

Faculty of Economy of the University of Porto
Master's in Environmental Economics and Management

Kelp Forests in the North of Portugal: Characterization of Ecosystem Services and its Importance for Coastal Management

Keywords: ecosystem services; kelp forests; NW Portugal; expert judgment; coastal
management

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Abstract

Marine ecosystems have been gaining momentum during the last decades, with a diverse range of international initiatives recognizing their profound importance for human well-being. Regarding coastal zones, kelp forests represent an essential habitat supplying several Ecosystem Services (ESs) fundamental to society and impact the economy and the environment. However, such importance is only sometimes reflected in the decision-making, management, and conservation strategies. Little is still known in Portugal about the meaningful importance of kelp forests, indicating a need for more public awareness and informed management policies. The present work aims to solve this knowledge gap by characterizing the ESs provided by the kelp forests of the Northern coast of Portugal. For that, the Ecosystem Service Cascade (ESC) approach was used to identify the ecological functions, ESs, and ultimately comprehend the social benefits and goods provided by kelp forests. A global list of all the potential ESs provided by kelp forests was produced following the recent classification from the Common International Classification of Ecosystem Services (CICES) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Overall, 19 potential ESs were identified by kelp forests generally, including five provisioning services, eight regulating and maintenance services, and six cultural services. Then, to assess if kelps delivered all these potential 19 ESs for Northwestern Portugal, they were ranked in terms of importance/relevance, using expert judgment. Based on those results, a final list of ESs provided by kelp forests from the northern coast of Portugal was identified. These results can be essential to promote a science-based solution to manage and preserve the kelps on the coast of Portugal, trying to ensure that these productive ecosystems continue to supply goods and services through the next generations.

Keywords: Ecosystem services; kelp forests; Northwestern Portugal; expert judgment; coastal management

Resumo

Os ecossistemas marinhos têm ganhado destaque nas últimas décadas, com uma ampla gama de iniciativas internacionais reconhecendo sua profunda importância para o bem-estar humano. No que diz respeito às zonas costeiras, as florestas de kelp representam um habitat essencial que fornece diversos Serviços Ecossistêmicos (SEs) fundamentais para a sociedade, com impacto na economia e no meio ambiente. No entanto, essa importância nem sempre se reflete nas estratégias de tomada de decisão, gestão e conservação. Em Portugal, ainda se sabe pouco sobre a significativa importância das florestas de kelp, indicando a necessidade de maior conscientização pública e políticas de gestão informadas. O presente trabalho tem como objetivo preencher essa lacuna de conhecimento, caracterizando os SEs fornecidos pelas florestas de kelp da costa norte de Portugal. Para isso, foi utilizada a abordagem da Ecosystem Services Cascade (ESC) para identificar as funções ecológicas, SEs e, por fim, compreender os benefícios sociais e bens fornecidos pelas florestas de algas. Foi produzida uma lista global de todos os potenciais SEs fornecidos pelas florestas de kelp, seguindo a classificação recente da Common International Classification of Ecosystem Services (CICES) e da Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). No total, 19 potenciais SEs foram identificados para as florestas de kelp em geral, incluindo cinco serviços de provisão, oito serviços de regulação e manutenção e seis serviços culturais. Em seguida, para avaliar se todos esses 19 SEs potenciais eram de fato fornecidos pelas algas do noroeste de Portugal, eles foram classificados em termos de importância/relevância, utilizando a avaliação de especialistas. Com base nesses resultados, foi identificada uma lista final de SEs fornecidos pelas florestas de algas da costa norte de Portugal. Esses resultados podem ser importantes para promover uma solução Science-based para gerir e preservar os kelps na costa de Portugal, visando garantir que esses ecossistemas produtivos continuem a fornecer bens e serviços às próximas gerações.

Palavras-chave: Serviços ecossistêmicos, florestas de kelp, noroeste de Portugal, avaliação de especialistas, gestão costeira

1. Introduction

In recent decades, the significance of oceans and seas has come into sharp focus. The United Nations' declaration of the Decade of the Oceans (from 2021 to 2030) and the adoption of Sustainable Development Goals have underscored the pressing need for a deeper understanding of these vital ecosystems, both in the public consciousness and within the academic sphere. Furthermore, with a substantial portion of the global population residing in close proximity to the ocean (Cuba et al., 2022), the imperative to comprehend marine ecosystems has become increasingly evident. This understanding is paramount not only for ecological and economic reasons but also due to the intricate and profound interconnection between the ocean and human well-being (Díaz et al., 2018).

In pursuit of comprehensive insights into this complexity, contemporary researchers are embracing a holistic approach, giving rise to multidisciplinary collaborations that inform decision-making processes. The goal is to integrate insights from a multitude of disciplines into the management and conservation of marine ecosystems with decisions structured in science-based solutions.

One such approach gaining considerable traction is the Ecosystem Services Framework. This approach has been evolving since the latter half of the 20th century and seeks to provide a comprehensive perspective that encompasses ecological, economic, and socio-cultural facets of the intricate relationship between nature and humanity (Díaz et al., 2018). Its roots can be traced back to the valuation of the pollination services rendered by bees (Costanza et al., 1997) and have since extended to encompass a diverse array of terrestrial and marine ecosystems. With the growing momentum in ocean research and exploration, the Ecosystem Services Approach emerges as a valuable tool for unraveling the complexities of a unique habitat known as 'blue forests,' specifically, the ones formed by kelps.

Kelp forests are essential habitats that yield a multitude of goods and services, both within their immediate vicinity and in remote, deep-sea regions, all of which are of significance to human communities. Over the years, kelp forests have been managed globally, often with a predominant focus on their economically perceived benefits to humans. These ecosystems serve as vital natural resources for numerous nations (Vásquez et al., 2014; Bayley et al., 2021; Eger et al., 2022)), with cultural and social relevance rooted in some cultures for centuries. Regrettably, this significance is not consistently reflected in decision-making and management strategies. Consequently, comprehensive local-level knowledge remains scarce for most

countries, hindering informed decision-making, environmental education, conservation, and effective kelp forest management.

In Portugal, kelp forests are present along the entire coastline, from the North to the South (Smale et al., 2013), constituting significant areas of forest ecosystems. However, their importance and relevance remain relatively understudied and underappreciated. This knowledge gap underscores the urgent need for a robust foundation of understanding to inform both decision-making processes and public perception of this natural resource. A science-based solution is imperative, and the Ecosystem Services Approach emerges as an instrument to bridge this knowledge gap.

The primary objective of this study is to address this knowledge gap by comprehensively characterizing the Ecosystem Services provided by kelp forests, enlightening those directly supplying the Northern coast of Portugal. To achieve this, we have employed the Ecosystem Service Cascade (ESC) approach, enabling us to identify the ecological functions, Ecosystem Services, and, ultimately, the social benefits and goods generated by kelp forests. Our methodology involved generating a comprehensive list of potential Ecosystem Services offered by kelp forests based on extensive literature research, aligning with the latest classifications from the Common International Classification of Ecosystem Services (CICES) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Subsequently, we adapted this list to the specific context of Portuguese kelp forests through expert judgment, identifying indicators and data relevant to each class of Ecosystem Services based on the answers given. The ESs were then ranked and assigned average grades based on this assessment. In total, we identified 19 potential Ecosystem Services provided by kelp forests, encompassing five provisioning services, eight regulating and maintenance services, and six cultural services. Our analysis further goes into the list of Ecosystem Services specific to kelp forests in Northwestern Portugal, fostering discussions on the critical need to integrate this newfound knowledge into the ongoing conservation and management efforts along the northern coast of Portugal.

2. Literature overview

The oceans represent the most considerable portion of Earth, and its encounter with the land is what we call "coastal zones" or "coastlines." These areas represent a significant small portion of the oceans and the land but concentrate a more significant part of the world's population (Cuba et al., 2022). Even with expressive demographics and evident importance for humans' lives, knowledge about the oceans is still scarce, and statistics suggest that about 80% of it is still to be mapped. At the same time, around 66% of the oceans suffered from human-made impacts and changed somehow negatively (IPBES, 2019; Ruckelshaus et al., 2020). The imbalance between the amount of information and the significant impact the oceans have on our daily lives made space for pressure in science to understand more about this ecosystem. Looking for the expansion of knowledge of marine ecosystems, international initiatives have been created to bring awareness about the importance of the ocean for a sustainable and healthy life. For example, the United Nations declared the Decade of the Oceans (from 2021 to 2030) and straightforwardly included the ocean in one of the 19 Development Goals (Goal 14: Life Bellow Water).

Considering the coastal zones they provide the chance to increase our understanding of the oceans with less difficulty due to their shallowness, which implies better visibility and atmospheric pressure for scientists to work in comparison with deep sea. They also represent a portion of the ocean with a tremendous direct impact on humans' lives and with a large diversity of species (Palmer, 2017), with daily lives but also tourism and research, which implies that decision-making and management policies should not ignore this area and all its complexity. Governments should consider this habitat's ecological functionalities and economic influence and the various social and cultural activities embedded in coastal zones (Costanza et al., 2017), that is, the services a habitat provides and the benefits we get as humans (IPBES, 2019). The marine ecosystems provide a series of impactful services, and their massive change in the last decades can end up causing problems regarding food security, flood protection, and land use. It is probable that species we have not even discovered yet are already at risk of disappearing (IPBES, 2019).

An integrated approach becomes necessary for balanced management and informed policy decisions, considering more than just monetary costs and risks and highlighting other essential parts such as social importance, cultural presence, and long-term risks. Considering this, the Ecosystem Services Framework can be a helpful tool, that has been frequently used, in the characterization and valuation of marine ecosystems. In the last years, its definition

has been changing and molding the various necessities involved in this process—definitions that are, until now, very context-dependent.

Even though there are differences between the interpretations of Ecosystem Services, it is unanimous that broad definitions are most popular and fit in more circumstances due to the crescent presence of human and nature's rights in the public eye (Costanza et al., 2017). One of these is called Nature Contributions to People, from IPBES (2019), and it differs from others in deeply considering the importance of the cultural services provided by the ecosystems. Although contemplated in other definitions, the cultural services receive a particular spot in IPBES work, considering its significant relationship with traditional communities and how they are highly impacted in the adverse scenarios we are facing and predicting.

For the approaches involving kelp forests, the simple characterization of Ecosystem Services is already scarce data. Some areas with better documentation appear to have focused on specific services, typically marketed ones, like the harvesting for human feeding purposes or the importation of alginate products; countries like Chile and Japan have a long history with kelp (Vásquez, 2014; Eger et al., 2022). However, kelps are present worldwide; this documentation is not equally represented in every site. Some works even focus on recognizing how this ecosystem is neglected even though they represent a significant economic source (Bennett et al., 2016). The lack of information shown in newspapers, research funds, and public perception can be reflected in the local management of the coastal zones or the absence of it.

Considering the deep complexity of the relationship between humans and nature, any framework should be multidisciplinary, covering the highest number of problems and trade-offs (Potschin & Haines-Young, 2011), providing decision-makers with resources to make science-based decisions and investments. This work also aims to supply the government with valuable information for informed management and decision-making regarding demarcations, conservation, population awareness, interventions, or any other modification in the coastal zone. We are bringing to the surface the debate and giving a first glimpse into what can become a deeper valuation considering monetary and non-monetary values.

2.1. Ecosystem Services

Ecosystem Services (ESs) is a term that encapsulates the benefits that nature bestows upon humanity. Beyond a simple notion of service and benefit, it represents a deep-rooted, age-old interdependence (Eger et al., 2023; Costanza et al., 2017). Nature is the wellspring of countless resources, and it is indisputable that altering or jeopardizing a single species or group can reverberate throughout the entire ecological web (Ehrlich & Mooney, 1993). The term "Ecosystem Services" was introduced to formalize this connection, and its definition has evolved since the 1970s. One of the pivotal studies that underscored the significance of this relationship was Costanza et al.'s groundbreaking work in 1997. This study sought to characterize the world's ESs and assign them monetary values.

A significant milestone in the recognition of ESs was the definition put forth by the Millennium Assessment in 2005, which defined ESs as "the benefits people obtain from ecosystems." However, debates arose about the broadness of this definition, as it was considered insufficient to comprehensively capture the complexity of the topic. Even simple terms become topic of diverge, from an economic perspective, for example, some argued that the use of the word "benefit" was problematic (Barbier, 2011) due to different meaning according to the study area. Consequently, alternative definitions emerged, each attempting to refine the concept, yet all circling back to the notion of nature providing essential resources that impact human lives and well-being. Despite ongoing discussions, a universally agreed-upon definition remains elusive.

However, one definition stands out by emphasizing a great holistic approach necessary for managing living ecosystems. The concept of "Nature's Contribution to People" (NCTP), as proposed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), not only offers a comprehensive ES framework but also delves into the social issues intertwined with the topic. NCTP places significant emphasis on the vital role of nature's functioning processes in human well-being, including aspects that might not be immediately perceptible, such as air quality, pollination, and the mitigation of natural hazards (IPBES, 2019). Notably, NCTP underscores the role of social and cultural values in recognizing these services, emphasizing the shared responsibility of individuals and groups in addressing the depletion of ESs.

One of the strengths of the NCTP framework is its recognition of inequalities in the distribution of ES benefits, which helps distribute accountability more equitably among various

stakeholders (IPBES, 2019). An inherent challenge in understanding ESs, in any definition, is the lack of information among those most affected by them. Often, there is a limited perception of the value of these services and the potential impact of changes in their lives (Barbier, 2011; Costanza et al., 2017). In this work, we focus only on the definitions offered by Nature's Contributions to People, opting for a different framework balancing between broader definitions and an ecologic perspective, which will be covered better in the Ecosystem Service Cascade section.

While definitions continue to be refined, Ecosystem Services are typically categorized into well-established divisions. First, they are classified into use and non-use values (Barbier, 2011), depending on whether there is direct interaction with the service. Within the realm of use values, a further subdivision distinguishes between those services that can be directly consumed and those that cannot. Another important consideration is whether a service possesses market value. If it does, methodologies to assign a monetary value based on traded market prices become more straightforward. On the other side, the valuation process becomes significantly more challenging when dealing with services lacking a direct market price (Barbier, 2011; Boyd & Banzhaf, 2007). This complexity underscores the importance of adopting fact-based and data-driven approaches to determine the true value of Ecosystem Services, particularly for habitats dominated by services without a market presence, to avoid undervaluation.

A primary obstacle in valuing non-marketed Ecosystem Services arises from inadequate information. Public perception often assigns low importance to certain habitats and the services they provide, resulting in limited support and research funding (Bennett et al., 2016), as well as low consideration for the services when the valuation depends on public willingness to preserve a habitat. Additionally, estimating the value of non-commercial services is intricate (Barbier et al., 2011), as it necessitates robust methodologies that account for abstract and indirect perceptions of value within cultural and societal contexts.

Even more important, many of these non-marketed Ecosystem Services play pivotal roles in stabilizing ecosystems and ensuring their quality (Barbier, 2011), often serving as supporting or intermediate services. Given the intricate interdependence of services and the intricate relationship between humans and nature, sometimes more than one approach can be used to investigate Ecosystem Services comprehensively. These approaches must consider these diverse scenarios and all processes inherent in a habitat, encompassing not only the final

service perceived as a benefit but also the intricate network of interactions within the ecosystem. While the definitions of Ecosystem Services continue to evolve and provoke debates, their significance in our relationship with nature remains unquestionable. As we navigate the complexities of valuing these services, it becomes evident that understanding their diverse dimensions and impacts is crucial for sustainable management and, ultimately, the preservation of our natural world.

2.2. Ecosystem Service Cascade (ESC)

The Ecosystem Service Cascade (ESC) offers a distinctive approach to understanding ecosystem services, drawing from the seminal work of Haynes-Young & Potschin (2010). It serves as a visual tool that arranges the processes, services, and goods or benefits provided by nature in a production chain format (Figure 1; Potschin & Haynes-Young, 2016)

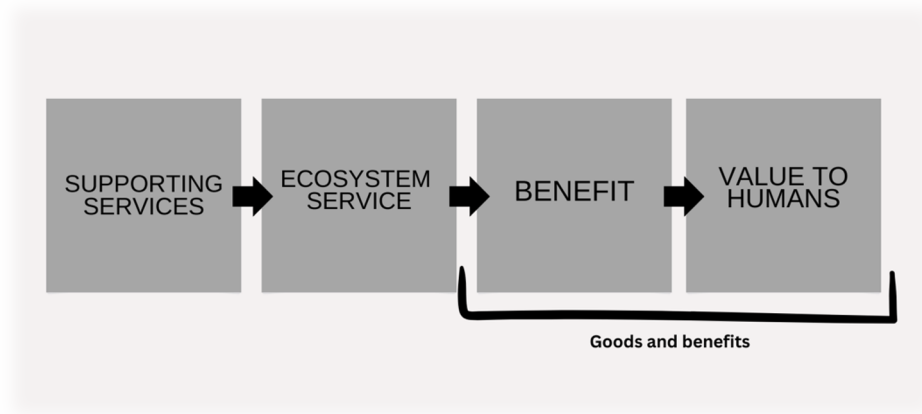


Figure 1 The image represents a simplification and adaptation of the Ecosystem Service Cascade from Potschin & Haines-Young, 2010. Where we can see the three main parts of the supporting service, the final service or ecosystem service, and the goods and benefits that come from it.

Ecosystem services, being a transdisciplinary topic with intersections across economics, biology, and social sciences, prompt various approaches with differing focuses. The ESC, however, adopts a primarily ecological perspective, emphasizing the significance of supporting services. These services are the foundational underpinning of all subsequent categories of services supplied by nature, named final services. According to the Common International Classification for Ecosystem Services (CICES), supporting services exert a substantial impact on human well-being. They are often indirectly perceived and typically non-consumable. These variations hold great importance when considering the classification of services, as different perspectives and purposes can lead to context-dependent interpretations (Barbier, 2011; Eger et al., 2022; Fisher et al., 2009). In the analysis of services, it becomes important to address the challenge of avoiding double counting, as the boundaries between services can blur and overlap, potentially leading to methodological overestimations (La Notte et al., 2017).

The Ecosystem Services Cascade is designed to tackle this issue by presenting supporting and final services in a sequential chain. This visual representation offers a centralized view of the service under consideration, enabling precise counting. The utility of this visualization is highlighted by ESC's proponents (Potschin-Young et al., 2018).

Moreover, this cascade can elucidate how a supporting service can transition into a final service depending on the chosen approach (such as CICES).

Another invaluable feature of the cascade is its capacity to provide a comprehensive perspective on the impacts within a chain. Once again, the creation of a visual tool can provide resources to study the consequences on ecosystem services, thereby affecting their perceived benefits (Potschin & Haynes-Young, 2016). The cascade provides an encompassing view of processes, which also contemplate the advantages associated with ecosystem preservation, which is crucial in the context of ecosystem management (Potschin & Haynes-Young, 2016)

The ESC stands out due to its recognition of the intricate relationships within trophic levels in nature and the intricate interplay between humans and the environment. Moreover, it introduces the idea that users can adapt the cascade's interpretation to suit their specific needs (Potschin & Haynes-Young, 2016). While some authors have raised concerns about context dependence (Phelan et al., 2020; Potschin & Haynes-Young, 2016) and the associated complexities in using this framework, especially regarding the fine lines involving avoiding overlap, the ESC emerges as an effective tool offering considerable opportunities.

In this research, we have employed the ESC as a foundational framework to identify the ecosystem services provided by kelp forests in Northern Portugal. The cascade's ecological perspective and its consideration of ecosystem services as part of a broader chain have proven instrumental in avoiding double counting of services. To categorize the characterized services, we followed the CICES classification, dividing them into three main categories: provisioning, regulation & maintenance, and cultural, with a focus only on the subdivision of biotic services. The cascade's inclusive approach, encompassing functions, services, and benefits, is particularly beneficial in understanding abstract services like cultural ones. This aids in comprehending the impacts these services may have on local communities and their interrelations, even before economic valuation is undertaken. Furthermore, the ESC provides a visual representation of how a biological function can influence components of the food web, various levels of organization, and species interactions in ways not addressed by purely economic perspectives. This highlights the cascade's utility in informing decision-making and facilitating science-based choices.

2.3. Kelp forests

Algae represent a great natural resource with relevant importance for humans. This group is formed by a diverse range of underwater species and can be visually differed in clusters by color. It's common to treat them as green, red, or brown algae. Kelps are composed by species of brown algae, and they are present worldwide. Studies suggest that kelps have been used by humans since pre-history, supporting great migrations of humans in early years (Smale et al., 2013).

In terms of taxonomic classification, kelps are part of the *Laminariales* order (Steneck et al., 2002), which contains some clear characteristics in common. They generally have a canopy formation structure, that's why many refer to it as marine or blue forests. They fixate in rocky or hard substrates and vary in size from centimeters to many meters, forming huge forests around the world (Smale et al., 2013). Even though depending on sun for physiological processes, they are found in colder waters such as near the poles. With a large variation of species, they represent a habitat for groups of animals in different life stages giving shelter, food, and a reproduction site (Steneck et al., 2002). These forests, as terrestrial ones, have a great impact on the maintenance of the ocean's stability and human lives.

The largest specimens of kelp can have up to 42kg of biomass (Wernberg et al., 2018) being an important primary producer with this amount of biomass, brown algae provide a rich source of organic components for its neighborhood areas.

Combined kelps form great forests with large impacts on human's well-being. Those services vary from physiological ones, like the primary production (Wernberg et al., 2018) to those better perceived by humans such as fisheries (Eger et al., 2023). Considering other examples in the category of use value, kelps are part of traditional cuisines around the globe (Eger et al., 2022), and as non-use we can enumerate all the effects of the regulation of climate and erosion (Barbier, 2011).

Some of the ecosystem services provided by kelps are well studied and recognized, however, there are still several that need to be further investigated. Such understanding becomes even more important considering how kelp forests are declining its presence around the world due to climate change, eutrophication, and uncontrolled land-use (Wernberg et al., 2018). A range of anthropogenic activities have become stressors for kelps and affect they physiological functionally. In some localities, estimates are that 50% of the marine forests are already lost and the remaining are declining (Eger et al., 2022). This decline affects the

delivery of services and therefore the values, monetary and non-monetary, that kelps provide, which can reach many millions of dollars (Filbee-Dexter & Wernberg, 2018).

Kelp forests in Portugal

In Europe, kelps are present and studied from the Mediterranean Sea to the northern countries like Norway (Araújo et al., 2016). Some of these countries are predicted to suffer most the impacts with global warming, due to changes in the water temperature, kelps are directly affected in their productivity and distribution (Wernberg et al., 2018). Considering the geographical location of Portugal and the trends in changes on kelp distribution, the Portuguese kelp populations or kelps are likely to be highly impacted by the global warming. Some kelp populations in the southern coast of Portugal are already declining, with other species migrating to North to cooler water (Araújo et al., 2016; Gaspar et al., 2019), expanding the role of the North part of Portugal as an important site to preserve the remaining groups.

The use of kelps has a long history in Portugal, dating from many centuries ago this natural resource was commonly used as fertilizers (Gaspar et al., 2019), and it is still used, in a smaller scale, nowadays. This utilization of kelps is seen in other countries around the world (Avila-Peltroche & Padilla-Vallejos, 2020; Smale et al., 2013), commonly by regional groups in artisanal way. The low information available about the uses of kelp in Portugal reflects a problem of underperception of the local population, as it happens in other countries (Bennett et al., 2016), and can represent a great space of expansion for local governments when it comes to management and decision-making in coastal zones.

2.4. Coastal management

Coastal zones have a crucial importance to society, since it concentrates most of the global population and therefore represent a significant spot for policy decisions and management (Cuba et al., 2022; Small & Nicholls, 2003). At the same time, ~90% of the ocean still needs to be studied according to UNESCO (<https://oceanliteracy.unesco.org/ocean-exploration/>) and about 66% has been changed due to human-made impacts (IPBES, 2019). Such knowledge gap is a critical issue for informed decision-making and sustainable management, land protection, and recovery of marine habitats.

The Ecosystem Services framework has been a valuable tool for managing ecosystems, including coastal zones. It offers a range of knowledge about the benefits we can get from the environment, considering cultural and social demands, and, in some cases, this approach provides a direction for valuation of ESs in monetary and non-monetary units. It has a role in supporting policy decisions by supplying awareness of the ecosystem services (Costanza et al., 2017) and in supporting ecological decisions. The evolving context of decision-making must consider the complex link between humans and the environment they are inserted. A great list of work could be used to better understand the ecosystem services and classify them, which is an important first step towards science-based decision-making. The Nature's Contribution to People definition by IPBES directs a social path when addressing the constant conflicts between demands and interests (Ellis et al., 2019); the work of La Notte (2017) aims to better classify the categories of services; and the work of Haines-Young and Potschin (2010) introduces a fluid framework with chain comprehension of ecosystems. All these works helped to frame a more whole perspective of the classification of ecosystem services, focused on kelp forests. Understanding which services are provided by a habitat becomes a helpful tool considering, for example, the social and cultural demands that different stakeholders can give to a particular environment, as consequently a reliable tool to assist decision-making in coastal management.

A constant growing presence of social and cultural values is seen pressuring policy makers in decision-making processes since the end of 20th century (Costanza et al., 2017). The considerations of these demands tend to reflect the complexity of social matters in different regional contexts (Potschin & Haines-Young, 2011), the unquestionable link between humans' well-being and nature (Díaz et al., 2017), as well as basic human health (Haines-Young, 2023) and the economic demands of local governments in a constantly

growing population. When more broad participation of stakeholders is considered, the social and cultural values of ESs cited since the Millenium Assessment (2005) tend to be highlighted. These participations of stakeholders can also show the unbalanced power between decision-makers and those who feel the impact of their decisions (Ellis et al., 2019; IPBES, 2019), and can be a recognition of the necessity of more equity measures.

The consideration of cultural values tends to be problematic for governments/local authorities, once it forces them to analyze trade-offs often unconsidered in these unbalanced power relations (Ellis et al., 2019). It also pushes decision-makers to interact with the local community and their various questions, shedding a light on how the range of economic power can vary significantly in many coastal zones. These areas can be hot spots for real-estate speculation and, at the same time, the home of traditional communities, such as fishermen (Buanes et al., 2004). This range can also reflect the differences in values each stakeholder gives to a specific ecosystem, their perception of the existence of ecosystems, and the impacts suffered in case of decreasing service capacity and can reflect in the low interest of the population over a service (Cuba et al., 2022).

All this complexity makes coastal management an excellent example of how a more holistic approach can help to implement better-aimed measures. The IPBES Nature's Contributions to People can contribute with this multidisciplinary framework addressing multiple questions of the human's relationship with nature (Díaz et al., 2018). Most governments use monetary units to determine if a management decision is correct, focusing on the determination of benefits over costs (Costanza et al., 2017); and this can be a useful tool for some services and work for specific aspects of the coastal management (Cuba et al., 2022). However, the governance of coastal areas is more complex, and as discussed above, demands that social, and cultural values are considered, as well as the impact on the environment, which cannot always be expressed by monetary units but are essential to be considered in a sustainable management (Barbier, 2011). Coastal areas, and for example kelp forests, present a large range of ESs that cannot be simply translated into monetary units, because they don't have an easy trade price, therefore, forms of valuation of non-monetary units should also be considered for a balanced and efficient decision-making process.

For the achievement of the valuation of a habitat, it's necessary to comprehend with species are present and which services they deliver. A first step can be the characterization of the ecosystem services provided by a certain focus species. When considering kelp forests,

there are still space for expanding our knowledge and consequently our capacity to better use, manage, and protect these areas that are crucial for human well-being (Cuba et al., 2022)

Due to the fact that much information about kelp forests is still to be discovered, local governments might fail to take them into proper consideration and may mine their local kelp capacity, or even worse, their decisions today may affect the delivery of the ecosystem services, provided by kelp forest, in the future. The characterization, therefore, works as a first step in identifying Ecosystem Services. It can, consequently, be the starting point of awareness about the presence of kelps and the actual value it holds locally, the identification of impacted stakeholders, and providing essential information for conservation measures (Potschin and Haines-Young 2011).

Characterization can be a tool for better-informed decisions and public awareness (Costanza et al., 2017), also it is important in supporting the design of marine protected areas (MPA) and creating rules for controlled use or quality standards. One crucial factor is the patchiness when establishing the limits of the MPAs, those holes between protected areas cause less effectiveness in the demarcation and preservation. Even though, kelp forests are resilient ecosystems, as previously mentioned, they are pressured by global warming and the habitat-loss due to land use of coastal zones (Wernberg et al., 2018). Estimates say that a significant portion of the kelp forests around the world are already lost (Filbee-Dexter & Wernberg, 2018), and studies suggest that the recovery process is better succeeded when native kelps are close to any inserted ones in any methodology of reforestation (Eger et al., 2022).

Coastal management in Portugal

The importance of sustainable coastal management turns greater for countries with their GDP depending on ocean activities. Portugal is well known in history for its marine expeditions in the 16th century, but the presence of coastal tourism, fisheries, importation, and exportation through ports, represent relevant assets of Portugal economy. It becomes extremely relevant for Portugal to get the most from its coastal areas, because they represent a chance of economic expansion, which is reduced through land. Being present in the interface of land and ocean, kelps forests functions can be explored in diverse forms of eco-tourism and as an economic resource but demand also protective measures in order to keep its intrinsic value (Vásquez et al., 2014).

The local potential of kelps is compromised, however, by the lack of information about its full potential and all the services provided (Gaspar et al., 2019), as well as the low public awareness of its benefits. In Portugal, coastal areas are under protection through several environmental legal policies. For example, the Natura 2000, which aimed to delimitate protected areas around Europe focusing on conservancy (Kati et al., 2014); EU MSFD; EU MSP; and other national policies, such as the Plano de Ordenamento da Orla Costeira (APA; <https://apambiente.pt/agua/planos-de-ordenamento-da-orla-costeira-0>). Even though, the marine protect areas in Portugal (continental and islands) counts for only around 5%, considering its total of 4 million km² of marine area it is not a lot and represent the second lowest in European Union's countries, losing only to Ireland according to the European Environment Agency (<https://www.eea.europa.eu/ims/marine-protected-areas-in-europes-seas>).

This represents a large space for growing knowledge about the benefits provided by oceans that go beyond those traditionally considered like fisheries and direct harvested material. Kelp forests, for example, represent a great source of potential from eco-tourism to even a key ally to control CO₂ emissions and help fight climate change. It can be a source with great potential when considered with the right lens.

2.5. Objectives

The present work aims to investigate the Ecosystem Services supplied by the kelp forests in the North of Portugal by classifying them using scientific tools to provide a complete view of the topic, such as the Ecosystem Services Cascade, framework the Common International Classification of Ecosystem Services classification, the Nature's Contribution to People by IPBES, and expert judgement.

Specific goal

- I) Classification of all potential ecosystem services supplied by kelp forests
- II) Identification of the ecosystem services delivered in the North of Portugal
- III) Prioritization of ecosystem services for management purposes

3. Materials and methods

The work was divided in three main parts in order to achieve the proposed objectives, namely: i) literature review, ii) classification of all ESs potentially provided by kelp forests, iii) identification of ESs provided by kelp forests from the NW of Portugal.

3.1. Literature review

The first part consisted in a literature review of kelp forests to access the large range of the ecosystem services provided by these ecosystems. We conducted a snowball sampling in scientific search platforms, we used Google Scholar and Web of Science the start and went on according to the papers we were finding. For this part we used the generalist keywords 'KELP' and 'ECOSYSTEM SERVICES' and set a criteria to accept the paper, namely the paper should be a peer reviewed work, in English and containing example of ecosystem services provided by kelp with numeric data either of valuation or distribution.

3.2 Classification of all Ecosystem Services potentially provided by kelp forests

Based on the information retrieve from all the papers accepted in the criteria, we identify all the ecosystem services that could be potentially delivered by kelp forests. The classification of ecosystem services was based on CICESV.5.1 classification (<https://cices.eu/>), following their three main categories: provisioning, regulation and maintenance, and cultural services. CICES also divide their categories in biotic and abiotic. For this work, as we were studying a living species, only biotic categories were considered.

To better fit the services into this classification we used the Ecosystem Service Cascade (ESC) framework from (Haynes-Young & Potschin, 2010) to avoid double counting of services and the work of La Notte et al. (2017) to better interpretate the services.

3.3. Identification of Ecosystem Services provided by kelp forests form the NW of Portugal

For the identification of ESs provided by kelp forests form the NW of Portugal, we used an expert judgment approach to identify from the previously classified ESs, the most relevant services provided by the kelp forests form the NW Portugal. This third part consisted in an expert judgement ranking focusing on accessing the relevance of each ecosystem service provided by the kelp forests of the Northwestern of Portugal. For this part we used a questionnaire from the Google Form, it was the preferred tool so no

participant could be influenced by the answer of another professional colleague. The form consisted of a general introduction of the purpose of the questionnaire, followed by the description of the service, a practical example of it in a kelp forest scenario, and a literature reference of each service provided by kelp forests (Appendix). We sent this form by e-mail to a list of experts that are part of the BlueForesteing Project, each expert could choose an answer ranging from 1 (least relevant), 2 (low relevance), 3 (medium relevance), 4 (relevant) to 5 (extremely relevant) of each ecosystem service.

3.4. Data analysis

We analyzed the classification of the experts and estimated an average (with $\pm$ standard deviation) classification for each potential ESs. And those with an average level lower than 3 were considered as not being delivered by the kelp forests from the NW Portugal and removed from the final list of ESs.

4. Results and discussion

4.1. Potential Ecosystem Services provided by Kelp forests

We characterized 19 ecosystem services supplied by kelp forests (Figure 2) based on the readings from 55 papers. They belonged to all three CICES categories: five provisioning, eight regulation & maintenance, and six cultural services. With most services in the regulation & maintenance category (table 1), followed by cultural (table 2), and then provisioning (table 3). It is well established that kelps represent an important natural resource for more than millennia (Eger et al., 2023), however a lot of information about it, it is still lacking scientific studies. Some services, normally provisioning ones, such as fisheries, raw material, and food have been contemplated in many scientific studies, and even been economically valued (Bayley et al., 2021; Bennett et al., 2016; Costanza et al., 1997; Eger et al., 2023; Filbee-Dexter & Wernberg, 2018; Vásquez et al., 2014). However, there is still scarce information regarding the other services, considered as non-materials, such as public perception and environmental education. This situation becomes more significative when we see that most services well documented represent the smaller parcel of the total services potentially provided by kelps. It shows we have a narrow perspective of the full capacity of kelps and that we might be overestimating monetary services' relevance due to the facility it provides with straightforward methodologies (Barbier, 2011; Boyd & Banzhaf, 2007).

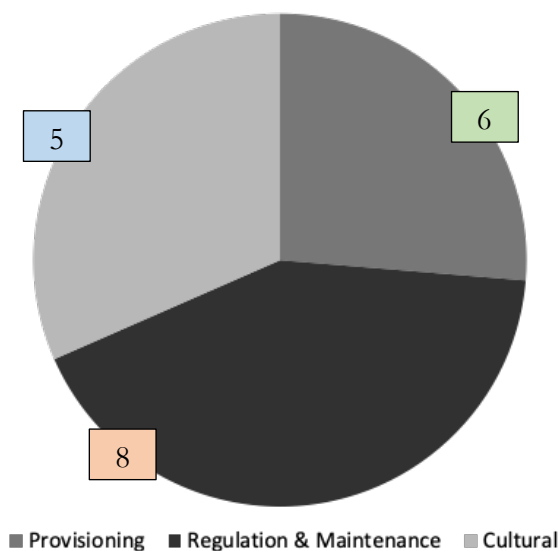


Figure 2 Classification of ecosystem services provided by kelp forests, following the Common International Classification of Ecosystem Services (CICES) classification.

This misperception of importance based in simply economic perspective ends up not considering the complex relation humans have with nature, how their moral and ethical questions influence it, as well as the variations of economic behaviors (Potschin and Haines-Young 2011) To address this issue, we identified all the potential services that kelps can deliver, instead of focusing on those with easier valuation processes. The objective was getting a wider picture of all the possible ecosystem services provided by kelp forests, in transdisciplinary way, helping to solve the lack of a full characterization. We considered it the initial path to increase the information we have about kelps in Portugal, specifically in the Northern coast. This wider list also allows us to analyze in greater perspective future targets for research and/or governmental decisions, highlighting information gaps regarding ecosystem services that are less investigated in literature, such as the cultural ones. Even more, it helps to reduce the problem of underestimation (Wernberg et al., 2018), as we show the parcel of importance the non-use value ecosystem services hold in the total of services provided, in this case for kelp forests.

Table 1 Table 1. Figure 3 The five ecosystem services provided by kelp forests that are classified as provisioning according to CICES v5.1.

Category	Service	Obs	Citation
Provisioning	Fisheries		"The potential fisheries value generated by kelp forests is substantial, with one hectare of underwater forest producing an average 2380 Kg/ hectare/year, of which 904 kg is harvested when applying a 38% extraction rate. The average economic value of that 38% harvest is \$29,851 per year, while a 20% harvest yields \$15,771 a year and a 70% harvest yields \$55,205 a year. Under these same scenarios, the global value of kelp forests shifts from \$500 billion to \$465 billion in the low harvest (Eger et al., 2022)"
Provisioning	Food		"In the NWPacific, kelp harvesting has played an important role in Japanese, Korean, and Chinese economies since the 8th century, where it is eaten as food and supports a myriad of associated plants and animals, many of which are also harvested (Eger et al. 2022)."
Provisioning	Aquaculture		"Kelp is currently commercially harvested in the northern and western isles of Scotland, while commercial farming of <i>L. digitata</i> has recently been developed off the west coast of Ireland (Smale et al., 2013)" "These reefs gave rise to the concept of marine ranching, which cultures species in the ocean for consumption. (...) NIFS (The National Institute of Fisheries Science) worked with kelp genera that were amenable to cultivation, focusing on <i>dasima</i> (<i>Saccharina japonica</i> C.E. Lane, C. Mayes, Druehl & G.W. Saunders), <i>Ecklonia</i> spp., <i>miyeok</i> (<i>Undaria pinnatifida</i> Suringar), and <i>Sargassum</i> spp. (...) Following the initial NIFS projects, the Korea Fisheries Resource Agency (FIRA) was established in 2009 and took over marine ranching, kelp restoration, and afforestation projects in Korea. (Eger et al., 2022)"
Provisioning	Raw material	Industry resource/biofuels	"Kelp washed up on beaches, after storms has traditionally been used to fertilize agricultural land (Williams et al., 2022)." "As bioresources, kelp species present a wide array of uses, representing the raw material for different industries, such as pharmaceuticals, cosmetics, fertilizers, textiles, medicine and culinary arts (Cuba et al., 2022)." "Thus, the economic value of kelps is mainly associated with the collection and harvesting of <i>Lessonia</i> species, and as raw material for the alginate extraction industry (Vázquez et al, 2013)." "Some recent efforts with private and state funding have been conducted to assess the feasibility of producing biofuel from mass cultivation of <i>M. pyrifera</i> in southern Chile (Vázques et al., 2013)."
Provisioning	Aquaculture for raw material	Industry resource/biofuels	"The current demand for clean, non-fossil-fuel-based energy production has thrown kelps into the limelight as potential sources of biofuels. Kelps can grow very quickly (up to 50 cm per day), are rich in polysaccharides, and do not compete with land-based crops for space, fertilizers, and water (Smale et al., 2013)." "Some recent efforts with private and state funding have been conducted to assess the feasibility of producing biofuel from mass cultivation of <i>M.pyrifera</i> in southern Chile (Vázques et al., 2013)." "Kelp is currently commercially harvested in the northern and western isles of Scotland, while commercial farming of <i>L. digitata</i> has recently been developed off the west coast of Ireland (Smale et al., 2013)" "Thus, the economic value of kelps is mainly associated with the collection and harvesting of <i>Lessonia</i> species, and as raw material for the alginate extraction industry (Vázquez et al, 2013)."

Table 2 The six ecosystem services provided by kelp forests that are classified as provisioning according to CICES v5.1.

Cultural	Intrinsic value/existence value		"(...) or for their importance as a reservoir of biodiversity, gene bank or potential source for harvesting (existence value; Vázquez et al, 2013)" "...whereas nonuse values do not, as the latter represent an individual valuing the pure existence of a natural habitat or ecosystem or wanting to bequeath it to future generations (Barbier, 2011)."
Cultural	Recreation/tourism		"Ecotourism in kelp forests is an environmentally responsible form of tourism that includes activities such as sport fishing and recreational diving in a column of water spatially structured by large-sized kelp like those from Laminariales. Recreational diving, along with underwater-guided "trails", can also serve as educational activities that bring people closer to biodiversity and the unique submarine landscape that kelp create (Vázquez et al, 2013)."
Cultural	Research		"(The relation about public perception and research) Similarly, or perhaps as a consequence, rates of research investment into understanding the ecology that underpins the GSR ecosystem are also low (Bennet et al., 2022)"
Cultural	Environmental education		"Ecosystems and their components and processes provide the basis for both formal and informal education in many societies (Munz, 2017)." "Recreational diving, along with underwater-guided "trails", can also serve as educational activities that bring people closer to biodiversity and the unique submarine landscape that kelp create (Vázquez et al, 2013)."
Cultural	Public perception		"Despite its intrinsic and economic value, public perceptions of the Great Southern Reef are low compared with other comparable natural assets in Australia such as the GBR (Australian's kelp forests; Bennet et al., 2022)."
Cultural	Aesthetic		"Cultural services derive from information. For example, we are able to receive the information from an amenity landscape given the human ability to perceive (receptor) and appreciate beauty (decodification and interpretation). This information might influence humans, for example triggering inspiration, a physiological relaxation, a sense of fulfilment, or a spiritual experience. (La Notte et al., 2017)."

Table 3 The eight ecosystem services provided by kelp forests that are classified as provisioning according to CICES v5.1.

Regulation & Maintenance	Primary production		"They support one of the highest productivity rates via photosynthesis, and greatly influence the physical environment in which they live, due to their three-dimensional structure. (Cuba et al, 2022)" "Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al., 2013)."
Regulation & Maintenance	Biorremediation		"Relatively higher concentrations of copper, manganese and vanadium found within the IMTA cultivated thalli are suggestive of increased metal uptake of certain metals when kelps are cultivated in the environs of salmon farming facilities (Ratcliff et al., 2016)" "Additionally, due to their bio-adsorption capacity they have been proposed as a promising alternative for bioremediation (Cuba et al, 2022)" "Clearly, the integration of seaweed cultivation with coastal industries for the purposes of metal remediation is at a nascent stage (Neveux et al., 2017)".
Regulation & Maintenance	Secondary production		"Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al., 2013)." "It is known that kelp detritus represents a subsidy of energy in low-productive habitats (Cuba et al, 2022)" "Evidence from elsewhere would indicate that kelp biomass is a hugely important source of exported energy, which influences patterns of secondary production and the distributions of marine organisms (Smale et al., 2013)."
Regulation & Maintenance	Climate regulation		"(...), we report strong interspecific differences in local macroalgal CSP (carbon sequestration potential) using a kelp forest of the genus <i>Laminaria</i> as a model system. To our knowledge, this is also the first detailed documentation of carbon flux (primary production, standing stock, particulate carbon export and remineralization) through a single kelp forest. (...) Our data suggest that local to regional kelp forest CSP may already have declined and probably will continue to do so with further poleward movement of <i>Laminaria</i> species under continued ocean warming (Wright, Pessarrodona & Foggo, 2022)"
Regulation & Maintenance	Coastal defense		"Kelp forests, such as other biogenic structures in coastal zones (e.g., salt marshes, mangroves), prevent and alleviate the damage caused by flooding and storm events (Smale et al., 2013)." "Coastal defense represents a critical ecosystem service that will become more important along many coastlines as the consequences of anthropogenic climate change intensify, namely sea-level rise and an increased magnitude and frequency of storms (Smale et al., 2013)"
Regulation & Maintenance	Habitat forming		"Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al., 2013)." "As habitat formers, a single kelp sporophyte directly provides three distinct primary spaces: the holdfast, the stipe and the lamina (Cuba et al, 2022)" "A forest can improve the habitability of the benthos and the water column, generating habitats for a biodiverse microbiome as well as breeding areas for other macrophytes, and both sessile and motile animal species (Cuba et al, 2022)."
Regulation & Maintenance	Water regulation		" <i>Laminaria hyperborea</i> influences its environment and other organisms by providing food and habitat and by altering light, water motion, sediment deposition, and physical disturbance through thallus scour (Smale et al., 2013)" "The use of the seaweed <i>S. latissima</i> shows potential for assimilation of nutrients, particularly nitrogen (Marinho et al., 2015)."
Regulation & Maintenance	Life cycle maintenance (Refuge area, feeding, biodiversity and nursery/spawning)		"A forest can improve the habitability of the benthos and the water column, generating habitats for a biodiverse microbiome as well as breeding areas for other macrophytes, and both sessile and motile animal species (Cuba et al, 2022)." "Bioresources including <i>Concholepas concholepas</i> (Chilean abalone), <i>Fisurella</i> spp. (keyhole limpets), <i>Loxechinus albus</i> (red sea urchin), <i>Pyura chilensis</i> (red sea squirt), <i>Octopus mimus</i> (gould octopus) and various rock fishes, such as <i>Cheilodactylus variegatus</i> (Peruvian morwong), <i>Paralabrax humeralis</i> (Peruvian rock seabass), <i>Pinguipes chilensis</i> (Chilean sandperch) and <i>Anisotremus scapularis</i> (Peruvian grunt) have been reported in Humboldtian kelp forests (Cuba et al., 2022)." "The biological engine of the GSR are the kelp forests, which provide both the habitat and trophic foundation to support the system. (...) There are many commercial fisheries operating along the GSR (Bennet et al., 2016)."

4.2. Ranking the relevance of Ecosystem Services in Northwestern Portugal

A total of ten experts participated in our survey, ranking the relevance of each of the 19 ecosystem services (Figure 5). The consensus among these experts is evident from the low standard deviation (SD) observed in the results.

Based on the scale established in our questionnaire, services with a rating below or equal to 3 were considered to be of medium to lesser relevance. In descending order of relevance, these services included raw material, bioremediation, aquaculture for raw material, aquaculture for food, and food. Conversely, services rated above 4, indicating the highest relevance, were fisheries, environmental education, climate regulation, intrinsic value, research, life cycle maintenance, primary production, and habitat forming.

It is worth noting that among the services rated above 4, only fisheries can be considered a marketed service. Consequently, fisheries benefit from more direct valuation methodologies, as discussed by Barbier (2011), and have a greater number of peer-reviewed papers dedicated to them. However, it is important to emphasize that the services considered most relevant by the experts are the very opposite, the non-marketable ones. As a result, quantifying their importance with a numeric value proves to be more challenging (Boyd & Banzhaf, 2007), but represent a significant part of a sustainable management

Table 4 Results from the questionnaire answered by experts about the relevance of the potential ecosystem services from kelp have to Northwestern Portugal

	Fisheries	Food	Aquaculture for food	Raw material	Aquaculture for raw material	Primary production	Secondary production	Bioremediation	Climate regulation	Coastal defense	Habitat forming	Water regulation	Life cycle maintenance	Existence value or intrinsic value	Recreation and tourism	Research	Environmental education	Public perception	Aesthetic
Expert A	4	1	1	4	3	5	2	3	5	3	5	4	5	5	4	4	4	2	4
Expert B	5	2	1	4	1	5	5	1	5	3	5	3	4	5	2	5	4	2	2
Expert C	4	2	2	4	3	5	5	5	5	5	5	5	5	5	4	4	5	5	4
Expert D	4	2	1	1	3	5	4	4	4	3	5	5	4	5	4	5	5	4	4
Expert E	5	1	2	2	1	4	3	2	3	3	4	2	5	5	5	5	5	4	5
Expert F	4	1	2	3	1	5	3	3	5	4	5	4	4	5	4	5	5	4	4
Expert G	2	1	1	4	1	3	3	2	4	4	5	4	4	2	1	5	4	4	3
Expert H	5	1	2	2	3	5	5	4	3	2	5	4	5	3	3	2	2	3	2
Expert I	5	3	4	4	4	5	5	4	5	4	5	4	5	5	5	5	5	4	4
Expert J	4	2	2	3	2	5	3	3	3	2	5	4	4	4	3	4	3	3	4
Average	4,2	1,6	1,8	3,1	2,2	4,7	3,8	3,1	4,2	3,3	4,9	3,9	4,5	4,4	3,5	4,4	4,2	3,5	3,6
SD	0,9189366	0,6992059	0,91893658	1,100505	1,13529242	0,6749486	1,13529242	1,197219	0,9189366	0,9486833	0,3162278	0,875595	0,527046277	1,0749677	1,26929552	0,9660918	1,032795559	0,97182532	0,966092

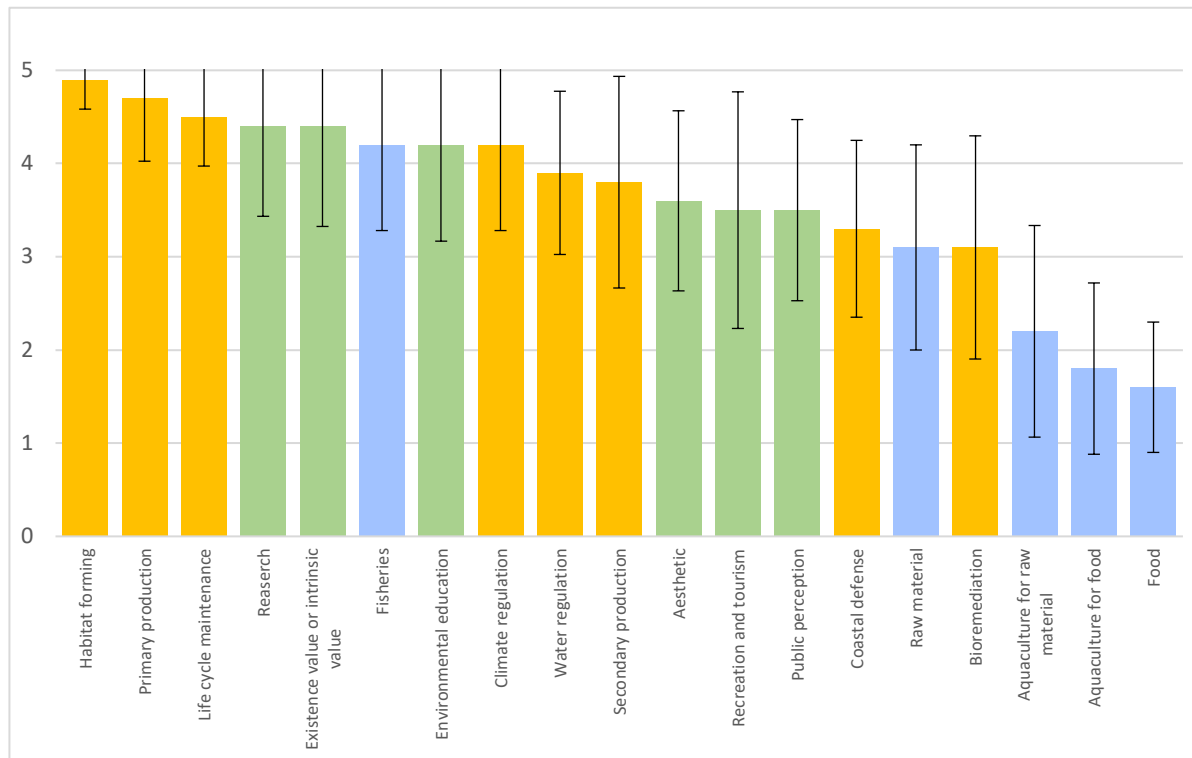


Figure 3 Ranking results of each ecosystem service (average $\pm$ standard deviation) based on expert answers

The fact that experts considered non-commercial services as more relevant reinforces the debate about methodologies and perspectives that consider whole aspects other than simply monetary costs and benefits in decision-making. Even more, if we consider that decision-making processes do require a numeric system of classification (Costanza et al., 2017), like monetary units, we need to expand our understanding to develop equivalences to the other range of ecosystem services if we intend to avoid underestimations.

In that context, we should also take in consideration that services above 4 that are part of the category of regulation and maintenance, which are climate regulation, intrinsic value, life cycle maintenance, primary production, and habitat forming might have important functions related to the foundation of others, as they can be interpreted as supporting services. They represent those services with influence in human health, well-being and safety (Haines-Young, R. 2023), and when working properly they guarantee the efficiency of the physiological processes of the environment and therefore the supplying of other services. With all that, it becomes even more crucial to avoid underestimation, if not for monetary

reasons to provide accurate values of the importance of kelps (Filbee-Dexter & Wernberg, 2018), for the preservation of a balanced environment.

4.3. The representative ecosystem services and their importance for coastal management

When eliminating those ecosystem services with average rate below 3, we end up with a list of 16 services considered representative for the Northwestern of Portugal (Table 6). The knowledge gap we are filling with a list of relevant services provided by kelp forests, can promote a better comprehension for decision makers in the public and private sphere. It happens due to the science-based information generated, but also because it helps those in charge to better understand the stakeholders involved and connected with that habitat. It becomes a mutual benefit as the integration of stakeholders in process of decision making tends to diminish social inequalities (Potschin & Haines-Young, 2011) at the same time that it can also provide an extra support for the development and implementation of projects (Kati et al., 2015).

Even though it might be difficult in the beginning, the more every group affected are present in the process of decision making for impactful projects the more we close the gap between the social, biological, and economic pillars (Barbier, 2011).

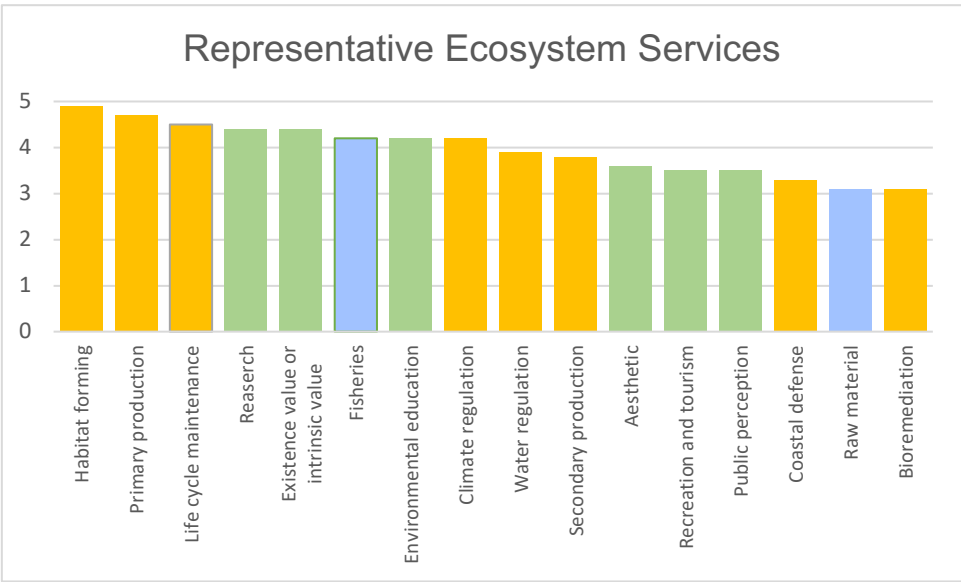


Figure 4 Priority ecosystem services from the data analysis of Figure 3

One more time, we see that we circle back to the ecosystem services belonging to those from non-market categories. Even though crucial for a sustainable management scenario, non-marketed services represent a challenge when it comes to fully analyze them (Barbier, 2011). For the fact that a monetary value is not easily designated, the importance of these services becomes even more abstract. For decades, specialists try to determine the value of the benefits given by ecosystem services (Costanza et al., 2017), but different perceptions of value are present according to culture and people's perceptions. Therefore, any estimative that consider only direct value of ecosystem services tend to result in underestimated assessments (Potschin and Haines-Young (2011); Wernberg et al., 2018).

This complex issue with methodologies it is not new in the scientific context, in this work it led us to the Ecosystem Service Cascade framework as the best option. It integrated well with the Common International Classification of Ecosystem Services, as one of the authors (Haines-Young, 2023) wrote the guideline for interpretation and CICES uses the same background of the ESC to establish its concepts. To complete this structure, we also considered the work of La Notte (2017), in which she better delimitates the three categories of CICES (provisioning, regulation & maintenance, and cultural) using an adaptation of the ESC. Align with the expert judgement it provided the first inputs for decision making and research directions.

We strongly recommend this to be only the first step and therefore be followed with other complementary work in order to expand the rigor of the information. Future research should include local assessments of the services provided by kelp forests of the North of Portugal, to support our results. So, we strongly recommend this work to be only the first step towards the better comprehension of the importance of kelp forests ecosystem services for the Northwestern of Portugal.

5. Final considerations

The present work had three specific goals to achieve. First a list of potential ecosystem services delivered by kelp forests was done demonstrating the presence of 19 ESs. From those, five belong to the provisioning category, eight to the regulation & maintenance, and six to the cultural.

From those we established a list of those which were better considered by the experts, as to be delivered by kelp forests from the North of Portugal. A total of 16 ESs were considered to have relevance to the Northwestern part of Portugal.

Lastly, we could analyze which services made the top of the list and could be considered priority in a policy decision.

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Category: Provisioning | Ecosystem service: Aquaculture for raw material

*

Example: "Some recent efforts with private and state funding have been conducted to assess the feasibility of producing biofuel from mass cultivation of *M.pyrifera* in southern Chile (Vázquez et al., 2013)."

"Thus, the economic value of kelps is mainly associated with the collection and harvesting of *Lessonia* species, and as raw material for the alginate extraction industry (Vásquez et al, 2013).

*Kelp farms used/harvested for non-feeding purposes, such as biofuel or for alginate industry

1 2 3 4 5

Not relevant ○ ○ ○ ○ ○ Extremely relevant

Not relevant

Extremely relevant

Category: Regulation & Maintenance | Ecosystem service: Primary production

*

Example: "They support one of the highest productivity rates via photosynthesis, and greatly influence the physical environment in which they live, due to their three-dimensional structure. (Cuba et al, 2022)"

"Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al., 2013)."

*Kelp as a source of organic matter for the food web (from soil to end consumers).

1 2 3 4 5

Not relevant ○ ○ ○ ○ ○ Extremely relevant

Not relevant

Extremely relevant

Category: Regulation & Maintenance | Ecosystem service: Secondary production



Example: "Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al, 2013)."

"Organic enrichment by macrophyte (kelp) detritus, and abundance patterns of megafaunal populations in submarine canyons (Vetter and Dayton, 1999)"

"It is known that kelp detritus represents a subsidy of energy in low-productive habitats (Cuba et al, 2022)"

"Finally, greater longevity of cold temperate kelp detritus likely allows for export to hypoxic regions of the deep sea where decomposition is slower (From Pedersen et al., 2021 in Wright, Pessarrodona & Foggo, 2022)

"Evidence from elsewhere would indicate that kelp biomass is a hugely important source of exported energy, which influences patterns of secondary production and the distributions of marine organisms (Smale et al., 2013)."

***Kelp as a source of organic matter for the food web in deep ocean where light presence is scarce.**

1 2 3 4 5

Not relevant ○ ○ ○ ○ ○ Extremely relevant

Category: Regulation & Maintenance | Ecosystem service: Coastal defense

*

Example: "Kelp forests, such as other biogenic structures in coastal zones (e.g., salt marshes, mangroves), prevent and alleviate the damage caused by flooding and storm events (Smale et al., 2013).

"Coastal defense represents a critical ecosystem service that will become more important along many coastlines as the consequences of anthropogenic climate change intensify, namely sea-level rise and an increased magnitude and frequency of storms (Smale et al., 2013)"

"Kelps forests alter water motion and provide a buffer against storm surges through wave damping and attenuation and by reducing the velocity of breaking waves (From Lovas and Torum 2001 in Smale et al, 2013)

***Kelp as a source of protection from high tides and storms.**

	1	2	3	4	5	
Not relevant	☐	☐	☐	☐	☐	Extremely relevant

Category: Regulation & Maintenance | Ecosystem service: Habitat forming

*

Example: "Kelp forests support high primary productivity, magnified secondary productivity, and a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important (Smale et al., 2013)."

"As habitat formers, a single kelp sporophyte directly provides three distinct primary spaces: the holdfast, the stipe and the lamina (Cuba et al, 2022)"

"A forest can improve the habitability of the benthos and the water column, generating habitats for a biodiverse microbiome as well as breeding areas for other macrophytes, and both sessile and motile animal species (Cuba et al, 2022)."

*Kelp as habitat forming due to its forest structure.

1 2 3 4 5

Not relevant ○ ○ ○ ○ ○ Extremely relevant

Category: Cultural services | Ecosystem service: Aesthetic



Exemple: "Cultural services derive from information. For example, we are able to receive the information from an amenity land- scape given the human ability to perceive (receptor) and appreciate beauty (decodification and interpretation). This information might influence humans, for example triggering inspiration, a physiological relaxation, a sense of fulfilment, or a spiritual experience. (La Notte et al., 2017)."

***Kelp as source of pleasant sightseeing either during a diving or in providing a better ocean view for those outside the water**

	1	2	3	4	5	
Not relevant	☐	☐	☐	☐	☐	Extremely relevant

Enviar

Limpar formulário