects (Cormier and others, 2018).

Mitigating undesirable effects, particularly at multiple spatial scales, requires management responses involving a series of measures. In practice, this means integrating environmental impact assessments for local projects, such as offshore wind farms (Oh and others, 2021), with regional environmental assessments for marine spatial planning (Cormier and others, 2022; Kirkfeldt and Andersen, 2021) and regional sea assessments. While cumulative effects assessments have been used extensively in Europe, they are less common in other regions (see the case studies on South Africa and Australia, below).

The integration of cumulative effects assessments into jurisdictional decision-making is an increasingly common practice, though progress has been slow, and such assessments have become policy documents. The present update is focused on where that transition is in process or has been made. Case studies that illustrate various policy applications of cumulative effects assessments in some jurisdictions since the publication of the second *World Ocean Assessment* are further detailed below.

3. Region-specific changes

Case study: South Africa

Compiling data and undertaking analysis for cumulative impacts assessments and other assessments of the state of marine ecosystems can be particularly difficult for developing countries, where data and capacity are more limited. South Africa is one of the few developing countries that have undertaken cumulative marine pressure mapping as part of its National Biodiversity Assessment, which is conducted every five to seven years. In the 2018 Assessment, 31 pressures on marine biodiversity were mapped (Sink and others, 2019), and additional pressures have been mapped for the 2025 assessment. A cumulative pressure map is used to develop a national map of ecosystem degradation, which is overlaid on an iteratively improving national map of marine ecosystem types to assess ecosystem threat status using an approach aligned with ecosystem red-listing standards developed by the International Union for Conservation of Nature (IUCN) (Keith and others, 2013). These products are used in policymaking, spatial planning and systematic conservation planning to support the expansion of marine protected areas (MPAs) (Sink and others, 2023b; South African National Biodiversity Institute and United Nations Environment Programme World Conservation Monitoring Centre, 2024).

The purpose of cumulative pressure mapping in South Africa is to produce a map of ecosystem conditions to determine the amount and location of remaining natural areas and their condition in terms of how their composition, structure and function have been modified from a "natural" reference condition. South Africa mapped and evaluated 31 different pressures individually and cumulatively as a surrogate for ecosystem degradation. The extent and intensity of pressures were considered, together with an expert-derived impact score that accounted for different combinations of pressures and ecosystem types (Sink and others, 2019). An ecosystem condition map was produced, with degradation assessed in four categories aligned with IUCN red-listing criteria for degradation (criteria C and D).

Building on the National Biodiversity Assessment, Skein and others (2022) drew from the cumulative pressure mapping and reports to undertake a scoping exercise for an integrated ecosystem assessment, considering 17 sectors, 17 key pressures, 23 key ecosystem characteristics and 23 ecosystem services. They noted that fishing, petroleum activities and shipping were widespread sectors resulting in many pressures on multiple ecosystem components and discussed the many interacting pressures that cumulatively affect South African marine ecosystems. Smit and others (2024) conducted the first ground truthing of marine ecosystem conditions in South Africa and showed that while pressure mapping was an effective proxy at broad national scales, updated and finer scale pressure mapping was needed to improve condition estimates. When planning and management decisions are based solely on cumulative impact scores, the actual condition of the environment may be misrepresented, especially at finer scales. Although South Africa has made progress with cumulative pressure mapping, there is a need to increase mapping, modelling and analysis capacity, account for non-linear, synergistic and antagonistic interactions among stressors and ground truth ecosystem conditions across multiple ecosystem functional groups. Failure to accurately map pressures and account for cumulative impacts will mean that potential impacts are missed and will increase the likeliness of poor spatial planning and decisions with negative impacts on people and the environment.

Case study: Mediterranean Sea

The Mediterranean Sea is the largest and deepest enclosed sea on Earth and a known biodiversity hotspot. The first cumulative effects assessment studies conducted in the early 2000s already contained reports of widespread and severe effects in both the western and eastern Mediterranean basins (Coll and others, 2012; Micheli and others, 2013). Pollution and widespread coastal development were identified as the two main pressures. That pattern remains consistent, as the Adriatic Sea and the western Mediterranean have been identified as the two areas in Europe with the most severe cumulative effects in the coastal and shelf areas owing to several anthropogenic pressures, particularly physical loss and disturbance due to intensive fishing, pollution and coastal activities (European Environment Agency (EEA), 2019). Across the entire basin, longstanding overexploitation of fish stocks (especially in narrow shelfs), marine litter, strong rates of warming and heatwaves and the high number of non-indigenous species (NIS), particularly in the eastern Mediterranean, are also generalized patterns (European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM), 2019).

In terms of species and ecosystem responses to cumulative effects, most studies over large scales assess the impact of a limited number of pressures (mainly climate and fishing impacts), with diversity synergistic or antagonistic responses across species and ecoregions over the entire basin (Coll and others, 2016; Corrales and others, 2018; Moullec and others, 2023). Many studies have also reported longstanding anthropogenic erosion of population and ecosystem resilience, which has triggered and heightened sensitivity to natural environmental variability (Fu and others, 2020; Hidalgo and others, 2011, 2022). Benthic habitats and associated vulnerable species, such as coralligenous species, have been shown to be sensitive to impacts, particularly to local anthropogenic impacts associated with coastal development (Bevilacqua and others, 2018). Mortality events of these marine forests are often associated with heatwave events in areas with high cumulative impacts (Garrabou and others, 2022; Canessa and others, 2024). In the eastern Mediterranean, cumulative scenarios suggest that the beneficial effects of regulating fishing efforts may be dampened by the impact of strong warming and alien species when acting together (Corrales and others, 2018). Spatial erosion of communities due to cumulative impacts is also increasing the heterogeneity of local and sub-regional ecosystem responses to warming and other impacts, disrupting natural biodiversity gradients as well (Pennino and others, 2024). Major data gaps have been identified in cumulative effects assessments in the Mediterranean Sea and the Black Sea, particularly with respect to offshore measurements and open sharing of national indicator threshold values (ETC/ICM, 2019). Knowledge gaps on marine litter, a well-established pressure, are being rapidly filled through recent efforts to develop monitoring and forecasting tools (Galli and others, 2023).

Case study: Baltic Sea

As part of the *State of the Baltic Sea 2023: Third HELCOM Holistic Assessment 2016–2021*, which included an extensive evaluation of the ecosystem health of the Baltic Sea over that period, the spatial distribution of pressure and impact assessment developed by the Baltic Marine Environment Protection Commission (HELCOM) was used to examine how human activities generated pressures on ecosystem components, such as species and habitats. By linking spatial data on ecosystem components with pressures, it served to identify overlaps and assess the sensitivity of ecosystems to specific pressures. This approach helped trace which activities drove the impacts and provided insights into the relative impact levels across the region. While the spatial distribution of pressure and impact assessment was used to support holistic assessments of the Baltic Sea, it did not quantify absolute pressure or impact magnitudes, nor did it function as a status assessment like the Water Framework Directive. Moreover, the spatial distribution of pressure and impact assessment was limited to expert knowledge and simplified pressure-response systems, and thus cumulative impacts were treated as the sum of individual pressures while synergistic interactions between them were overlooked. This limitation generates biases in ecosystem-based management of human activities at sea, threatening the achievement of environmental and socioeconomic sustainability goals.

Nevertheless, a substantial body of scientific literature has been developed, exploring both the separate and interactive effects of multiple pressures on diverse ecosystem assets and services. This enables a shift away from expert-based cumulative effects assessments towards assessments with data-driven approaches, allowing for the inclusion of more complex responses to various pressures. The recently developed PlanWise4Blue tool introduces a methodology for cumulative effects assessments in which scientific evidence is combined with expert judgment and presented using an interactive online tool for environmental managers (Kotta and others, 2020). The tool's knowledge matrix, which is based on cause-effect data, quantifies both single and synergistic effects of key human activities on a wide range of nature assets, providing real-world metrics (such as species biomass or habitat loss or gain) under different scenarios instead of arbitrary indices. While some impact coefficients still rely on expert judgment, empirical data will be increasingly incorporated into the tool as it becomes available. The free-to-use tool is designed for marine managers and policymakers without scientific backgrounds, offering user-friendly access to the best available data for decision-making.

The tool has been used for maritime spatial planning in Estonia to evaluate environmental sustainability and is fully functional across the Baltic Sea, with plans for expansion to other marine systems (Vaher and others, 2022). Future versions will feature an artificial intelligence-driven multimodal information retrieval system, capable of extracting and processing impact-related data from scientific publications and integrating such data into predictive models.

Case study: Australia

The cumulative effects assessment has been identified as an important part of environmental management under the Environmental Protection and Biodiversity Conservation Act of 1999. While the Act provides for broad regional assessments of cumulative effects, it does not explicitly require cumulative effects assessments as they are commonly understood in the scientific literature (Dales, 2011; Dunstan and others, 2020, 2023; Hayes and others, 2021; Ostwald and others, 2021). The lack of a formal regulatory framework in Australia for cumulative effects assessments notwithstanding, there has been an increasing number of cumulative effect assessments at both the local (Fulton and others, 2017) and regional scales (Hayes and others, 2021). These assessments have been developed by the scientific community in collaboration with proponents of such assessments and government agencies as part of strategic, regional or national assessments.

Notable examples of regional or strategic cumulative effects assessments include the *NSW Marine Estate Management Strategy 2018–2028* (Marine State Management Authority (MEMA), 2018), the *Marine and Coastal Policy* of the State of Victoria (Department of Environment, Land, Water and Planning (DELWP), 2020) and the cumulative effects assessments prepared for the Spencer Gulf (Gillanders and others, 2016), Gladstone Harbour (Eco Logical Australia, 2019; Fulton and others, 2017), the Great Barrier Reef (Dunstan and others, 2020), the Gascoyne Region (Fulton and others, 2015) and the Kimberley Region

(Boschetti and others, 2020). The approaches applied in such assessments vary from the typical spatial additive assessment frameworks (Halpern and others, 2008; Stelzenmüller and others, 2018; Hayes and others, 2021; Dunstan and others, 2023), which calculate the sum of the direct effects on ecosystems, to more strategic, quantitative ecosystem-based assessments, which explicitly address non-additive and non-linear combinations of effects through the entire ecosystem (Fulton and others, 2015; Fulton and others, 2017; Boschetti and others, 2020).

At the national level, the approach set out in the Parks Australia monitoring, evaluation, reporting and improvement framework (Hayes and others, 2021; Dunstan and others, 2023) included a spatial additive assessment of cumulative impacts across the exclusive economic zone (EEZ) of Australia, based on 39 identified activities that were expected to alter the natural state of the country's marine ecosystems. A cumulative effects assessment was used to prioritize the locations of monitoring efforts in Commonwealth marine reserves to test the effectiveness of management. Recently, an Australia-wide cumulative effects assessment focused specifically on the effects of commercial, recreational and customary fisheries on at-risk species in State and Commonwealth jurisdictions was completed (Fulton and others, 2023). The approach used entailed a hierarchical cumulative effects assessment, in which a spatial cumulative additive fishing pressure map based on 409 species that commonly interact with Australian fisheries was implemented (see sect. 4, subchap. 6E, figure I). A key aspect of the hierarchical cumulative effects assessment framework is to move to a quantitative ecosystem model approach in areas where species have been identified as being at higher risk due to spatial cumulative effect hotspots. Then, more specific modelling approaches that deal with ecosystem dynamics between effects and ecosystem values can be developed for such areas, with a view to building a more strategic management framework for high-risk regions. Lastly, as part of the National Climate Risk Assessment, a cumulative effects assessment on the impact of key climate hazards on the country's marine ecosystems was developed. The Assessment looked at the trajectories of relative ecosystem risk under different global warming levels to identify which parts of the country's EEZ are most at risk from near-term (global warming level 1.5ºC) and long-term (global warming level 3.0ºC) climate impacts.

4. Key remaining knowledge and capacity gaps and new gaps. It is necessary to jointly develop global platforms that can be used to map human pressures and natural assets, as well as a knowledge base that can be used to predict the potential effects of different combinations of human pressures on such assets. Such platforms should not only enable the assessment of the effects of current pressures but also offer capacity for scenario analysis, thereby helping to prevent unnecessary damage to ecosystems. .The pressures that are considered in cumulative effects assessments vary in spatial footprint. Effects such as fishing and infrastructure have a clear spatial footprint and generate impacts on a local scale, while others related to climate change, such as warming, generate impacts over regional or larger scales. . Ecosystem responses are often context-dependent; the responses to a given pressure or combination of pressures may not be identical in all places. Activities and stressor footprints do not necessarily inform on the population and ecosystem responses, which often occupy different space and timescales (Low and others, 2023).

Ecoystem responses can be observed at both a larger and a smaller scale than the stressor footprint. In addition, changes in ecosystem structure and species abundance response can often be seen away from the activity footprint, triggering asynoptic effects on ecosystems, as typically observed in river run-off or localized pollution sources. Temporal mismatches between stressor addition and ecosystem responses are also generated by legacies and carry-over effects (Low and others, 2023). For instance, a large response footprint to a stressor can occur if the ecosystem response persists for longer than the stressor or if ecosystems do not recover after stressor cessation (i.e., a legacy remains) or due to carry-over effects of stressors on future life stages of, for example, anadromous or migratory species. Differential spatial and temporal degradation can result in patchy ecosystem responses. In addition, natural variation in seascape characteristics may result in some areas being more sensitive to similar effects. In such cases, dispersal and ecological connectivity can help to mitigate spatially heterogenous cumulative disturbances, such as spatial insurances (Loreau and others, 2023). The way in which the components of ecological systems are spatially and temporally connected and distributed is critical for withstanding the cumulative combination of natural and anthropogenic disturbances and therefore is fundamental for resilience. Marine connectivity plays a pivotal role in supporting resilience (Hilty and others, 2020; Pearson and others, 2021), but how this influence is mediated and which are the mechanisms of action is still poorly understood.

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