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EXTENDING THE DRIVER-PRESSURE-STATE-IMPACT-RESPONSE CAUSAL CHAIN FRAMEWORK TO INCLUDE HUMAN ACTIVITIES, WELFARE AND MANAGEMENT

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SUMMARY

The Sargasso Sea is a major component of the ICCAT Convention area and provides various ecosystem services in the Atlantic region. The ecosystem report card (EcoCard) was developed using a Driver-Pressure-State-Impact-Response (DPSIR) causal-chain framework. We extend the approach to help develop a shared understanding of how human activities affect the Atlantic ecosystem by extending the DPSIR to DAPSI(W)R(M). Where Drivers (D) now refer to basic needs (e.g., food, energy) necessary for sustaining human life. To fulfil these basic needs, economic sectors develop specific Activities (A), e.g., fishing, shipping, which may generate Pressures (P) on the environment. These pressures lead to a change in the State (S) of the environment and ecosystem services that impact (I) human Welfare (W). Therefore, Effective Responses (R) and Management Measures (M) that depend on scientific knowledge can be systematically developed to inform appropriate policies and regulations. The Sargasso Sea provides an ideal case study for ICCAT to collaborate with other RFMOs and management bodies responsible for implementing EAFM within the Atlantic and other regions. It particularly facilitates the development of fishery-independent and model-based indicators.

RÉSUMÉ

La mer des Sargasses est une composante majeure de la zone de la Convention de l'ICCAT et fournit divers services écosystémiques dans la région de l'Atlantique. La fiche informative sur les écosystèmes (EcoCard) a été élaborée à l'aide d'un cadre de chaîne de force motrice-pression-état-impact-réponse (DPSIR). Nous étendons l'approche pour aider à développer une compréhension commune de la façon dont les activités humaines affectent l'écosystème atlantique en élargissant le DPSIR au DAPSI(W)R(M), où les facteurs (D) font désormais référence aux besoins fondamentaux (par exemple, la nourriture, l'énergie) nécessaires à la vie humaine. Pour satisfaire ces besoins fondamentaux, les secteurs économiques développent des activités spécifiques (A), par exemple la pêche ou la navigation, qui peuvent générer des pressions (P) sur l'environnement. Ces pressions entraînent une modification de l'état (S) de l'environnement et des services écosystémiques qui ont un impact (I) sur le bien-être humain (W). Par conséquent, des réponses efficaces (R) et des mesures de gestion (M) reposant sur des connaissances scientifiques peuvent être systématiquement élaborées pour informer les politiques et les réglementations appropriées. La mer des Sargasses constitue une étude de cas idéale pour que l'ICCAT puisse collaborer avec d'autres ORGP et organismes de gestion responsables de la mise en œuvre de l'EAFM dans l'Atlantique et dans d'autres régions. Elle facilite tout particulièrement le développement d'indicateurs indépendants de la pêche et basés sur des modèles.

RESUMEN

El mar de los Sargazos es un componente principal de la zona del Convenio de ICCAT, y proporciona una variedad de servicios ecosistémicos a ICCAT y a otras organizaciones regionales de ordenación pesquera (OROP) en la región del Atlántico. La ficha informativa sobre ecosistemas EcoCard se desarrolló utilizando un marco de cadena causal fuerza motriz-presión-estado-impacto-respuesta (DPSIR). Se amplió el enfoque para ayudar a desarrollar una comprensión compartida de cómo afectan las actividades humanas al ecosistema atlántico extendiendo el DPSIR al DAPSI(W)R(M). Los impulsores (D) se refieren ahora a las necesidades básicas (por ejemplo, alimentos, energía) necesarias para mantener la vida humana. Para satisfacer estas

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necesidades básicas, los sectores económicos desarrollan Actividades específicas (A), por ejemplo, la pesca, la navegación, que pueden generar Presiones (P) sobre el medio ambiente. Estas presiones provocan un cambio en el estado (S) del medio ambiente y de los servicios ecosistémicos que repercuten (I) en el bienestar humano (W). Por lo tanto, las respuestas eficaces (R) y las medidas de ordenación (M) que dependen de los conocimientos científicos pueden desarrollarse sistemáticamente para fundamentar las políticas y normas adecuadas. El mar de los Sargazos proporciona un caso de estudio ideal para que ICCAT colabore con otras OROP y organismos de ordenación, que tienen la responsabilidad de implementar la EAFM dentro del Atlántico y en otras regiones. En particular facilita el desarrollo de indicadores basados en modelos e independientes de las pesquerías.

KEYWORDS

Fisheries Management; Ecosystem Management;
Biodiversity; Social; Economic; Stakeholder framework

Highlights

- The extended DAPSI(W)R(M) framework promotes a collaborative approach to strengthen the stewardship of the Sargasso Sea, an economically and biologically significant high seas area.
- The framework is an extended version of the preliminary DPSIR (Kell & Luckhurst, 2018), with an additional reference value feature for measuring the impacts using appropriate units of measurement.
- This tool enables stakeholders to develop EAFM implementation in the Sargasso Sea.

1. Introduction

In order to facilitate the operationalization of the Ecosystem Approach to Fisheries Management (EAFM), the Sub-Committee on Ecosystems of The International Commission for the Conservation of Atlantic Tuna has developed an indicator-based ecosystem report card. The main objective is to improve dialogue between scientists and managers and increase awareness of the state of the different ecosystem components managed by ICCAT. The ecosystem report card was developed using a Driver-Pressure-State-Impact-Response (DPSIR) approach. We show how this approach can be extended to develop a shared understanding of how human activities affect the Atlantic ecosystem and how the root causes can be addressed.

In June 2020, the Global Environment Facility (GEF) Council approved its latest Areas Beyond National Jurisdiction (ABNJ) programme entitled "*Common Oceans - Sustainable Utilisation and Conservation of Biodiversity in areas beyond national jurisdiction*"; the programme is financed under the GEF's International Waters focal area. One component of the GEF ABNJ programme is the project, "Strengthening the stewardship of an economically and biologically significant high seas area – the Sargasso Sea. The Sargasso Sea is a significant component of the ICCAT convention area. It provides ecosystem services to ICCAT and other Regional Fisheries Management Organisations (RFMOs) in the Atlantic and adjacent seas. Ecosystem services include various products, such as fish for food, and processes that regulate and maintain our environment and cultural experiences. Therefore, the Sargasso Sea provides an ideal case study for ICCAT to collaborate with other RFMOs and management bodies responsible for implementing EAFM within the Atlantic and other regions, particularly for developing independent and model-based fisheries indicators. This will help facilitate a collaborative, cross-sectoral, and sustainable stewardship approach for the Sargasso Sea by improving the knowledge base and strengthening frameworks for collaborative management and governance.

GEF projects apply the Transboundary Diagnostic Analysis/Strategic Action Programme (TDA/SAP) approach. This highly collaborative process has proven to be a major component of GEF International Waters projects over the last 26 years. As part of this methodology, GEF conducts a Causal Chain Analysis (CCA) which is closely related to the DPSIR framework. At its most basic, a causal chain is an ordered sequence of events linking the causes of a problem with its effects. A simple schematic showing the major components of a CCA is shown below in **Figure 1**. Each link in the causal chain is created by repeatedly answering the question 'Why?'

CCA is predicated on the belief that problems are best solved by attempting to address, correct or eliminate root causes instead of merely addressing the immediately obvious symptoms. Historically, CCA approaches have been used linearly, examining cause and effect. However, although often displayed linearly, a causal chain is a component of a policy response system, which by its very nature is cyclical.

The ecosystem report card was developed using a Driver-Pressure-State-Impact-Response (DPSIR) approach. We show how this approach can be extended to develop a shared understanding of the different human activities that affect the Atlantic ecosystem and how the root causes can be addressed. To do this, we extend the DPSIR to DAPSI(W)R(M) (Patrício *et al*., 2016). Where Drivers (D) now refer to fundamental (basic) needs (e.g., food, energy, space, movement of goods, security, or recreation) necessary for sustaining human life. To fulfil these basic needs, economic sectors develop specific Activities (A), such as fishing, shipping, and deep-sea mining, which may generate Pressures (P) on the environment. These pressures lead to a change in the State of the environment and ecosystem services, such as provisioning and cultural services, impacting human Welfare (W). Effective Responses as Management Measures (M) depend on scientific knowledge to inform the appropriate policies and regulations. Therefore, the Sargasso Sea provides an ideal case study for ICCAT to collaborate with other RFMOs and management bodies responsible for implementing EAFM within the Atlantic and other regions, particularly for developing fishery-independent and model-based indicators. A move from DPSIR to DAPSI(W)R(M) will aid Ecosystem Management to promote sustainable fisheries and biodiversity conservation in areas beyond national jurisdiction (ABNJ).

2. Material and Methods

Kell and Luckhurst (2018) showed how the DPSIR framework could help develop a shared understanding of how human activities affect the Sargasso Sea and the Atlantic ecosystem. This was done by developing a conceptual model and proposing indicators that can be included in tools such as the Ecosystem Report Card. The paper also discussed how these indicators could be validated and used to assess the state of the Sargasso Sea and monitor the impact of management.

Their conceptual model of the system included the following components:

1. Scientific – fisheries biology, oceanography, climate change
2. Political – legislation, policies
3. Regulatory – organisations, e.g., ICCAT, NAFO, ICES, IWC, OSPAR, IMO, MARPOL
4. Social – social and economic factors affecting the system.
5. Institutional settings – government and other policymaking bodies

The main steps required to build a DPSIR framework were then to:

1. Define the system and develop a mechanism to pursue conservation measures for the Sargasso Sea ecosystem through existing regional and international organisations for the benefit of present and future generations (Hamilton Declaration, 2014).
2. List key concepts related to the system: e.g., fisheries catch, conservation, fisheries management, regional and international organisations, and existing statutes for Areas Beyond National Jurisdiction (ABNJ.).
3. Determine concepts that are causing the problem (uphill) or result from the problem (downhill).
4. Use uphill and downhill links to fill in all five sections of the DPSIR framework with relevant, linked concepts.

Examples of uphill links are a) Fishing activity; b) By-catch; c) IUU fishing; d) Pollution; e) Climate change and effects on ocean chemistry; f) Shipping; g) Terrestrial activities e.g., plastics. While examples of downhill links are a) Fish stock depletion; b) By-catch mortality affecting ecosystem structure; c) IUU – undocumented catch; d) Pollution – effects on the trophic web; e) Climate change – Distribution pattern changes, seasonality of migrations; f) Shipping - Hydrocarbon discharges, noise pollution for marine mammals; g) Other human activities such as the continuing commercial interest in harvesting Sargassum, the impact of submarine cables, and seabed mining (see Laffoley *et al.*, 2011).

The preliminary version of the DPSIR framework for the Sargasso Sea, as proposed by Kell and Luckhurst (2018), is summarized in **Table 1.**

2.1 DAPSI(W)R(M)

The DAPSI(W)R(M) framework (pronounced "dap-see-worm") in which Drivers of basic human needs lead to Activities being done to fulfil the needs, which lead in turn to Pressures (Elliott *et al.*, 2017). The pressures are mechanisms of State change on the natural system that leads to Impacts, including those on human Welfare. These indicators then trigger Responses, that are well informed by Reference Values to set out appropriate Measures.

The first step was conceptualising and tailoring the DPSIR framework to the Sargasso Sea, next the categories corresponding to the DAPSI(W)R(M) elements, were grouped by each driver based on the three pillars of sustainability, i.e., Environmental, Economic and Social.

In reviewing the literature for the Response layer, a management matrix was created, which is a summary of policies related to the protection of Sargasso Sea key species, i.e., Tuna, Squid, Sargassum, with a focus on four illustrative activities: Harvesting, Submarine Cabling, Seabed Mining and Sargassum.

The evolution of the DPSIR is recorded in **Figure 2**. Concepts were added to the original DPSIR, and the structure extended. The final structure of the extended DPSIR is displayed in **Figure 3**. Moreover, each concept was catalogued with systematic labelling, i.e., layer initial, pillar initial and numbering. Then for each concept, the relationships were established and added to the bibliography. For this first attempt at developing the framework, vertical relationships (linkages) were established following the feedback cycle, as illustrated by the arrows in **Figure 3**. This gives the users a relevant amount of complexity of the Sargasso Sea system within a clear visual framework.

At the top of **Figure 3** is the 'Driver' layer, consisting of the three sustainability pillars. To establish consistent grouping of concepts within the subsequent layers, a set of three words is employed to define each pillar:

1. Ecological, i.e., Biodiversity, Ecosystem Service, Endangered, Threatened and Protected (ETP) Species
2. Economic, i.e., Profit, Employment, Economic Development.
3. Social, i.e., Livelihood, Cultural Value, and Food Security

Furthermore, the 'Activities' layer is the undertaking or function of change, and then the 'Pressure' layer is any dynamic process affected by Activities. After that, the State layer is an instantaneous value (at a particular time and spatial value). The 'Impact' layer includes concepts from objective-based evaluation of the state change effects.

A new element outside the original framework was added, i.e., a 'Reference value', defined as a unit of analysis of the change. It informs the users on which data is needed and values that trigger responses, making the decision-making more efficient and effective. The final part is the 'Response' layer which is filled with existing policies implemented to manage 'Pressure' by regulating 'Activities', i.e., fishing (Tuna and Squid), Harvesting (Sargassum) and high seas industries within the project scope.

3. Results

3.1 DPSIR Framework as a starting point

An objective of the research was to develop a DPSIR framework that would help to support an Ecosystem Diagnostic Analysis (EDA) for the Sargasso Sea. The DPSIR Framework was extended into DAPSI(W)R(M) (Drivers - Activities-Pressures-States-Impacts (including human Welfare)- Reference Value-Responses (by taking Measures) to accommodate Sargasso Sea complexity. Two commercial key species are being studied in this case: Tuna and Squid. Sargassum is also included due to its recent trend of commercial harvesting and its importance as a signature species. The authors established vertical causal-effect relationships between the concepts (i.e., Driver to Pressure, etc.). The linking words are left out to leave room for interpretation by the user. The outcome of DAPSI(W)R(M) is illustrated in **Figure 5**.

In addition, we also demonstrate that horizontal links can also be derived from the framework. The example in **Figure 4** illustrates horizontal relationships between fishing/harvesting and ocean changes and the key species.

Users navigate the framework from the Drivers layer (**Figure 6**) to the Activities layer (**Figure 7**), down to the ‘Pressure’ layer (**Figure 8**). The linkages can extend to more than one relevant concept. Following the 'Pressure' layer is the State layer (**Figure 9**) that leads to the Impact section (**Figure 10**). Users then use appropriate units of measurement in the Reference Value layer (**Figure 10**) to quantify the impacts in relation to some management criteria. Finally, using the well-informed analysis, users can take appropriate action in response to the issue(s), which becomes a feedback loop (**Figure 11**). The response layer consists of in-force policies from the relevant existing international or regional management organisations.

As a result, the DAPSI(W)R(M) led to the development of a prototype Productivity-Susceptibility Analysis (PSA) tool for pelagic fishing impacts on target and bycaught species in the Sargasso Sea, see Leach, *et al.* (2023).

4. Discussion

The research findings provide an innovative approach for ecosystem risk assessment by developing complementary tools that support stakeholders in developing the implementation of ecosystem-based risk management in the Sargasso Sea. Due to the limitations of the current research, the results should be interpreted cautiously.

The experiment of extending the previous DPSIR framework effectively provides a new, relevant approach to identifying risks in the Sargasso Sea. Significant development of the adapted framework can be seen in two aspects, i.e., the systemised structure and customised details. The outcome of the extended DAPSI(W)R(M) framework (**Figure 5**) provides a new structure compared to the previous Sargasso Sea DPSIR framework. The addition of the reference value as another layer that measures the scale of impact using appropriate units can be used to capture key indicators and effects for the ecosystem report card. The layer also helps the users to review information needed to assess the state of an issue, set management, and monitor responses’ effectiveness, hence the feedback loop arrow (**Figure 5**). This will help to address the issue raised by Fulton, *et al.* (2014) on how ecosystem-based fisheries management implementation has been slow because the measures are ambiguous.

The extended framework also provides greater detail in a more systematic arrangement. The concepts and the linkages illustrate the multiple interactions within the DAPSI(W)R(M) framework, resembling the real complex situation. The linkages also express measurable relationships between concepts, with the addition of relevant reference values as units of analysis. The framework can also facilitate greater flexibility to navigate concepts between or within the same layer, i.e., horizontally (**Figure 4**). This feature attempts to resemble an actual situation where a pressure component may influence another pressure. Overall, as a conceptual model, the extended DPSIR provides insights and a clear basis for developing semi-quantitative models (such as PSA) and quantitative models.

A practical implementation of the framework involves utilizing the adapted DAPSI(W)R(M) framework to facilitate the risk prioritization process within the Sargasso Sea ecosystem, thereby highlighting its inherent complexity. As the framework continues to evolve and expand, it enables the refinement of the system, ultimately leading to a reduction in uncertainties.

4.1 DAPSI(W)R(M) application for Socio-Ecosystem Diagnostic Analysis (SEDA)

Through its diverse Implementing Agencies, the Global Environment Facility (GEF) has developed an effective methodology for designing and implementing regional management strategies tailored to Large Marine Ecosystems (LMEs). This approach is well-suited to meet the requirements for establishing a stewardship mechanism for the Sargasso Sea. It involves conducting a Transboundary Diagnostic Analysis, which assesses the significance of the ecosystem, the value of its resources and services, the beneficiaries of these resources and services, as well as the potential threats and impacts to the ecosystem. The analysis also explores potential measures to mitigate or eliminate these threats. In the case of the Sargasso Sea, a similar process will be undertaken, referred to as a Socio-Ecosystem Diagnostic Analysis (SEDA), given that the Sargasso Sea extends beyond strict transboundary boundaries as an Area Beyond National Jurisdiction (ABNJ).

Subsequently, the project will translate the findings from the SEDA into a Strategic Action Programme (SAP), which outlines the necessary actions for effective ecosystem management and specifies the responsible entities. The SAP will also address partnership formation and sustainability considerations, encompassing management, administrative, and financial requirements. This policy-level document will be negotiated among relevant stakeholders associated with the Sargasso Sea ecosystem, its resources, and services, aiming for implementation by signatories to the Hamilton Declaration and the partners of the Sargasso Sea Commission.

The DAPSI(W)R(M) process will constitute a vital component of the SEDA. Its purpose will be to identify existing data on natural (physical, biochemical, ecological) and social (economic, regulatory, institutional, sociological) components of the ecosystem. The outcomes of the DAPSI(W)R(M) approach will provide input for the customary Causal Chain Analysis required by GEF as part of a diagnostic assessment. The Causal Chain Analysis will elucidate the primary threats and impacts, encompassing environmental and socioeconomic dimensions, and trace them back to their Immediate Cause(s) and Root Cause(s), thereby identifying the necessary actions to address and mitigate these root causes. Often, the root causes reside at the levels of policy and management.

5. Conclusion

The research presents an innovative approach to ecosystem risk assessment, offering complementary tools for implementing ecosystem-based risk management in the Sargasso Sea. The extension of the DPSIR framework to DAPSI(W)R(M) provides a new structure and increased detail, enabling the measurement of impacts through the inclusion of reference values. The framework supports risk prioritization and addresses the ambiguity in ecosystem-based fisheries management measures. Additionally, its application in the Socio-Ecosystem Diagnostic Analysis (SEDA) facilitates the development of a Strategic Action Programme (SAP) for effective ecosystem management in the Sargasso Sea. The DAPSI(W)R(M) process plays a vital role in identifying data and analysing natural and social components, contributing to the understanding of threats and their root causes. The evolving framework reduces uncertainties and provides valuable insights for semi-quantitative and quantitative modelling.

By using the DPSIR framework as a conceptual model framework, stakeholders can understand ecosystems' functions and how stressors and management actions affect them. The DAPSI(W)R(M) framework appears to be a good starting point for developing a quantitative model that goes beyond conceptual approaches to better manage risks in the Sargasso Sea. Although this approach has some limitations, it represents a practical step toward EAFM that can be adapted to meet various ecosystem objectives and integrated into existing management practices.

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Table 1. Examples of a Driver-Pressure-State-Impact-Response (DPSIR) analysis for the Sargasso Sea (Kell & Luckhurst, 2018).

Drivers	Pressures	State	Impacts	Responses
Fishing				
Food Financial gain Employment Food Security	Catch – target species By-catch Endangered species Destructive fishing gear Lost fishing gear IUU fishing	Fisheries landings – target species Fisheries by-catch – non-target spp. Landings – Angullid eels in coastal waters (glass eels) and freshwater (in rivers)	Overfishing of target species Excessive by-catch ecosystem dynamics Endangered species Overfishing of vulnerable seamounts	Economic loss Fisheries management By-catch mitigation Conservation programs
Shipping				
International commerce	Noise pollution-cetaceans Hydrocarbon pollution Air pollution Ballast water – invasive spp.	Maritime traffic increase Ship size increase Increase spread of invasive spp.	Oil tanker spills – ecosystem impacts Fisheries declines from pollution	IMO ship regulations Air pollution abatement Increase fuel efficiency MARPOL pollution abatement
Climate change				
Economic growth	Greenhouse gases – incl. CO2, methane, N2O	Ocean acidification Ocean temperature increase Sea level rise North Atlantic Oscillation (NAO)	Effects on calcifying organism e.g., corals Temperature effects – migration, spawning Trophic web changes – keystones species Changes in current systems	Attempt to limit negative effects Renewable energy sources Green economies
Plastics				
Economic growth	Ubiquitous use of plastics for packaging, food	Volume of plastics increases with economic growth	Microplastics ingestion – plankton, fish Macroplastics entanglement, ingestion – turtles, cetaceans	Recycle, re-use plastic Develop degradable plastic
Sargassum				
Essential habitat	Commercial harvesting limited Ocean chemistry – eutrophication from agriculture run-off	New production area – North equatorial Recirculation Region of North Atlantic	Excessive quantities affect fisheries, tourism in Carribean, but not coming from Sargasso Sea	Mitigation strategies - beaches
Mining				
Economic growth	Seabed mining – impacts on benthos, habitat	State of seabed largely unknown due to limited mapping	Habitat destruction and modification Removal of minerals – unknown effects	Technological advances to mitigate mining impacts
Undersea Cables				
Economic growth	Market demand to increase communication capacity	Laying cables are expensive, disrupts benthic habitat	Long term impact of cables are poorly known In sediment areas, provide substrate	Cable-laying to minimize impact

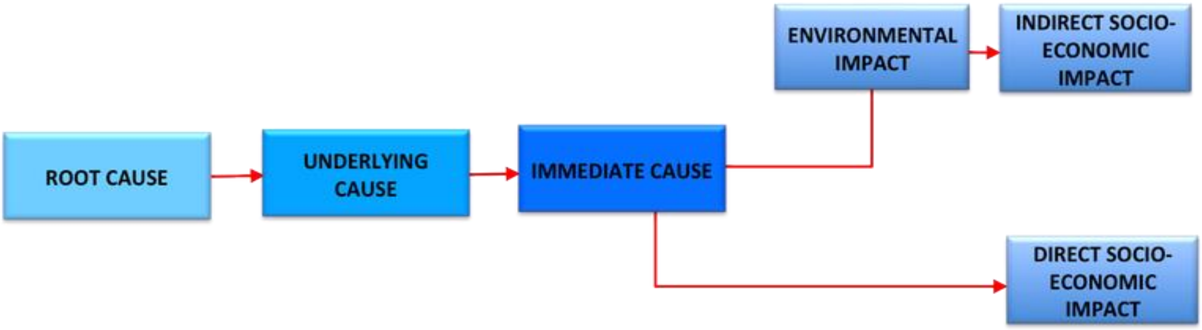

Figure 1. Steps of the Causal Chain Analysis (CCA)

Figure 2. DPSIR evolution timeline with the approaches taken (from top left-down left).

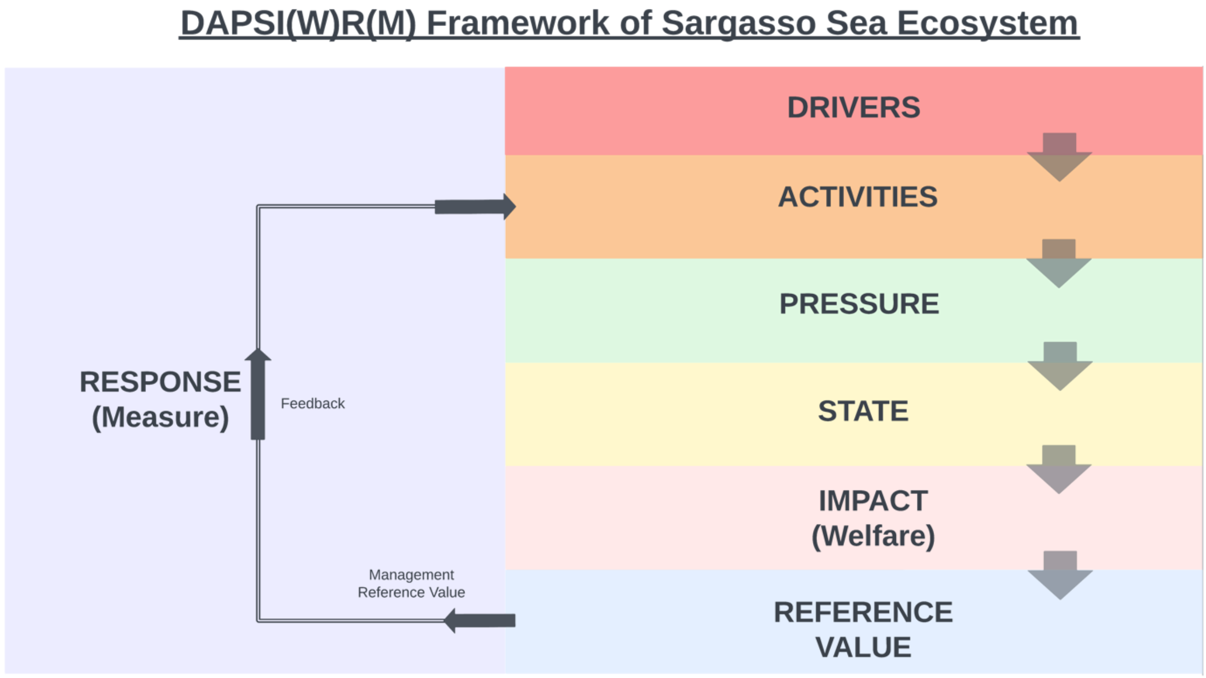

Figure 3. The structural progression from DPSIR to DAPSI(W)R(M) involves a series of layered transformation.

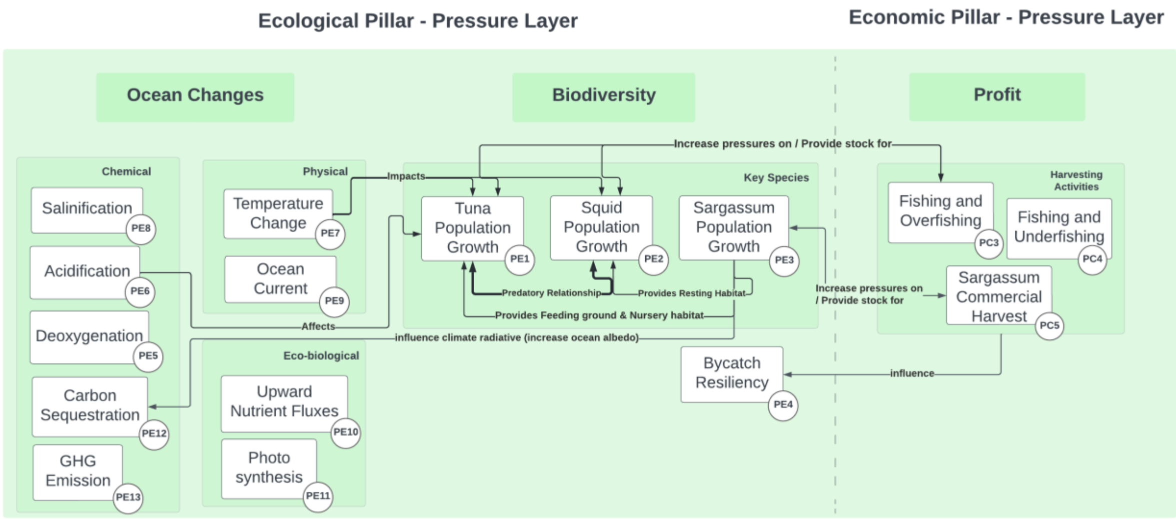

Figure 4. Example of horizontal linkages between ecological-economic drivers within Pressure Layer.

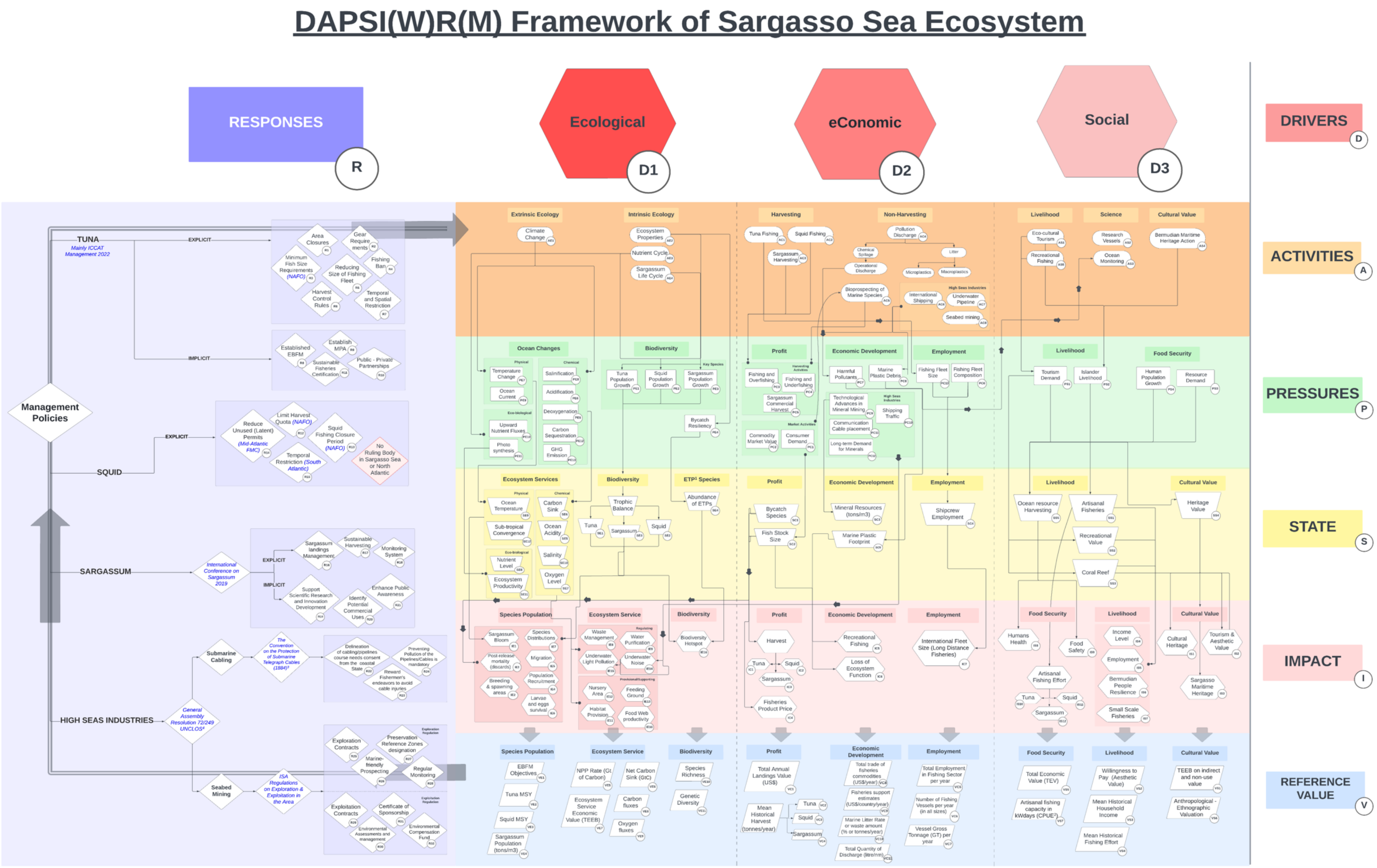

Figure 5. Main catalogue of the extended DAPSI(W)R(M) framework with some identified linkage.

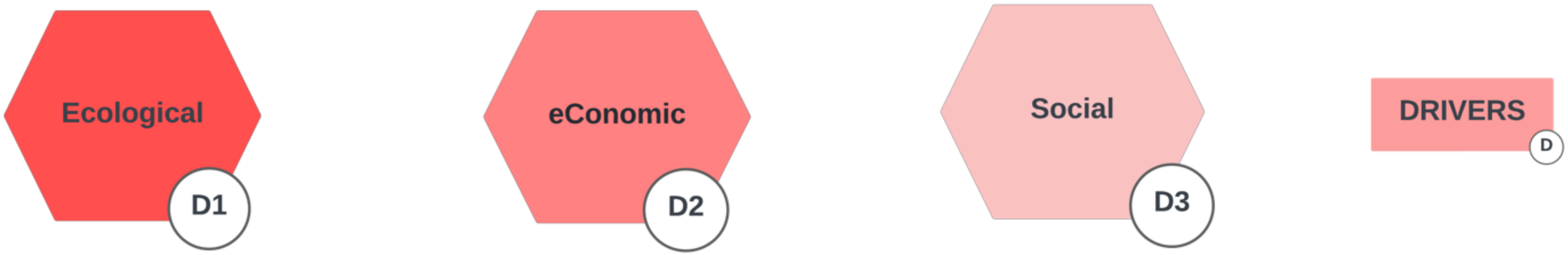

Figure 6. The Drivers Layer

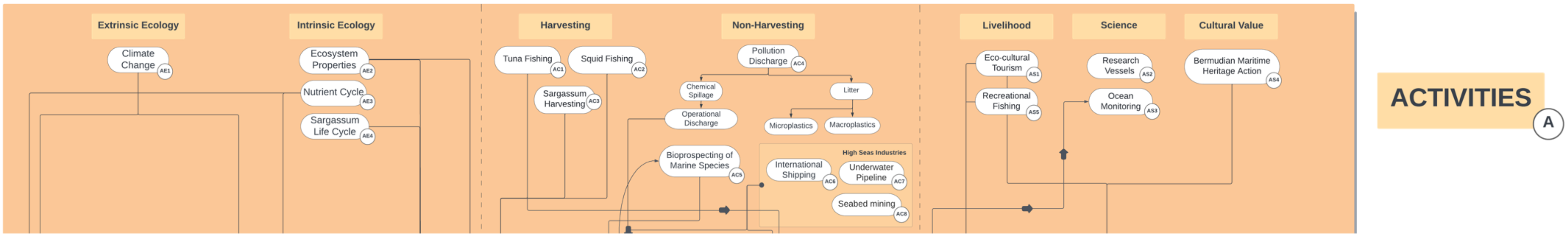

Figure 7. The Activities Layer

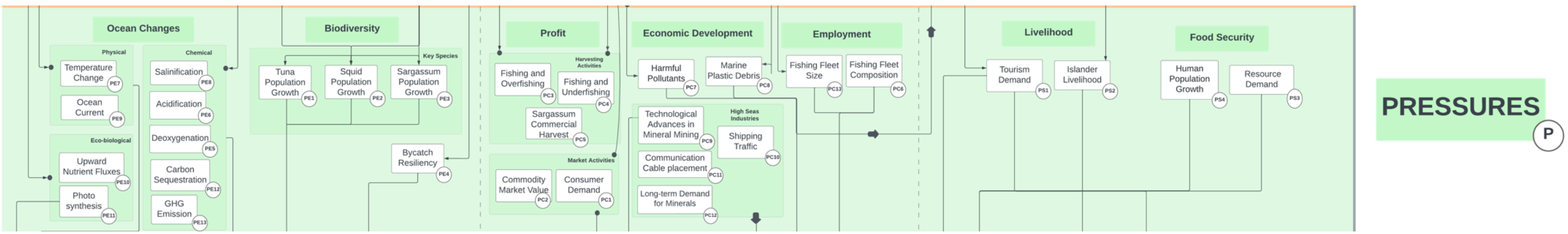

Figure 8. The Pressure Layer

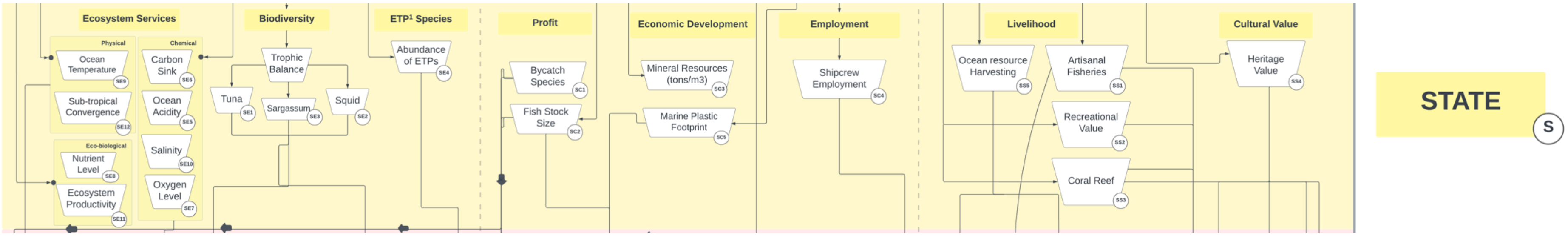

Figure 9. The State Layer.

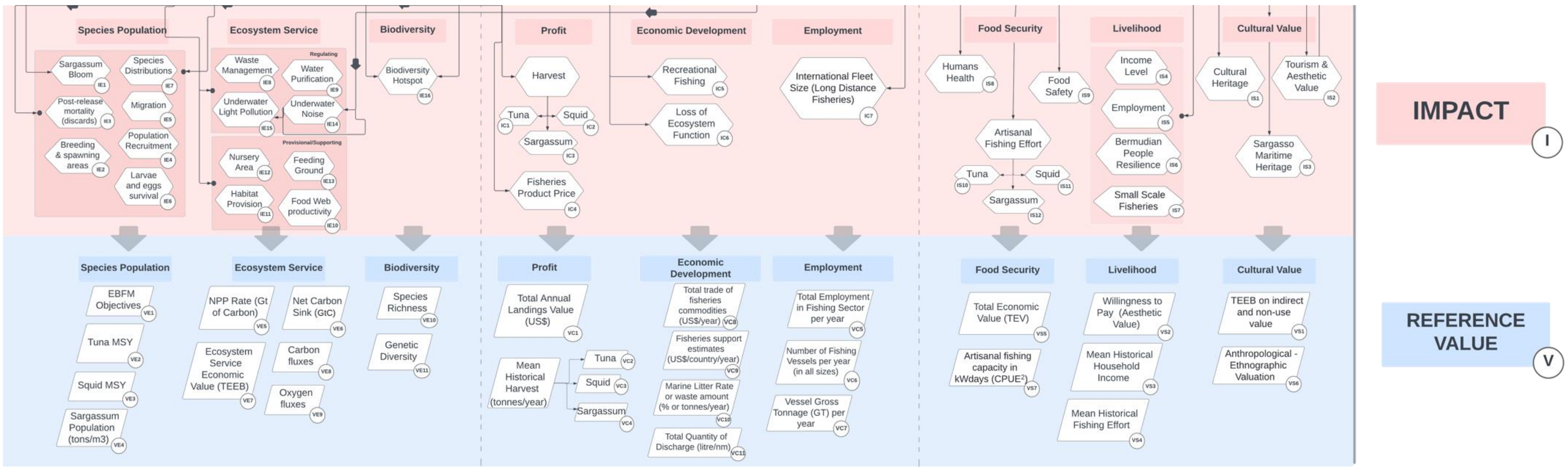

Figure 10. The Impact layer is complemented by the incorporation of a Reference Value, which serves to demonstrate how the reference value can provide a suitable metric for individually quantifying each impact.

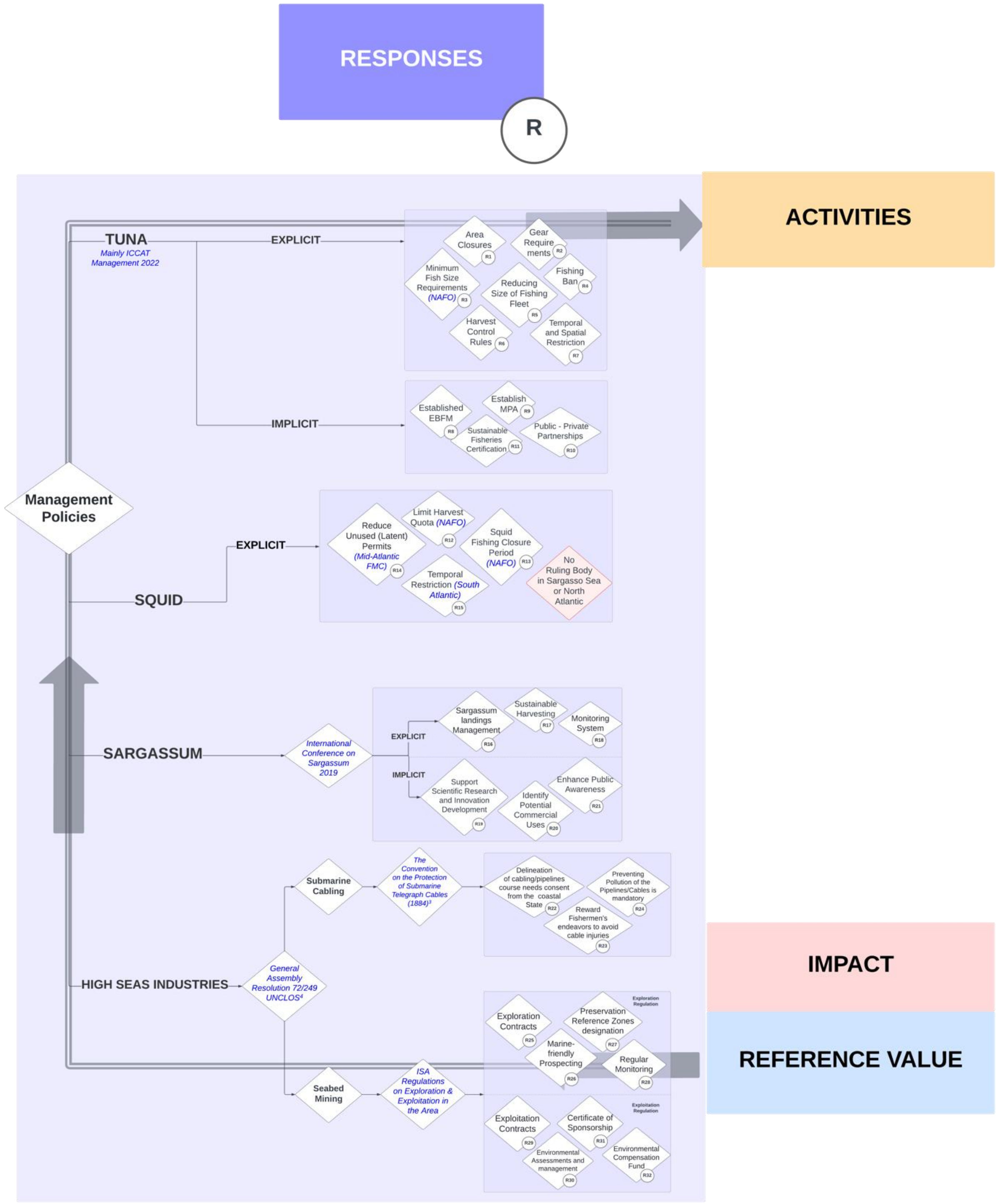

Figure 11. The Response layer forms a continuous loop starting from the Reference Value layer, which is intricately connected to the Impact layer, and subsequently loops back to the Activities layer.