Impacts of the shipbuilding industry on the ecosystem services and the challenges for a sustainable blue economy: Case study of a coastal ecosystem in the Eastern Mediterranean

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Abstract. Blue Economy includes all economic activities that take place in the ocean, sea and coastal areas. Despite their importance and continuous growth, the blue economy activities have serious impacts on the marine and coastal environment. A sustainable blue economy preserves social cohesion, promotes environmental protection and produces economic growth. Shipbuilding is one of the main blue economy sectors, covering the construction of the cargo, passenger, military and research fleet and its maintenance. The shipbuilding sector is important for the EU economy, in terms of economic development, employment and support of the supply chain. The last years, the shipbuilding and repair industry of Greece is reborn, with a respected number of shipyards to increase their activities. The shipbuilding activities belong to the so called "heavy" industries, creating significant environmental pressures to the coastal ecosystem, that affect a series of ecosystem services. Case study of this research is the Gulf of Elefsis, a vulnerable ecosystem facing the impacts of the industrial activities of shipbuilding and repair, and the environmental problems that occur. The present study is an attempt to spot the ecosystem services that are threatened by the shipbuilding industry and to propose the appropriate measures and responses to face the existing pressures.

1 Introduction

Blue Economy includes all economic activities that take place in the ocean, sea and coastal areas. Specifically, blue economy encompasses marine based activities and marine based activities using products or producing services for the ocean [1]. Moreover, blue economy and the growth obtained from the blue economy activities, known as blue growth, operate as the economic engines of the seas and the oceans. The sectors of blue economy are maritime, tourism, renewable energy, aquaculture, shipbuilding and repair and many more [2]. Despite their importance and continuous growth, the blue economy activities have serious impacts on the marine and coastal environment. In order to preserve the increasing pace of development, all blue economy sectors should operate under a framework based on the principles of sustainable development [3, 4]. In other words, no sustainable growth can be obtained from a blue economy sector (e.g., shipbuilding), if no appropriate measures for environmental preservation are taken and no respect is given, and no actions are made towards social prosperity. A sustainable blue economy preserves social cohesion, promotes environmental protection, and produces economic growth.

2 The Shipbuilding Industry

Shipbuilding is one of the main blue economy sectors, covering the construction of the cargo, passenger, military and research fleet and its maintenance. The shipbuilding sector is important for the EU economy, in terms of economic development, employment and support of the supply chain. The GVA of the shipbuilding and repair industry in the European Union raised to 15,6 million € in 2019, while more than 300.000 employees worked in European shipyards [5]. Greece has traditionally been one of Europe's countries with a developed shipbuilding and repair sector. Especially the last years, the shipbuilding and repair industry of the country is reborn, with a respected number of shipyards to increase their activities. According to the Hellenic Statistics Agency [6], only in the year 2022, the number of repaired ships in reached 593 vessels with a total tonnage of 8.554.615 GT. The largest number of ships was repaired out of the repairing tanks. More specifically, 66.1% of the repaired ships (392 ships) of total tonnage 5.909.789 have been repaired out of tanks. The remaining 33.9% of the repaired ships (201 ships) with a total tonnage of 2.644.826 GT have been repaired inside tanks. The evolution of the shipbuilding and repair industry in Greece in the last decade, is presented in Figure 2 below.

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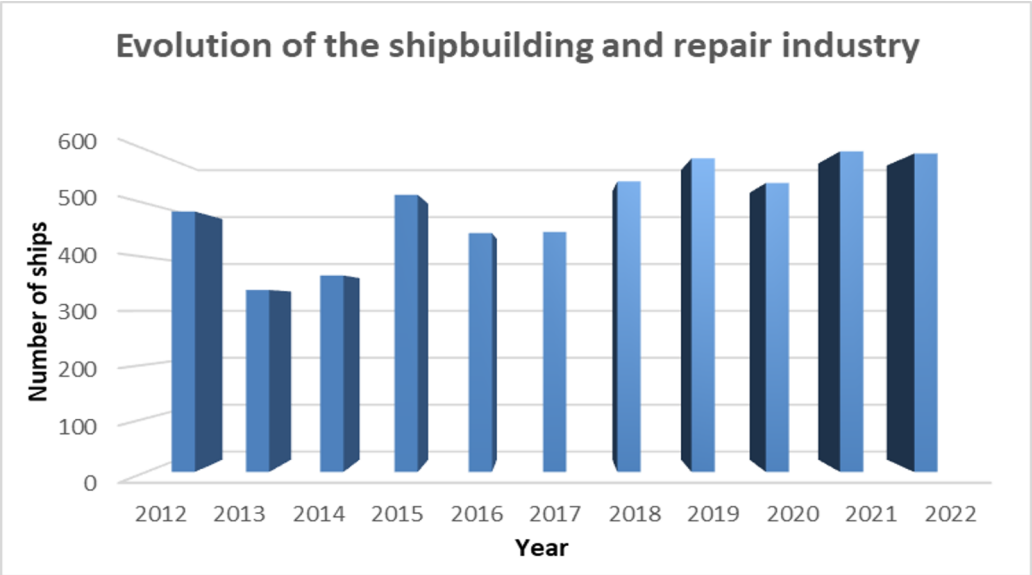

Fig 1 : The evolution of the shipbuilding and repair industry in the last decade.

The shipbuilding activities belong to the so called "heavy" industries, creating significant environmental pressures to the coastal ecosystem. Atmospheric emissions, noise, wastewater, leakages of toxic chemicals and other substances, are some of the impacts of the shipbuilding industry to the coastal ecosystem (Figure 2). The environmental impacts of the shipbuilding and repair industry, affect and threaten a series of ecosystem services of the coastal environment.

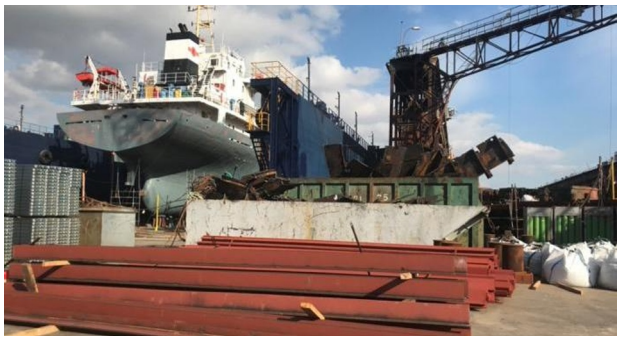

Fig 2: Vessel repair works in a shipyard.

3 The Study Area

The case study of this paper is Elefsis Gulf, a coastal industrialized ecosystem located 18 km east of Athens metropolitan area (Figure 3).

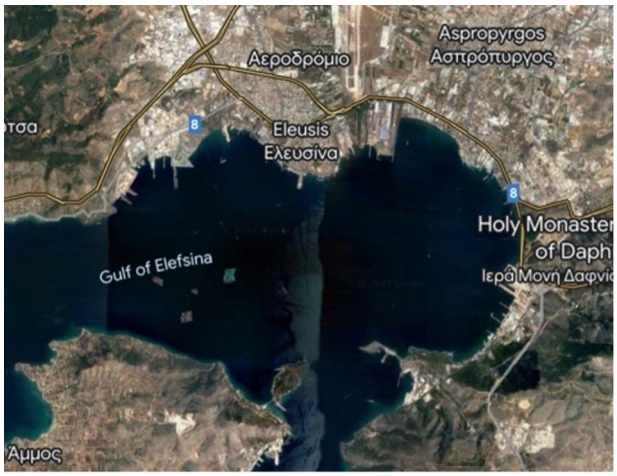

Fig 3 : The map of the study area.

The Gulf of Elefsis is characterized by the heavy industrial activities that operate for more than 100 years, the protected natural environment of Lake Koumoundourou, the important cultural heritage and the contemporary urban development of the city of Elefsis. It should be noted that the wider metropolitan area of Elefsis is the cultural capital of Europe for the year 2023 [7]. The maximum depth in the gulf of Elefsis is 35m (Figure 4), while the west part of the bed is the deepest operating as a sediment trap and the eastern part of the bed has a smaller depth that fluctuates from 10 to 25m [8, 9]. The acreage of Elefsis Gulf is 68 m2, shaping a small and semi-closed bay [10]. The gulf of Elefsis is connected to the Saronic Gulf through two narrow and shallow inlets [11]. The salinity in Elefsis Gulf presents a relative homogeneity with a seasonal variation from 37.5 to 39 of from March to summer respectively [12]. The salinity in the coastal areas of the bay is lower, due to the brackish wastewater and the underwater sources flowing in Elefsis Gulf [13]. As for the temperature data in the gulf of Elefsis, the maximum temperature appears in the months of July and August reaching 25°C, while the lowest

temperatures are reported in the months February and March, reaching 10°C [14].

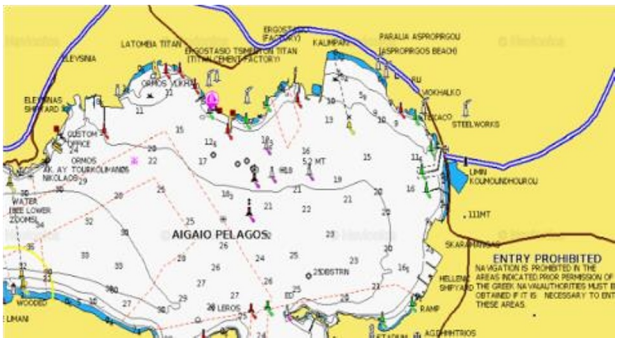

Fig 4 : Bathometric map of Elefsis Gulf.

The study area includes the protected natural environment of lake Koumoundourou (Figure 5), an ecosystem with high environmental and cultural importance. More specifically, Lake Koumoundourou includes numerous species of avifauna (gulls, starlings and more) and flora, while since the 70's is protected the Greek legislation as an archaeological site [15]. Furthermore, Koumoundourou lake is surrounded by polluting neighbour's including oil tanks, military facilities, and heavy industries.

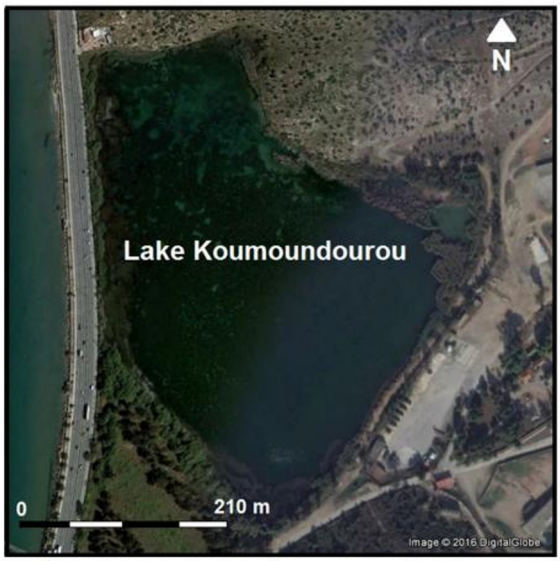

Fig 5 : Lake Koumoundourou.

Among the industries operating in the wider area are oil refineries, steel works, shipyards, cement factories, as well as chemical, mechanical, tire and plastic factories produce various pollutants, while there is also a trade port and important urban development. The bay receives also environmental pressure from Piraeus port. The high amounts of contaminants released in the environment were responsible for a tremendous ecological harm in the period 1960-1980 [16, 17]. The accumulation of heavy metals in marine sediments caused severe impacts to the marine species. In the following years, metal pollution in seawater, marine sediment and tissue of marine biota showed a stable or decreasing trend [18]. The enrichment of muddy surficial sediment of the Elefsis bay in metal content and organic carbon causes environmental stress on benthic foraminifera leading to a low species diversity fauna dominated by stress-tolerant species [19]. Moreover, the extreme water column stratification in the Elefsis bay may cause anoxic conditions particularly during the summer period. Seasonal anoxia in the near bottom layer was found to contribute to mass mortality of benthic macrofauna. It might also have significant ecological impacts on many other marine species [20].

3.1 Ecosystem services in the study area

Ecosystem services are usually described as the goods and the services, that people derive from the natural environment and benefit from them in multiple ways [21, 22]. The term ecosystem services is often interpreted as the result of ecological processes that contribute to social well-being [23]. Moreover, the concept of ecosystem services is increasingly applied for the purpose of assessing the possible effects of the changes of human behavior in the environment [24]. The concept of ecosystem services connects the function of the ecosystem with the human wellbeing and prosperity in regional and global level [25]. Elefsis Gulf and the surrounding coastal ecosystem provide a series of important ecosystem services to the local community and to the environment. These ecosystem services are under threat, due to the increased shipbuilding activities. The ecosystem services in Elefsis Gulf are presented in Table 1 below.

Table 1 : The ecosystem services in the study area [21, 26, 27].

Category	**Ecosystem services**
Provisioning	Food
	Raw materials
	Freshwater
	Energy
Regulating	Local climate air quality
	Carbon sequestration and storage
	Moderation of extreme events
	Waste-water treatment

	Erosion prevention and maintenance of soil fertility
	Biological control
	Regulation of water flow
Supporting	Habitat for species
	Photosynthesis
	Healthy soils
	Nutrient cycling
Cultural	Recreation and mental and physical health
	Tourism
	Aesthetic appreciation and inspiration for culture, art and design
	Spiritual experience and sense of place
	Education and educational values
	Religious experience

4 Methodology

For the analysis of the pressures of the shipbuilding activity in Elefsis Gulf, the DPSIR model has been used. Specifically, the DPSIR is a pressure analysis model, that contributes to the identification and the understanding of the interaction of ecological and social parameters, to the prediction of changes and to the management of the system and its upcoming changes [28]. The DPSIR model consists of 5 elements as its acronym: Drivers, Pressures, State, Impacts and Responses. The Drivers create Pressures on the environment, that accordingly influence its State. The influence on the State has Impacts on the local ecosystem, that to be faced require specific Responses. The structure of the DPSIR model is presented in Figure 7 below. It should be noted that this model has successfully been used for the analysis of coastal ecosystems [29].

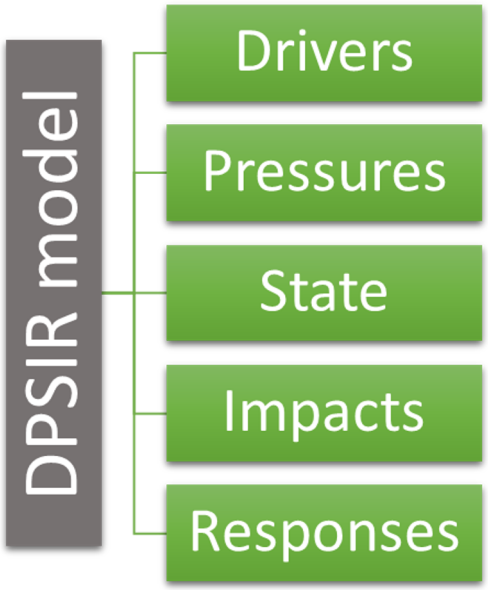

Fig 6 : The structure of the DPSIR model.

As it has already been mentioned, the shipbuilding activity in Elefsis Gulf is intense and practiced for more than 60 years, while recently more shipyards started operating again. As a result, the shipbuilding activity is continuously growing, as well as the environmental impacts and the pressures acted in the coastal and marine environment of the study area. Under this scheme, the main drivers and pressures of the shipbuilding and repair industry in Elefsis Gulf have been identified and analyzed through the DPSIR model.

5 Results

The application of the DPSIR model in the study area, resulted into the creation of the wider DPSER model, that incorporates the impacts with the affected ecosystem services (Figure 7). As it is presented in box A, the drivers that generate pressures to the coastal ecosystem of Elefsis Gulf are shipbuilding, ship-repair and a wide range of infrastructure works, such as excavation, that take place into the shipyards and the associated industrial plants. Those pressures affect the state of the ecosystem (box B), which is expressed by the air quality, the ecological and the chemical status of the water and the biodiversity. Box D presents of the pressures on the coastal ecosystem of Elefsis and the affected ecosystem services. Among the main impacts are the occurrence of eutrophication phenomena, that affects a series of important ecosystem services (e.g., nutrient cycling, photosynthesis, food), the degradation of tourism and the atmospheric pollution. Finally, Box C presents the responses to the acted pressures, such as the enactment of a stricter legislative framework that will include lower emission limits, often inspections of the industrial plants, higher fines, and stricter penalties to the violators. Other responses include the adoption of clean production practices and technologies, the education of the related stakeholders and the application of compensatory measures to the

shipbuilding industries. As it is presented by the arrows in Figure 8, all the components of the DPSER model (boxes A-D) are interconnected.

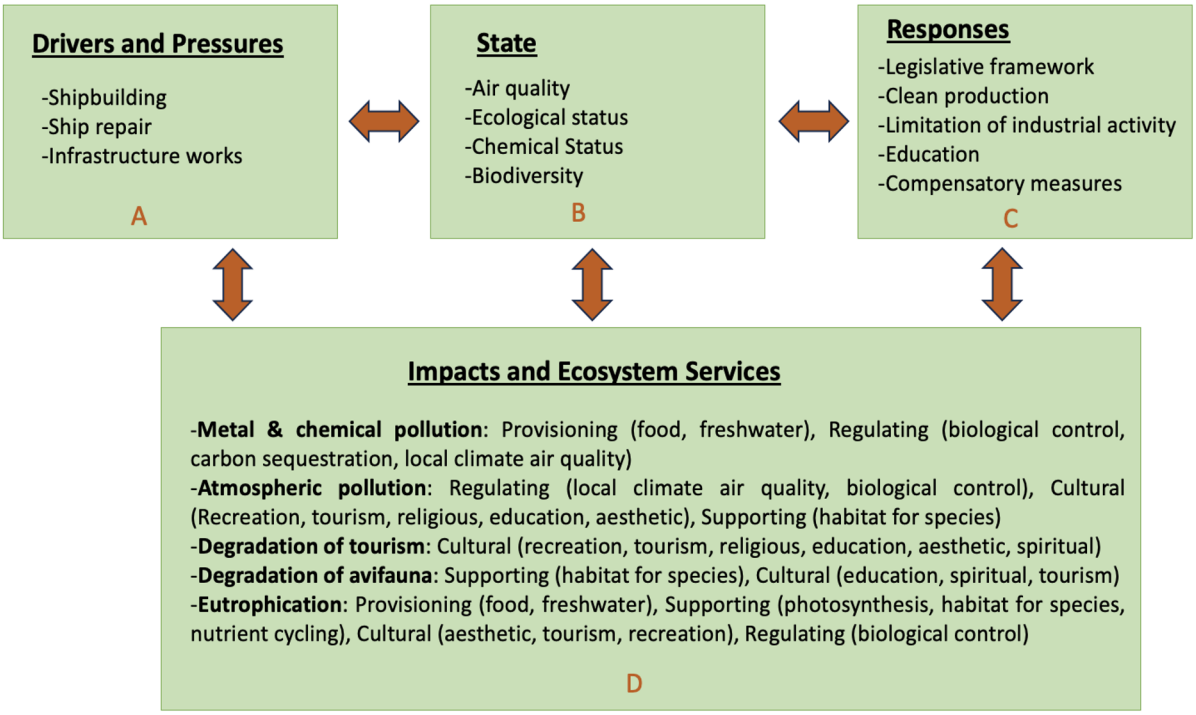

Fig 8 : The DPSER model.

6 Discussion

Compared to other mediterranean coastal ecosystems, Elefsis Gulf belongs to the vulnerable ecosystems, as many ecosystem services are endangered, especially cultural ones, which has been proven by previous research [30]. Cultural ecosystem services are the most important ecosystem services for the achievement of sustainable blue economy in the coastal zone, as they express two of the three pillats of sustainability, the economic and the social one [30]. The special characteristic of Elefsis Gulf is the fact that in a small piece of land, many different land uses are concentrated, including a great cultural heritage, intense industrial activities, urban development and tourism. Coastal ecosystems including shipyards and a protected natural area, such as the Aliaga area in southeastern Turkey, are connected to less ecosystem services than Elefsis Gulf, which faces more threats. This can be concluded by the geomorpholgy and the specific hydrological characteristics of the study area, as well as by the fact that Elefsis Gulf includes more land uses connected to numerous cultural ecosystems services.

7 Conclusions

There is an emerging need for the adoption of a sustainable blue economy framework for all blue economy sectors. Especially when it comes to the shipbuilding and repair industry, one of the main sectors of blue economy, a series of sustainable blue economy principles should be implemented. The vulnerable coastal ecosystem of Elefsis Gulf hosts the largest share of the shipbuilding and repair industry in Greece, facing a series of impacts and threats on it's ecosystem services. The analysis of the pressures that this ecosystem receives, through the DPSIR model showed that the important ecosystem services are affected, such as provisioning (food, freshwater) and regulating ecosystem services (biological control, carbon sequestration, local climate air quality) due to metal and chemical pollution. Among the necessary responses for the confrontation of thoses pressures are the adoption of the "polluter pays" principle by the shipbuilding industries, the installation of state-of-the-art technological equipment under the context of a cleaner production initiative, the enactment of a strong legislative framework and the information of the local communities on the related environmental challenges. Moreover, the shipbuilding and repair industries should respect the status of the coastal ecosystem and operate

based on the ecosystem's current capacity, to achieve an environmental balance and a harmonized co-existance with the natural environment and the local communities, as a sustainable blue economy requires.

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