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FISHERIES MODEL FOR MEDITERRANEAN SEA OVEREXPLOITATION

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1. INTRODUCTION

Fisheries have meant the employment, economy and livelihood of Mediterranean people since ancient times. Nevertheless, the scarce management of marine resources in the sea, mainly focused on establishing closing seasons, protecting juveniles or spawning beds and banning certain active fishing gears, has not been enough to deter the permanent increase in anthropogenic pressure.

Albeit the overexploited assessed stocks have decreased from 88% to 78% during the last years, it has not been enough to avoid the Mediterranean be the most overfished sea all over the world. The excessive effort deployed has not only caused species such as European hake be fished over 12 times the level considered to be biologically sustainable, but has also led to a tremendously overcapitalised fishing fleet. On the whole, this has implied substantial costs and low economic yields for fishermen, who report less and less catches each year and alarm the looming loss of the Mediterranean traditions, employment or food supply, among other things. However, problems do not end here. In addition to the concerns produced by externalities from the fishing industry itself such as bycatch or seabed destruction, new challenges arising from external disturbances causing climate change, acidification or biological invasions are jeopardising the stocks of the most important fish species in the Mediterranean.

The objective of this final degree project is to run two logistic growth models with critical depensation in order to assess the effectiveness of private property resources over open access extraction for the conservation of Mediterranean stocks at biological sustainable levels in the long-run. One for European hake in the western Mediterranean with a restriction in the effort exerted, measured in fishing days and another for small pelagic, namely sardine and European anchovy, in the Adriatic Sea, with a Total Allowable Catch (TAC) of 101,711 annual tonnes.

For this purpose, data have been collected from the General Fisheries Commission of the Mediterranean and the fishing measures implemented correspond to the 2020 fishing opportunities for certain stocks and groups of stocks in the Mediterranean and black sea from the European Union regulation.

To begin with, the text will carry out a brief review of the history of fishing in the Mediterranean and what it has meant for its people.

2. OVERVIEW OF THE MEDITERRANEAN SEA

2.1. Crucible of civilization

The Mediterranean region has been the cradle of some of the oldest civilizations in human history, who have used the sea and its natural resources to develop their own approach to understand the world. Consequently, the Mediterranean has become a prolific place in terms of environmental and cultural diversity.

In light of this, fishing has meant more than just a provision of food and economic activity since time immemorial. Its interest is appreciated through art in coins, kraters or mosaics depicting gods such as the brave Heracles along with his tuna captures. Similarly, soldiers in Imperial Rome ingested dried tuna fillets and tuna eggs as a source of protein to wage war (Randone et al., 2017). Nevertheless, fishes in the Mediterranean have also had other alternative and more exotic appliances that soared the prices of many of them. Catfish, for instance, was used in medicine, swordfish as an aphrodisiac in the Far East and murex were mashed to obtain lavish purple for dyeing or placed on tombs for the deceased. In Ancient Greece, sumptuous votive offerings were also dedicated to the sanctuaries of Apollo in Delphi or Zeus in Olympia, as a reminiscent of an exceedingly good catch of fish. Likewise, important colonies such as Byzantium were deliberately founded in places where several fishermen had already established fisheries (Blázquez Martínez, 2007).

Fishes were so abundant in certain parts of the Mediterranean that Pliny the Elder described how Alexander the Great felt obliged to place his boats in battle order as the only way to get through a huge migrating shoal of tunas that were blocking his passage to Asia. Amazing as it might seem, shipbuilding, fishing gear and fishing practices were highly sophisticated in ancient times and have been minimally modified. At a time when captures exceeded fish demand, many states began developing new methods of fish conservation e.g. the salting industry. This required an excellent organisation in fish markets and appropriate channels of distribution. Historical evidences proof the existence of fishing guilds and documents containing rights for fishermen or lists of prices for different fish species. Captures were, in fact, sometimes controlled by the States through the payment of taxes on fish products (Blázquez Martínez, 2007).

From east to west and north to south, the sea never constituted a dividing barrier, but rather a means of easy and cheap trade and communication. Thus, the exchange of fish for other food, raw materials, technology or ideas is likely to have accelerated the expansion of

philosophy, mythology, religion, literature or theatre. In essence, a myriad of ingredients that ended up shaping the idiosyncratic western civilization and our everyday lives.

2.2. Mediterranean governance

Even so, it would not be precise to analyse the Mediterranean as a whole. The apparent similarities of its picture are eclipsed by a much more complex situation. The sea bathes the coastlines of 21 countries: 13 European, 3 Asiatic, 5 African and 2 Eurasian, which, in fact, exhibit important disparities among them.

The northern States, most of them belonging to the European Union, encompass industrialised societies with entrenched democratic systems, where the Christian religion and an ageing population predominates. Some of these factors contribute to the existence of a strong governance, but have also triggered many problems for the sea, as their demand for marine resources is much higher than the sustainable supply. On the other hand, in southern States, with the exception of Israel, developing economies with Muslim religion and growing populations prevail. Even though the resource exploitation of these countries is, in general, not so extended, they show an increasing demand at the same time their governance is still considerably weak in most cases.

These asymmetries in development levels and living standards between countries coupled with the conflicts in the region are imposing numerous hindrances for the sustainable use of the Mediterranean Sea and its resources. The only feasible solution is to nurture a common governance to effectively monitor and control fishing efforts against overfished stocks, IUU (Illegal, Unreported and unregulated) fishing or environmental degradation (Jeffries, 2017). So, we will see how the Mediterranean particularities contribute to the lack of coordination over water jurisdiction hereafter (Suárez de Vivero et al., 2010).

Territorial Use Rights in Fisheries

With regard to establish a comprehensive set of rules to govern all uses of the oceans and their resources, in 1982, the United Nations Convention on the Law of the Sea (UNCLOS) defined the territorial spaces that may be proclaimed by coastal states.

This meant the possibility for coastal states to extend their jurisdiction beyond the 12 nautical miles presumed from the **Territorial sea**. In this manner, every state can claim for an **Exclusive Economic Zone (EEZ)** and exercise sovereignty rights for the purposes of exploring and exploiting, conserving and managing the natural resources. The additional area could reach up to a limit not exceeding 200 nautical miles from the baselines from which the Territorial sea is measured (United Nations, 1982).

Nevertheless, the truth is that, as a narrow and semi-enclosed sea, the Mediterranean imposes numerous hindrances to establish EEZs. If countries both at the north and the south shores claimed for EEZs, there would not be enough space to cover the 400 miles required for both areas. As a matter of fact, few States have claimed to extend the 12 nautical miles of their national jurisdiction, namely Egypt, Morocco, Tunisia, Spain or France. Others have exacerbated their disputes, after decades of discrepancies for the territorial use rights of the Mediterranean, e.g. Greece and Turkey in the Aegean.

This lack of EEZs has led to the **existence of a lot of high seas areas, where any State is free to act**. This entails significant difficulties for the governance of the Mediterranean Sea, as it requires a large level of cooperation between coastal States to ensure the sustainable use and conservation of sea resources. Indeed, even though many experts sustain that the creation of more EEZs would provide a better control of fishery resources and pollution, the situation has proved not to be resolving (Martinez et al., 2009).

Marine Protected Areas (MPAs)

Marine Protected Areas (MPAs) are an efficient tool for the sustainable management of the marine environment. They promote the preservation of species and their habitats while enhancing fish stocks as well as spur the local economy through job creation, ecotourism and especially ensure the livelihood of fishermen (MedPAN, MPAs of the Mediterranean, 2012).

In 2016, (MedPAN, et al., 2019) found 1,231 MPAs and Other Effective area-based Conservation Measures (OECMs) in the Mediterranean. They cover 11,362km^2 and encompass a surface of 6.81% under very different legal destinations. National designations account only for 1.27% (32,065km^2) and no-go, no-take or no-fishing zones for 0.04% (976km^2). Besides, they also include the coverage of two sensitive habitats, 39.78% of Posidonia beds and 32.78% of coralligenous Mediterranean communities.

Nonetheless, over 72.77% of the surface covered is located in the western Mediterranean and 90.05% is found in EU waters, proof again of the disparities in protection measures in different parts of the sea. The problem is that although some areas have been already protected, effective management is still to be determined and the lack of financial resources and technical capacity, as well as legal and policy gaps hinder the process to establish more MPAs.

Sustainable Development Goals (SDGs)

Following the thread of the Millennium Development Goals targeted for 2015, the United Nations designed a new plan to build a better world for humanity, namely the **2030 Agenda for Sustainable Development**. This Agenda calls on countries to begin efforts and achieve 17 goals during the next 15 years.

In the Mediterranean, as in the rest of the seas in the world, the agenda pursues achieving food security through sustainable fish consumption, decent employment for fishermen or urgent action to combat climate change and its impacts. However, the goal 14 advocates more specifically for the **conservation and sustainable use of our oceans, seas and marine resources**. It includes some major guidelines to prevent and significantly reduce marine pollution, minimize ocean acidification or regulate harvesting. Eventually, the goal 15 introduces additional measures to prevent the introduction of invasive alien species and significantly halt their impact on biodiversity loss in the Mediterranean.

Similarly, the Mediterranean Strategy for Sustainable Development 2016-2025 has been also established in order to provide a local strategic policy framework to complement the global Agenda for Sustainable Development and achieve a social and economic development in a sustainable environment.

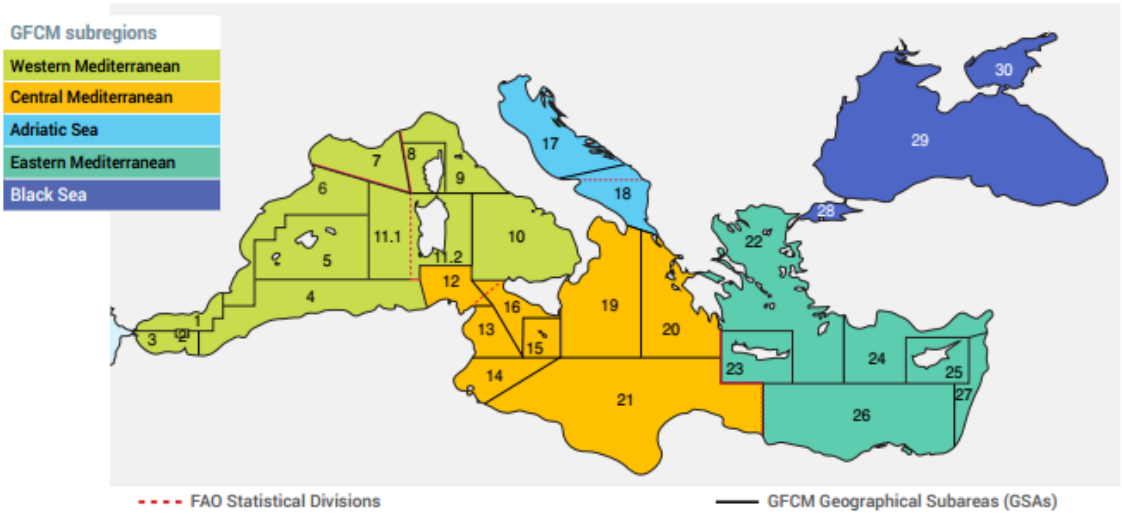
RFMOs in the Mediterranean

Regional Fisheries Management Organisations (RFMOs) are international bodies made up of countries that work together towards the conservation and sustainable management of fish stocks. They are usually in charge of collecting fisheries statistics, assessing resources, making management decisions and monitoring activities. They exist in the majority of high sea areas that have major deep-sea fisheries, such as in the Mediterranean and Black Seas, where the **General Fisheries Commission for the Mediterranean (GFCM)** is directly concerned their governance (FAO, n.a.).

Since its creation in 1949 under the provisions of the Food and Agriculture Organization (FAO), the GFCM, together with its 24 contracting parties and 5 cooperating non-contracting parties, several measures have been undertaken. Among other things, the commission has: regulated the fishing methods, gear and minimum landing size; established spatial protection procedures; controlled fishing effort; or elaborated multiannual management plans.

In its task, the GFCM disaggregates information differentiating two spatial scales in the Mediterranean, namely GFCM Subregions and Geographical Subareas (GSAs) as observed in Figure 1. Thus, in order to facilitate the analysis, most of the information provided throughout this paper will be provided taking into account this classification or, less often, national specifications in the Mediterranean. At the same time, circumstances in the Black Sea (GSAs 28, 29 and 30) are ignored.

Figure 1. GFCM area of application, subregions and geographical subareas



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - South of Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Source: General Fisheries Commission for the Mediterranean

The labour of the GFCM, as the main regulatory body in the Mediterranean, ensuring the sustainable management of marine species is complemented with the **International Commission for the Conservation of Atlantic Tunas (ICCAT)**. The commission is responsible for conducting data collection, scientific monitoring or management of highly migratory species in the Mediterranean. The value of total catches counts for more than 10% and species such as bluefin tuna have been of major importance along the sea.

Alternative organisations struggling for the conservation of the Mediterranean environment such as the World Wildlife Foundation (WWF) or the International Union for Conservation of Nature (IUCN), or others like the Union for the Mediterranean or

Oceana, that have also put effort on promoting the socio-economic stability, an important issue featured below.

2.3. Socio-economic analysis

The provision and consumption of fishing goods has traditionally been one of the most important activities developed in the region. Directly embedded in the daily lives of many families, it has meant their employment, economy and livelihood for centuries. Hence, in this section we will observe how revenue, employment, remuneration, trade and consumption are distributed along the Mediterranean.

Revenue

Albeit fishing represents a minimum percentage of the total GDP for most of the Mediterranean countries, according to (FAO, 2018), it does produce an overall estimated annual revenue of USD 2.44 billion. Even so, these calculations seem to be underestimated, and the whole economic impact, including direct, indirect and induced revenue could actually account for about USD 6.34 billion. This is a faithful reflection of the tremendous impact that fishing has for the Mediterranean population.

The 35% of the landing value in the Mediterranean is received by the western subregion, that is USD 867,717,141. The following subregions are the eastern and central Mediterranean, with 654,257,188 and 507,730,096 dollars respectively. Finally, the Adriatic Sea accounts for USD 353,754,385, less than half that of the western subregion (See annex Figures 1 and 2).

Employment

Apart from being responsible for about the 15% of the human food protein intake (European Commission, 2017), the Mediterranean also creates employment for about 227,250 people (FAO, 2018). Again, calculations are just bearing in mind employment onboard fishing vessels and obviating some important activities such as pre- and post-harvest labour, gleaning or family support.

In contrast to what happened in the previous section, where revenue was higher in the Western and Eastern Mediterranean subregions, Figures 3 and 4 from the Annex display how now, each of them employ about 64,000 fishermen. Notwithstanding, the central Mediterranean encompasses a higher number of fishermen, 81,635 (36%), whilst the Adriatic Sea gives opportunities for 17,034 seafarers, a scarce 8% of total employment.

Average remuneration

In the vast majority of world fisheries, crew are paid following remuneration systems regarding the economic performance of vessels. It is obvious that technology has improved enormously during the last few years, reducing the effort applied for harvesting. All the same, such high levels of sea overexploitation have dwindled productivity and thus wages have decreased for fishermen (Guillén, et al., 2017).

Regarding once more the data provided by (FAO, 2018), an average fisherman in the GFCM area, including the Black Sea, produces approximately USD 14000 in annual catch value. Even though it can be convenient as a measure of productivity, the landing value per employee provides a misrepresented picture of remuneration per fisher as it does not take into account part-time employment and is not aware of costs.

Results from Figure 5 from the Annex surprisingly reveal how fishermen from the Adriatic Sea, the Mediterranean subregion with lowest landing value, gains far more in average than the rest subregions. Something easily explained by the reduced number of sailors in the area, almost 5 times smaller than in Central Mediterranean, and more than 3 times than in eastern Western Mediterranean.

Nevertheless, moving far deeply in our analysis, we realise that captures in the Adriatic Sea are mainly coming from Croatia and Italy, two countries belonging to the European Union. Conversely, the rest of the subregions are composed by a combination of European and African or Asiatic countries, where economies are less developed and gross value of their captures is quite lower (FAO, 2018). Previously, we announced these mismatches and here we have our first evidence.

Fish trade

The trade of fish products is very important in the Mediterranean region, and specially between the European and non-European countries. According to (Jeffries, 2017), the total value traded considering catches and aquaculture reaches USD 40.5 billion, over 16 times the regional landing value at first sale.

To meet the high demand for fish, European Mediterranean countries depend largely on imports from other Mediterranean developing countries (Morocco, Turkey, Tunisia, Egypt, Algeria, Libya). Around 1.8 million tonnes of fish were imported from these locations in 2014, and around 335,000 tonnes were caught in these countries' waters under license, in most cases high value products (Jeffries, 2017). This is just another signal of the perceptible

disparities between Mediterranean countries. Despite European Mediterranean nations also export fish in the other direction, the quantities are much smaller and most products are processed or canned, and sold at relatively low prices with other purposes than human consumption e.g. feeding aquaculture.

Trade can alleviate poverty in developing countries and build long-term fishing sustainability. Nevertheless, there is a spread thought in Europe that the low prices of these imports from developing nations face unfair competition to local fishers. To avoid that and engage in further negative impacts, fishery rules and controls must be effectively implemented both in EU and non-EU countries (Jeffries, 2017).

Fish consumption

As inferred from previous parts, the use of fish products has been central in the renowned Mediterranean diet. In effect, the region has an annual mean consumption of 33.4kg of fish per capita. Spain is the highest country consumer in the region with 42.4kg, just exceeded all over the world by Portugal. These numbers are quite higher than the EU average of 22.9kg, and even more if we compare it with the global average of 19.2kg (Jeffries, 2017).

Overall, European Mediterranean countries consume almost 7.5 million tonnes of fish each year, yet little more than a third come from domestic sources and the rest is imported. This might imply an excessive extraction to compensate the huge demand. In light of this, providing consumers with appropriate education and information can help by purchasing fish from sustainable fisheries and make better decisions by buying only species whose populations are not threatened, what is crucial to save and restore stocks. Some actions could be teaching them to check the label to see what you are actually buying, avoiding juvenile fish or trying different species apart from the most popular to reduce pressure on the stocks (Jeffries, 2017).

Once discussed the current background of the fishing industry in the Mediterranean, the next step is to analyse the specificities of the Mediterranean fisheries.

2.4. Mediterranean fisheries

By marine fishery we mean a collection of fish that inhabit a reasonably well delimited marine habitat. It can be fish of a single species or fish of multiple, but related, species. Fisheries have been a source for food for many mammals, and not only humans.

There was a time when the Mediterranean was considered so vast and inexhaustible that fish extraction could be unlimited. Nevertheless, the continuous increase in anthropogenic

pressure has changed our image over Mediterranean fisheries. As a result, today we encounter that the 78% of the assessed fish stocks are overfished, the fishing fleet is overcapitalised and produces large amounts of bycatch and there are enormous environmental challenges such as climate change, pollution or invasive species. These conditions together make the Mediterranean the most overexploited sea all over the world.

Consequences aggravate each year, as fishermen report less and less catches. This is translated in a reduced activity and low employment levels in many ports (OCEANA, 2016). As a matter of fact, traditional ways of life are disappearing coupled with the social cohesion they used to ensure.

Small-scale or artisanal fisheries

Today, industrial, semi-industrial and small-scale fisheries coexist in the region, although the last ones still predominate along the Mediterranean, and play a fundamental role for the economy of coastal villages.

Small-scale or artisanal fisheries are commonly a large number of family-owned boats of low tonnage (between 1 and 4 tonnes) that require low capital investments and come back to port every day (European Commission, 2020). A low-damaging and very diversified fishing gear is used to extract a wide variety of species (FAO, 2016). Overall, they compose the 84% of the total Mediterranean fishing fleet. In this light, the importance of small-scale fisheries is also visible through employment, especially in rural communities. It records 134300 seafarers onboard fishing vessels (59% of total employment), against the 92975 sailors registered on large-scale fisheries. Although as discussed before, these calculations are ignoring certain activities that are even more important in artisanal fisheries than for the rest (FAO, 2018).

Despite these great scores, small-scale fisheries account for a scarce 24% of the total revenue, about USD 519 million, even though their total economic impact is also estimated to be 2,6 times higher. Notwithstanding, these numbers obscure particular inequalities among regions. With regard to Figure 6 from the Annex, surprisingly, the Central Mediterranean subregion has the highest percentage (75%) of on-vessel employment from small-scale fisheries, where for the rest remains at about 50% or lower.

The most striking feature here, however, is that, in comparison with Figure 7 from the Annex, the percentage of landing value from small-scale fisheries in this region (29%), although being heavier, it is quite similar to other subregions (25%, 15% and 23%).

These marks reinforce our initial statement of the profound asymmetries between northern and southern States. In regions such as the central Mediterranean, where a higher fish extraction is committed by African countries, more artisanal methods with more sailors and lower landing value.

Inside small-scale fisheries, we could also include **recreational fisheries**. They refer to non-commercial fishing activities exploiting marine aquatic resources for recreation, tourism or sport (FAO, 2018). In the Mediterranean region, in fact, there is a long tradition of both, fishing for pleasure and for food.

3. MEDITERRANEAN FISHERIES MODEL

Although marine fisheries are considered to be renewable resources, they have limited capacity and, if excessive and prolonged harvesting takes place, stocks can also be exhausted. Hence, the increasing awareness about the state of the Mediterranean fisheries has led us to develop a logistic-growth model as presented by Schaefer in 1957, to predict and identify the important challenges its stocks face and put immediate solutions.

Any model has two different dimensions:

- The **biological dimension**, representing the natural growth process of the fishery
- The **economic dimension**, describing the economic behaviour of fishermen

In order to ensure a sustainable use of fisheries, these dimensions need to reach a common scope, the **bioeconomic equilibrium.**

6.1. Biological growth, harvest and steady states.

The **stock biomass, S** is a measure of the quantity of the resource existing in a fishery at a point in time, gauged as the aggregate weight of all the individuals composing a fishery. The study of age and growth of marine fisheries is fundamental to collect information on recruitment, longevity, mortality and fluctuations that modify the level of stock. The following equation presents the evolution of the biomass:

$$S_t = S_{t-1} + G(S_{t-1}) \qquad [1]$$

However, under certain environmental conditions, every stock has an upper bound on the size to which population can grow, namely the **carrying capacity, S_{MAX}**. But that is not all, populations also need to maintain themselves above a **minimum viable threshold, S_{MIN}** in order to survive in the wild. Otherwise, deaths and out-migration would exceed births

and in-migration and they would inevitably disappear. This takes us to the generalised logistic function and its representation for the Mediterranean fisheries:

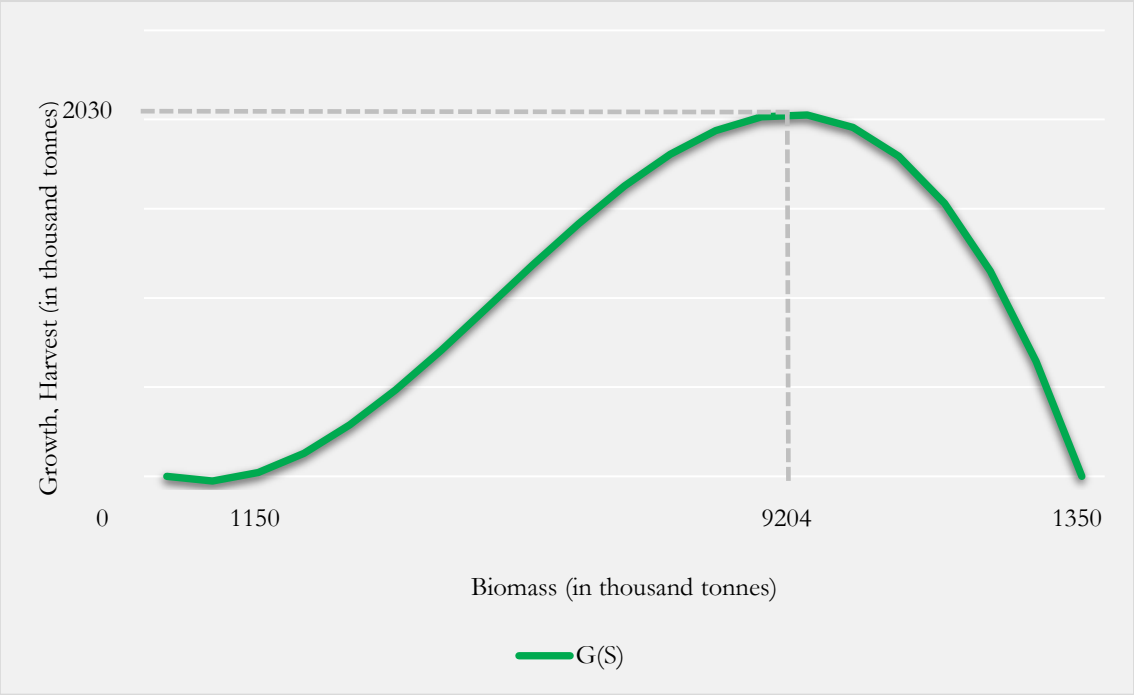
$$G(S) = g\left(\frac{S}{S_{MIN}} - 1\right)\left(1 - \frac{S}{S_{MAX}}\right)S \qquad [2]$$

Where g, is the intrinsic growth rate of the biomass

Figure 2 shows the growth function in equation [2] for the Mediterranean as a single fishery. The parameterization used for this modelling is the following: carrying capacity in thousand tonnes, $S_{MAX} = 13500$; minimum viable threshold in thousand tonnes, $S_{MIN} = 1150$; intrinsic growth rate, $g = 0.099$. Observe that, whenever the biomass is below the minimum viable threshold, $S < S_{min}$, natural growth is negative, $G(S) < 0$, showing than the species is not able to survive. Natural growth is positive whenever $S_{MIN} < S < S_{MAX}$ and the biomass increases according to equation [1]. Therefore, without any external shock or human intervention, the biomass will reach an equilibrium at the carrying capacity S_{MAX} where natural growth is equal to zero, $G(S_{MAX}) = 0$. The carrying capacity is also known as the natural equilibrium of the fishery.

There is a biomass level, called the maximum sustainable yield level, S_{MSY}, for which the natural growth is maximum. With the proposed parametrization, $S_{MSY} = 9204$ and correspond with a natural growth $G_{MSY} = 2030$. In addition, this natural growth is said to have depensation, for low levels of biomass, the growth rate, $G(S)/S$ is an increasing function of the biomass. Observe that, in the model, there is depensation if $S < 9204$ and compensation thereafter. The combination of minimum viable threshold and depensation is call critical depensation.

Figure 2. Mediterranean growth logistic model with critical depensation



Source: Own calculations

When fisheries are exploited, the evolution of the biomass is determined by the relation between the biomass growth and the level of harvest at a certain moment.

$$S_t = S_{t-1} + G(S_{t-1}) - H_{t-1} \qquad [3]$$

Accordingly, depending on if harvest is higher, lower or equal than the biomass growth, the stock biomass will decrease, increase or remain unchanged. A fishery is said to be in biological equilibrium or steady state whenever the biomass natural growth is equal to the harvest and, consequently, the biomass remains unchanged. At a biological equilibrium, the harvest yield can be sustained over time.

For every fishery, there is a certain biomass level (S_{MSY}) at which the natural growth is maximum (G_{MSY}). Therefore, that level will also give us the **Maximum Sustainable Yield (MSY)**, that is, the maximum catch that can be harvested from a fishery over an indefinite period (Tsikliras & Froese, 2019). MSYs for different species in the Mediterranean Sea are calculated by the EU Scientific, Technical and Economic Committee for Fisheries (STECF), the International Council for the Exploration of the Sea (ICES) and obviously the GFCM. Despite this, it may not always be the most economically profitable level of harvest.

In either case, any harvest must be between zero and the Maximum Sustainable Yield to be a **feasible steady-state harvest, $\boldsymbol{H \in (0, G_{MSY})}$**. Albeit circumstances in stocks are

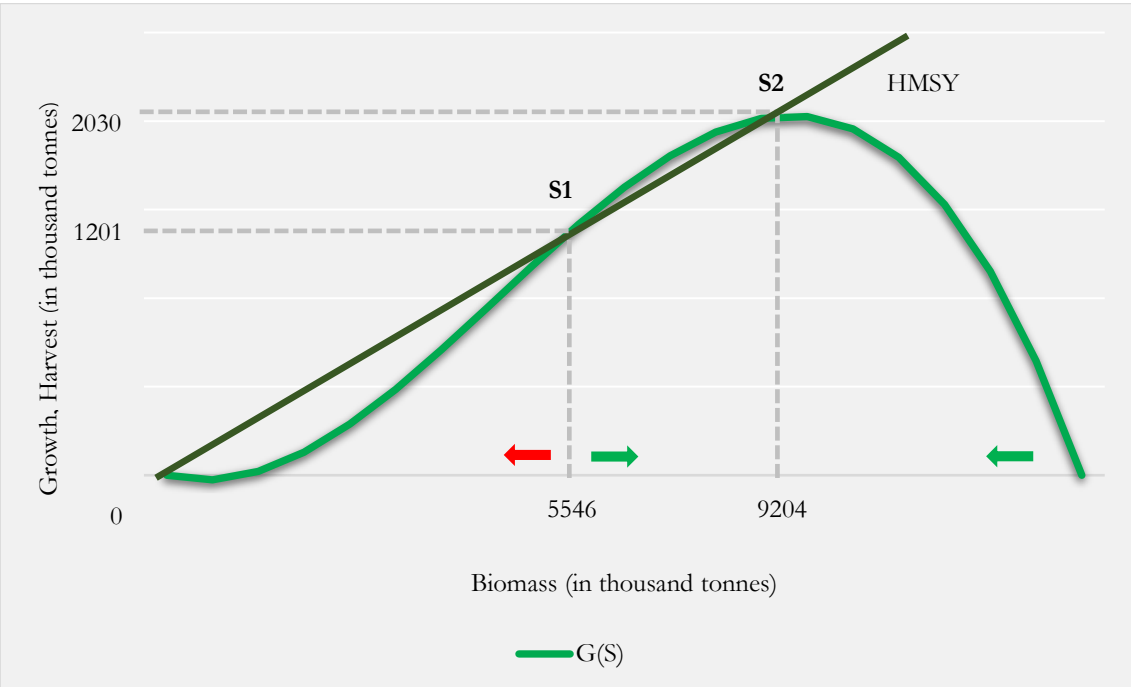
constantly changing and populations are hardly ever in steady-states, this model will consider a continuous harvest reaching an equilibrium.

Although many factors determine the size of the harvest, H, in any given period, we will just consider two of them in our model, **fishing effort, E** and the **size of the resource stock, S**.

$$H = H(E, S) = qES \qquad [4]$$

We use the Schaefer specification, $H = qES$, where q is a constant number (0.0062), called catchability coefficient. Fishing effort can be measured deeming many different dimensions, these include the number of vessels used and their technology or the number of days spent fishing at sea. Ceteris paribus, the higher the level of the stock or effort deployed, the larger the catch.

Figure 3. Mediterranean steady-state harvest



Source: Own calculations

For instance, in Figure 3, HMSY is the harvest function for an effort level $E = 36$ and it is an increasing function of S. The fishery has two feasible steady-states, S1 and S2, each one characterized by a biomass and a harvest (S, H), for S1 $(5446, 1201)$ and for S2 $(9204, 2030)$. So, we have to make a distinction between them. Observe the biomass dynamics around S1; if the biomass is slightly below 5446, the natural growth is below the harvest, and according to equation [3], the biomass decreases and, following the dynamics,

that population will go to extinction. On the other hand, if the biomass is slightly above 5446, the natural growth exceeds the harvest and the biomass increases, and following the dynamics in equation [3] the biomass will increase until 9204, that is, steady state S2. That is, steady state S1 is unstable. The arrows in Figure 3 show these dynamics. Following the same reasoning, it is easy to observe that steady state S2 is stable. Observe that, if the effort level is high enough (H_{MSY},shifts upwards) there will be no steady state and the biomass dynamics will lead the fishery towards extinction in the long-run.

3.1. Open access and the tragedy of the commons

Once studied the socioeconomic characteristics of the Mediterranean and the biological dimension of fisheries, it is time to examine its economic scope.

Open access is the condition where **the absence of enforceable property rights** allows the free extraction of marine resources to everyone. Thus, fishermen have individual property rights to any fish they have already caught.

A large number of independent fishermen taking market price of landed fish as given. As long as fishermen earn positive economic profits, they will continue entering into the fishery or, conversely, leaving when economic profits are negative.

As a result, an equilibrium is only possible when rents have been driven to zero, so that there is no longer incentive for entry into or exit from the industry, nor for the fishing effort on the part of existing fishermen to change:

$$G(S) = H \qquad [5]$$

$$Net\ Benefits = Benefits - Costs = PH - wE = 0 \qquad [6]$$

where P is the resource market price; and w is the cost per unit of effort

Nevertheless, this cannot last indefinitely. After some time, the stock biomass would decrease and fish would become harder to catch, so that the cost per fish caught would rise. This profit squeeze means that fishermen will have economic losses rather profits, so they will leave the fishery and so the process described goes into reverse, with stocks rising and effort falling.

However, if stock and effort oscillations were quite large, the population may be driven down to a level from which it cannot recover, and the fishery would collapse.

Tragedy of the commons: ***Although reducing the total catch would beneficial for all fishermen in order to allow fish stocks to recover and grow, it is not rational for any fisherman to individually restrict fishing effort over common property resources.***

3.2. Mediterranean overexploitation

Marine resources have been barely managed in the Mediterranean in the last twenty years, and they have been exploited under a free access regime (Lucchetti, et al., 2014), what has had strong implications for the fishing industry and Mediterranean fisheries in general.

3.2.1. Overcapitalization

It occurs when the amount of harvesting capacity in a fishery exceeds the amount needed to harvest the desired amount of fish at least cost. The Mediterranean fishing fleet is formed by approximately 82000 vessels (European Commission, 2020). Almost 7500 of them are operating, although these numbers should be considered to be underestimated, given the lack of data (FAO, 2018). There are simply **'too many boats chasing too few fish'**.

a) **Fleet composition:** Greece owns the largest fishing fleet in the Mediterranean (14,987 vessels), what makes the Aegean Sea subarea and the Eastern Mediterranean subregion gather the 19.2% and 35.3% of the total Mediterranean fleet, respectively. Tunisia stands in second place with 13124 vessels, accounting the Central Mediterranean for the 30.5% of the total fleet. Although the Mediterranean subregion with the lowest percentage of fishing vessels is the Adriatic Sea (14.2%), its northern subarea accounts for 11.82% of them and Italy owns 11255 boats. The remaining 20% of the Mediterranean vessels are located in the Western subregion, where some areas such as the Alboran Island, Corsica or the Balearic Islands do not reach a 0.5%.[1]

b) **Fishing fleet age:** Retaining and using old boats could jeopardise the fishermen's safety and fishing productivity. Additionally, they must constantly be repaired and transformed to continue operating. Thus, this leads to a steady accumulation of extra fishing gear, spare parts or paint layers which produces heavier vessels with higher fuel consumption and an unimprovement in working conditions coming

[1] The GFCM displays common information for its whole area of application, that is, including the Black Sea. In this sense, Turkey has the largest fishing fleet with a 17.8%, however, considering evidence from its fishing activities we reckon that the number of Turkish fishing vessels operating in the Mediterranean in isolation is much lower than in other countries.

from the lack of technological advances (Food and Agriculture Organization of the United Nations, 2016). On the contrary, the replacement of vessels may increase the fishing capacity and if no rules prevent from doing it (FAO, 2018).

In average, more than half of the Mediterranean fishing fleet is older than 35 years old. Among others, we can find countries with high fishing capacity such as Italy (36 years old) or Greece (37 years old) above that level. On the opposite side, Tunisia (28 years old) or specially Argelia (19 years old) at significantly lower levels.

c) **Fishing capacity:** It is the ability of a stock of inputs (capital) to produce output (effort or catch). It is commonly measured in terms of two vessel characteristics (Lindebo, 2003):

- **Gross tonnage (GT)** is a function of the moulded volume of all enclosed spaces of the ship (International Maritime Organization, 1982). Italy, Egypt, Tunisia and Greece alone, with 143,535, 121,953, 104,535 and 71,085 GT respectively, account for more than 50% of total gross tonnage. Other national fleets with more than 50,000 GT are Algeria or Spain.
- **Engine power** is the total power that can be obtained from each engine used to propel a fishing vessel, measured in kilowatts (kW). This time Italy continues having the most powerful fleet (918,885 kW), followed by Tunisia (596,060) and Algeria (507,614), most probably due to their younger fleet. Greek and Spanish fleets who are older and Egyptian, from which there are no data have also more than 300,000Kw.

d) **Fleet segment:** It is the combination of a particular fishing technique category and a vessel length category. As it is observed in table 1, the GFCM makes a distinction among the different vessel categories:

Polyvalent vessels combine small-scale vessels using passive gear with and without engine and other polyvalent vessels. As predicted earlier, the sea is filled with polyvalent vessels across all regions, but specially in the Central Mediterranean, where the percentage of small-scale fisheries is higher (87.5%).

Trawlers group contains common trawlers as well as beam trawlers. They are of greater importance in the Adriatic Sea (15%) and in the Western Mediterranean (13%), where the presence of **purse seiners and pelagic trawlers** is also slightly superior to the rest subregions (11.6%), arguably owing to the higher importance of large-scale fisheries using active gear. Finally, **other fleet segments** include

longliners, tuna seiners or dredgers and the subregion using a greater percentage of them is the Eastern Mediterranean (17.7%).

Table 1. Group of fleet segments by GFCM subregion

Group of fleet segments	GFCM subregions				Mediterranean Sea (%)
	Western Mediterranean (%)	Central Mediterranean (%)	Adriatic Sea (%)	Eastern Mediterranean (%)	
Polyvalent vessels (all lengths)	72,6	87,5	74,6	73,2	**77,8**
Trawlers (> 6m LOA)	13	5,1	15	6,3	**8,6**
Purse seiners and pelagic trawlers (> 6m LOA)	11,6	3	3,4	2,7	**4,8**
Other fleet segments	2,8	4,3	7	17,7	**8,8**
Total %	**100**	**100**	**100**	**100**	**100**

Source: Own calculations based on General Fisheries Commission for the Mediterranean, 2018

While fleet overcapitalization gives an idea of the high amount of effort applied in the Mediterranean, the abundance of small-scale vessels has a significant effect on the **number of days spent at sea**. As fishermen in these boats commonly live close to the coast, a wide majority of them return to port every day and land a mix of several species. In fact, as most of them are less than 10 metres long, boats are not required to register catches.

Fishing subsidies

Subsidies are government or public bodies interventions that modify and support the potential profits of the fisheries industry (Food and Agriculture Organization of the United Nations, 2002). In light of this, the fisheries industry can receive benefits in terms of any type of input, for instance, fuel tax rebates, provision of landing site facilities, investment grants, no resource access fees or market price support. Thus, subsidies are essential to guarantee that governments find a sustainable balance between supporting production and fisheries conservation (World Trade Organization, 2020). Nonetheless, if inaccurately delivered, they can contribute to overcapitalization and overfishing.

The case of the Mediterranean Sea is not exempt from this kind of subsidies and the EU is liable for it. Although the European bodies resolved to reform the Common Fisheries Policy and progressively remove subsidies to fishing vessels, financial support continues being allocated through the European Maritime and Fisheries fund (EMFF), which assists member States to co-finance operational programs and projects mainly for small-scale fishermen (OCEANA, 2020).

3.2.2. The most overfished sea in the world

During the '70s, the development of more sophisticated fishing gear along with a growth in human population and fish consumption made a lot of fish stocks begin to decline (OCEANA, 2016). The scarce management of marine resources, translated mainly by the lack of pertinent enforceable regulation, has allowed fishermen to continue fishing without restricting their efforts for many years. Accordingly, many individuals have kept exploiting fisheries above the level they are believed to be biologically sustainable in the long-term. Despite in 2014, the 88% of the assessed Mediterranean stocks were overexploited, the latest studies show this percentage has decreased to 78% (FAO, 2018). Furthermore, evidence from the European stocks in the Mediterranean revels that **only 9% of fish stock assessed have been fished at levels below the H_{MSY}** (European Commission, 2020)

Nevertheless, some captures in the Mediterranean, as in other seas, are unreported due to several reasons, and is responsible of augmented overexploitation.

IUU fishing

Illegal, unreported, and unregulated (IUU) fishing is liable for the depletion of fish stocks, destruction of marine habitats, undermining of righteous fishers and weakening of coastal communities (European Commission, 2019). Hence, it remains one of the greatest challenges to confront overfishing in the Mediterranean Sea (UNFAO, 2020).

- **Fishing is illegal** when vessels have no authorisation, operate against conservation and management measures adopted by the GFCM or ICCAT or violate national and international obligations.
- **Fishing is unreported** when it is not reported, misreported or reporting infringes the procedures of GFCM or ICCAT.
- **Fishing is unregulated** when vessels operate without nationality or unauthorised nationality or when fishing activities jeopardise fish stocks.

IUU fishing appears most commonly in countries with poor governance, particularly in developing regions with a lack of capacity and resources for effective monitoring, control and surveillance (MCS).

In 2017, the GFCM, following the steps indicated in the Agreement on Port State Measures (PSMA), elaborated a Regional Plan of Action to prevent, deter and eliminate IUU fishing in the Mediterranean Sea. This promotes cooperation among the CPCs (or States) by providing comprehensive, effective and transparent measures to take action, emphasizing special requirements for developing states. The agreement basically lies down minimum standards that need to be applied by port states receiving fishing vessels into their port. Accordingly, they must ensure that no vessel engaged in IUU fishing lands fish, but also enters in the ports (UNFAO, 2019).

In this regard, the GFCM is also in charge of preparing a list of vessels that are presumed to have carried out IUU fishing in the Mediterranean. Currently data record the apparition of 65 vessels (GFCM, 2019). Likewise, (OCEANA, 2019) has also contributed with the provision of several case studies and recommendations concerning suspected bottom trawlers operating in existing Fisheries Restricted Areas (FRAs) or suspected cases of foreign fishing vessels active in waters under the jurisdiction of a country.

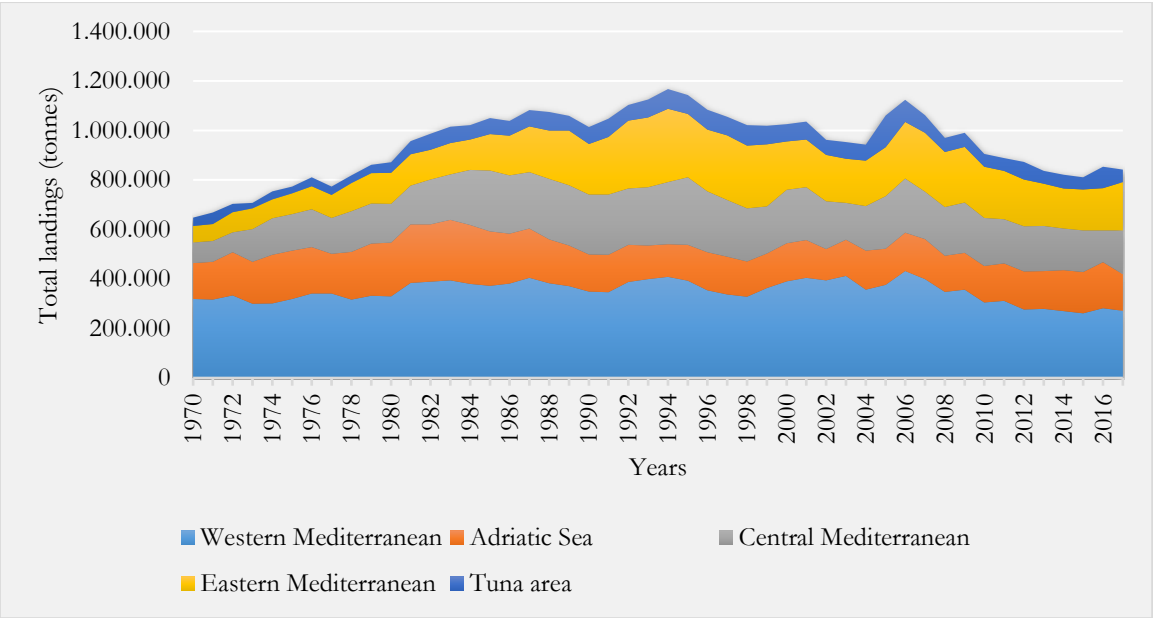
Recreational IUU fishing

Almost 48% of non-professional fishers admitted selling their catch, what must be considered illegal fishing too. Overall, illegal and recreational fishing represent the 40% and 20% of commercial fishing in the Mediterranean. The potential economic values of illegal and recreational fishing catch are considerably higher than for commercial fishing (Lamine, Di Franco, Romdhane, & Francour, 2018), what threatens the livelihood of honest fishermen and enhances food insecurity for consumers, as they do not really know the origin of fish.

Figure 3 displays the reported landings during the 1970-2017 period by subregion. Although evidence from the last two years shows an increase in total catch along the Mediterranean with respect to previous periods, it is quite far away from the levels achieved since the eighties until the beginning of the 21st century. More than 1,160,000 tonnes were reported by the GFCM back in 1994 while now harvest is below 850,000 tonnes. To this should be added a considerable amount of all kinds of IUU fishing that, according to certain sources such as (Sea Around Us, 2016), it may have actually accounted for even twice the amount recorded in some periods. This gives us an idea of the tremendous

pressure placed during decades and the still low biomass level in the Mediterranean stocks at present. This introduces a new distinction in our model.

Figure 3. Reported Mediterranean landings by subregion



Source: Own calculations based on General Fisheries Commission for the Mediterranean

3.3. Current biomass level of the Mediterranean stocks

For the time being, we have asserted that the higher the effort applied for fishing, the larger will be our fish capture. This argument might have validity in the short-run in certain cases. Notwithstanding, the steady-state equilibrium in the long-run does not only depend on the level of effort exerted, but also on the initial level of biomass. Nowadays, as we have observed, many Mediterranean stocks are being overexploited and are on the verge of depletion, however, the situation is still reversible. In fact, a recent biomass level analysis developed by the GFCM in 62 stocks showed that 47% of those stocks have a low biomass (<33% SMAX), 31% have an intermediate biomass and 22% have a high biomass (>66% SMAX).

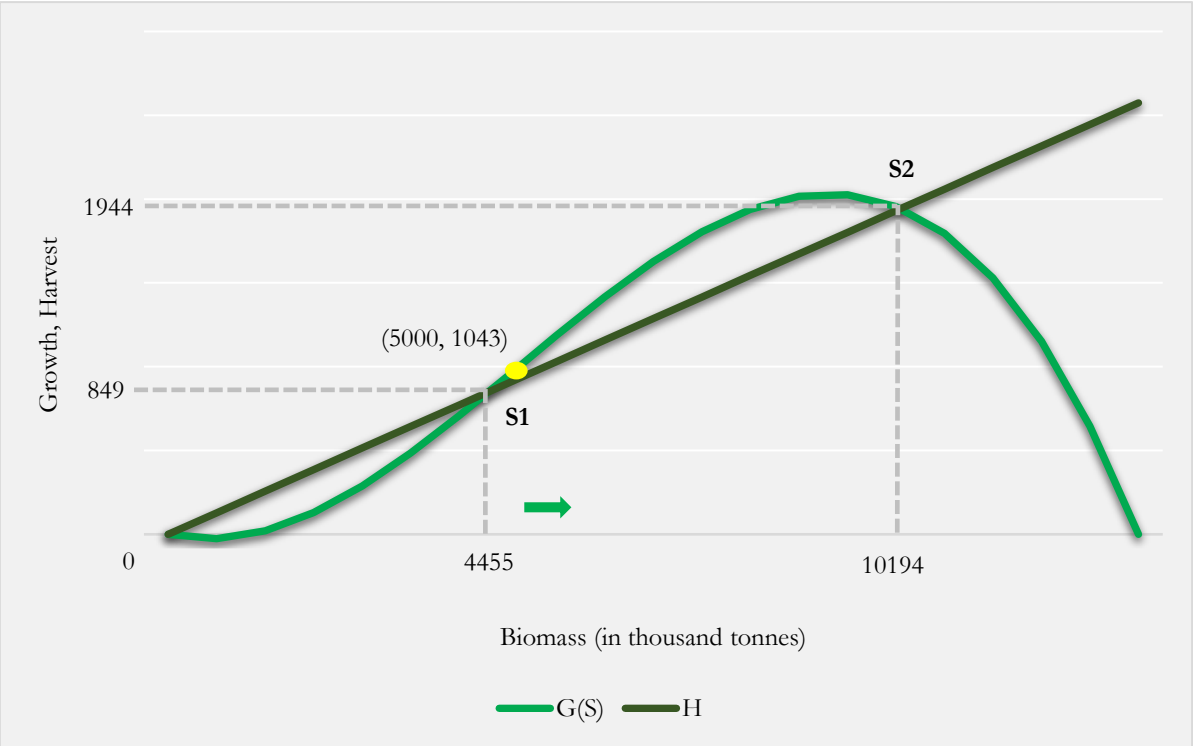
Most stocks in the western, central and Adriatic Mediterranean are at low or intermediate levels. Albeit not many stocks have been assessed in the eastern Mediterranean, still half of them were at low levels and the rest at high levels (FAO, 2018).

As it can be observed from Figure 4, the current biomass in the Mediterranean is about 5000 thousand tonnes. This point is situated above the unstable steady-state harvest level

[2] Tuna catches are not allocated according to the GFCM statistical divisions, but according to the ICCAT division.

S1, where the fishery growth (1076) is greater than the amount harvested (1043). Accordingly, the Mediterranean stock would be expected to recover slowly and reach the steady-state level, S2, in the long-run if the current level of effort E=31 is sustained.

Figure 4. Mediterranean current biomass level



Source: Own calculations

After decades of overfishing, the Mediterranean stocks seem to have started recovering gently during last years and leaving overexploitation trends. This gives hope for the sea to be fished at biologically sustainable levels in the future, although it will vary depending on each fish species.

3.4. State of the Mediterranean species

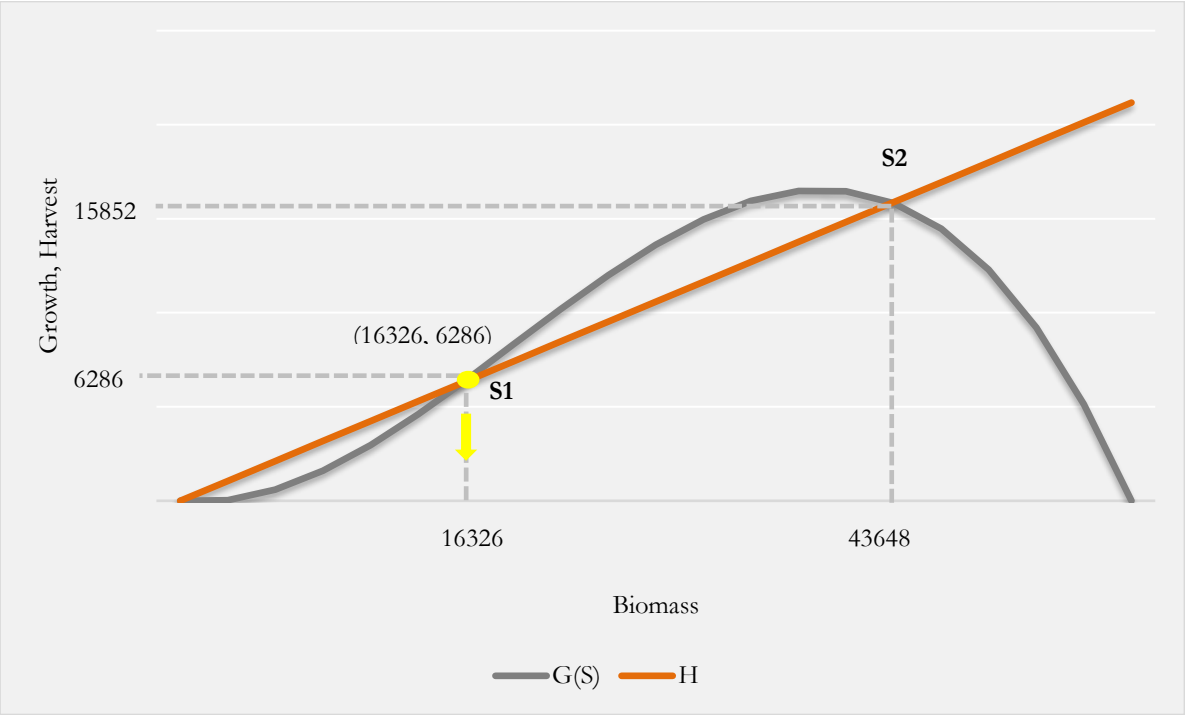
All demersal and pelagic priority species are overfished in the Mediterranean (Bourdouresque, et al., 2017), however, the stock levels of the former ones are in greatest danger. According to the (FAO, 2018), **European hake (Merluccius Merluccius) is the most overfished species**, whose trend mortality is five times greater than the target level and almost thirteen times in the Gulf of Lion (western Mediterranean). The mortality rates of other species such as red mullet, anglerfish or blue whiting, have also been more than six times higher than the MSY.

Regarding the biomass status of species, most stocks of deep-water rose shrimp have a low biomass, while **none of European hake stocks have a high biomass status**, what confirms our intuitions about the initial biomass level. In contrast, other stocks of demersal species such as deep-water rose shrimp, blue and red shrimp and even red mullet, the second most overexploited species, generally display decreasing trends. Finally, red mullet, giant red shrimp and blue and red shrimp stocks, for their part, do not have such a dramatic situation and for the moment (See table 1 from the Annex).

Thus, in this section a new model for European hake in the western Mediterranean subregion will be presented in order to illustrate the current challenges faced by this fish species and provide different solutions to deal with the problem.

As figure 5 shows, the current level of biomass is at 16326, exactly at the unstable steady-state harvest, where growth is equal to harvest (6286). This means that, with the given catchability coefficient q=0.007 and maintaining the current level of effort E=55, biomass will stay at S2 in the long-run.

Figure 5. European hake in Western Mediterranean



Source: Own calculations

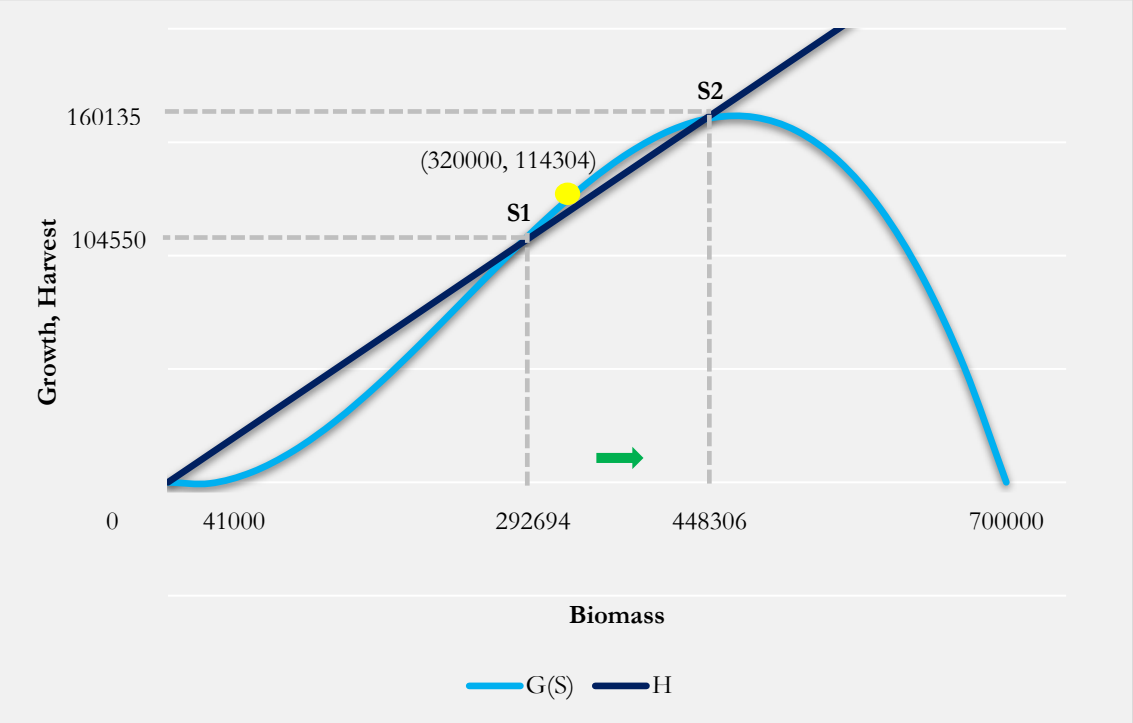
This kind of model is most suitable for non-migratory species that reside in particular locations. Hence, demersal or bottom-feeding populations such as European hake are better explained than populations of pelagic fish such as Atlantic bluefin tuna, sardine or

European anchovy, which are characterised by a major migratory behaviour (Perman, Ma, McGilvray, & Common, 2003). Nonetheless, as a semi-enclosed Sea, the Mediterranean does not give room for vast migrations.

In this light, despite stocks of sardine (Sardina pilchardus) or European anchovy (Engraulis Encrasicolus) are still exploited at levels considered to be biologically sustainable and its preservation is still quite encouraging, they have shown increasing exploitation trends during last years. In fact, they are also the two most important species in terms of catch volume in the Mediterranean with the 33% of total landed tonnes and especially in the Adriatic Sea, where their landing tonnes account for more than 60% of the subregion. This makes its conservation is crucial, and even more if we consider potential threats they could experience in a near future and that will be considered below.

Figure 6 displays the model for small pelagic in the Adriatic Sea. As it can be observed, this fishery is not so overexploited as the previous one and its current level of biomass is still at 320000. At this point, growth (118210) is larger than harvest (114304) for the current level of effort E=47, therefore, it is expected in the long-run to achieve the steady-state equilibrium S2 if effort does not continue increasing as during previous years. At this point, harvest would be 160135, quite close to the MSY and the stock biomass 448306, a biologically sustainable level.

Figure 6. Small pelagic in the Adriatic Sea



Source: Own calculations

Although substantial improvements have been achieved in the quantity of assessed stocks as well as in our knowledge about their status, there are a lot of stocks still unassessed all over the Mediterranean that could be crucial for future prospects. For the moment, in spite of the fact that most stocks are still overexploited, the number of overexploited stocks seems to be diminishing.

4. EXTERNALITIES

Externalities are unintended changes in an ecosystem services that arise when an activity affects other activities in the ecosystem. Externalities in the Mediterranean ecosystem have strong implications on the status of the fishery stock and, thus, on its extraction. Generally, externalities impose a cost on fisheries that can be contained either in the benefits function i.e. bycatch or in the production function such as destructive fishing gear. This section will differentiate externalities caused by the fishing sector itself, but also from other external sources.

4.1. Fishing sector

These occur when fishers extract resources without considering the external effects it may impose on others.

Bycatch and discards

When fishermen carry out fishing operations, they may also accidentally catch other species to the ones they originally targeted, that is what we call bycatch. It can consist of **other commercial species**, **non-commercial species** or **incidental catch of vulnerable species**. This is considered to be a negative externality for two main reasons: it is produced a potential loss of the Mediterranean marine biodiversity and it contributes to the shrinking of fish stocks (FAO, 2018).

In this regard, species have two possible destinations: to be sold in the market; or to be discarded at sea during the fishing operation. Even though discards are not usually considered in fishery models, it may account for a large proportion of fishing mortality.

A great proportion of the Mediterranean discards comes from juvenile fishes. These comprise a group of immature fishes whose biomass is far from achieving its maximum size and have not been able to spawn yet. Accordingly, the current stock biomass is still quite reduced compared to the potential biomass they could achieve in the future and prospective economic profits are, thus, reasonably limited. A lot of fishes are also discarded owing to their low commercial value. This might be caused because they are not included

in the common diet of the region's population and do not entail substantial benefits in the market (FAO, 2018). If landed, they are usually allocated to feed other species in aquaculture or as fertilizer for crops. Albeit representing a narrow part of total discards, the lack of space on board is fairly more often in the Central Mediterranean than in the rest of the subregions. As previously analysed, it may be due to the prominence of small-scale fisheries in the subregion that wages a fishing fleet composed of many small vessels.

Discards have been recognised as a major problem not only for the ecosystem, but also for the Mediterranean economy. They are a waste of natural resources that may provoke deep changes in the overall structure of the trophic web and marine habitats. On the whole, Mediterranean discards count for 230,000 tonnes, what represents approximately 18% of the bycatch. On account of that, the Common Fisheries Policy has decided to impose the obligation to land all catches and prohibit the discarding of species that are subject to catch and minimum size limits (FAO, 2018).

Fishing gear

Depending on the type of fishing gear used, resources are destroyed at one extent or another. Catching demersal fishes generally produces higher proportion of discards, which can be up to 50 percent of the total catch in some cases. Probably, the most common method for resource harvesting this type of fishes is bottom trawling, also the most important gear in terms of economic value. Its average discard value is 33% of total catch, as its catch mixes different species from the seabed. High impact specially in western and Adriatic Sea. Other gear not so extended could be beam trawling, dredgers (molluscs, decapods and equinodems, Adriatic Sea clams) or demersal longliners, which are probably the less harmful fishing method, producing minimal discards below 15%.

Another sort of longliners are also used for extracting pelagic species. They are considered to be highly selective for large pelagic like swordfish or bluefin tuna. However, they produce a high incidental catch of a large number of seabirds, turtles and marine mammals. For capturing smaller specimens such as sardine and anchovy, pelagic trawling and specially purse seine are used. This is the most important method in terms of volume in the Mediterranean. Targeted species usually represent more than 90% of the catch for purse seiners because of the low diversity of species and their marketability. This implies that, although discards may be low as percentage, quantities are high.

Finally, small-scale fisheries, as already analysed, target many different species and use a great variety of fishing gear (e.g. gillnets, trammel, nets, longliners, traps, pots and other

small-scale gear) and often switching among them during a fish trip. This makes low discarding, generally below 15% of total catch (FAO, 2018).

Seabed function

Seabed is often destroyed in many fisheries due to the use of harmful fishing gear. Trawling for instance, can cause the demise of thousands of km2 of endemic species of seagrass such as Posidonia, considered of particular importance for the Mediterranean Sea (Díaz Almela & Duarte, 2008). This results from the fact that they provide important ecological services such as water filtration or CO2 storage, while they also serve as spawning grounds and protection or nursery areas and, habitat in general, for many different fish species. Eventually, it can be also said that they are the source of food for many herbivores and, thus, sustain and vital part of the Mediterranean food web (Ruiz Fernandez, Enríquez, & Bourdouresque, 2009). All in all, the use of harmful fishing gear can cause such an immense damage to seabed species that can cause the direct collapse of their populations.

Incidental catch of vulnerable species (VU)

Species are vulnerable when the best available evidence indicates that they are facing a high risk of extinction in the wild (IUCN , 2012). In the Mediterranean Sea, bycatch mortality represents a particular conservation concern for large marine vertebrates, especially for sea turtles and elasmobranchs (sharks, rays…), which represent the 80% and 16%, respectively of these incidental reported catches. The remaining 4% of the incidental catches mainly correspond to seabirds and marine mammals (cetaceans and monk seals). Longliners are the primary responsible for incidental catches of vulnerable species in all Mediterranean subregions, but particularly in the western and central Mediterranean (FAO, 2018).

4.2. Habitat degradation

Environmental conditions in the Mediterranean are being profoundly altered by externalities coming from a range of sources irrespective of the fishing industry:

Climate change

The Mediterranean Sea structure has undergone deep transformations during the last 10000 years, having important implications for nature and humans (Gofredo & Zvy, 2014). Nonetheless, climate change resulting from human action is expected to disturb Mediterranean ecosystems as it has not happened since the last glacial period (Randone et al., 2017). Average annual temperatures are now 1.5ºC higher than during the preindustrial period and above current global warming trends (+1.1ºC). In 2016, 160 countries ratified

the Paris Agreement to reduce the future prospect increase in 2.2ºC by 2040 so as to maintain the ecosystem within its boundaries (Guiot & Cramer, 2017).

Mediterranean warming is also visible in water temperature, what can modify the species composition and abundance. As an enclosed sea, migration of species from the Mediterranean to cooler areas is quite limited (MedECC, 2019) and species do not have enough time to adjust their life cycles to these abrupt variations. In this sense, while cold-water species are becoming endangered and or even extinct because, warm-water species are replacing them. Not only fish species are threatened by climate change, but seagrass meadows, sponges or molluscs are highly vulnerable to seawater warming. This causes degradation of marine habitats and triggers innumerable fatal consequences.

When temperature in seas rises, the capacity of water to retain so much oxygen is impaired. Moreover, additional oxygen is demanded by living organisms in order to survive (IUCN, 2019). This process is called **deoxygenation** and it implies a reduction in the oxygen available for marine life, especially in the upper strata, where species richness and abundance are highest.

Notwithstanding, challenges do not end here. Indeed, as **Marine pollution** disrupts the ecosystem with millions of pounds of trash and other chemicals, causing, among others:

Ocean acidification

When too much carbon dioxide (CO2) is dissolved in oceans water, a series of chemical reactions reduce pH in seawater and produces a phenomenon known as ocean acidification. This dissolves the carbonate structure (e.g. shells and skeletons) of species such as corals, shellfish or sea urchins and some of these species form essential habitats that sustain the entire ecosystem by providing shelter, nurseries, and feeding grounds to many other important commercial species. Besides, acidification might also avoid certain types of plankton to form their shells, what would disrupt the whole food web as most fishes feed on plankton (MedSeA, 2014). Conversely, other organisms absorbing C02 to carry out the photosynthesis like algae and seagrasses may benefit from higher CO_2 levels.

Eutrophication

The huge deposition of nutrients coming from fertilizer run-off, sewage, animal waste, aquaculture and nitrogen from burned fossil fuels produce an excessive growth of plant life, particularly algae, in a process known as eutrophication. The loss of oxygen fosters the

accumulation of nutrients in the water and aggravates more the situation, entering in a deteriorating loop with difficult solution (IUCN, 2019).

It is quite remarkable the case of the Mar Menor. The landscape of this coastal saltwater lagoon in Murcia, Spain, has been suffering the impact of mining, excessive coastal urbanization and tourism and intensive agriculture for many years, leading to the accumulation of nitrates in water. Well, this situation broke out when in September 2019 the cold front took place (European Parliament, 2019), when about 80% of Mar Menor ran out of oxygen and thousands of fishes and crustaceans died stranded in the shore.

Plastic pollution

The Mediterranean is one of the seas with more plastic pollution in the world. Plastics account for 95% of the waste in the open sea, on the seabed and on beaches. Plastics can cause injuries, lesions and deformities and prevent animals from escaping from predators, swim or feed. Subsequently, many fishes die from hunger, drowning or because they become easy prey. Damage infringed by macroplastics such as the one coming from lost or discarded fishing gear is more visible, however, microplastics (fragments of less than 5mm) have been tested to cause the greatest impact on marine life (Alessi & Di Carlo, 2018).

Evidence from (Romeo, et al., 2015) shows 18% of tuna and swordfish have plastic debris in their stomach. Others such as anchovies eat plastic by mistake due to its similar smell to krill. Ignoring birds or marine mammals, in total, 60 fish species have been recorded to have swallowed plastic (Alessi & Di Carlo, 2018). Ultimately, this means Mediterranean consumers ingest thousands of pieces of microplastic each year, with still unknown effects on human health (ten Brink, Schweitzer, Watkins, & Howe, 2016).

4.3. The wealth of Mediterranean biodiversity

Broadly speaking, biodiversity refers to variety of life on earth. However, we use to relate it with all the animal, plant, bacteria or fungi species in one region or ecosystem (National Geographic, 2011).

In general, ecosystems with higher biodiversity tend to be more stable and have greater resilience to environmental damage (Perman, Ma, McGilvray, & Common, 2003), as the increased complexity of the marine ecosystem results in a larger number of species with greater interactions among individuals. Hence, populations have the capacity to recover and grow faster.

Fortunately, the Mediterranean is one of the 25 top global biodiversity hotspots. As long as it represents just 0.7% of the world ocean surface area, it harbours 17000 species in total, which comprise the 7.5% of the world's marine fauna and the 18% of marine flora, with 28% of endemic species (RAC/SPA, 2020). This provided us a relatively high intrinsic growth rate for our model that derived in a higher fish productivity and ecosystem resilience.

Nowadays, the Mediterranean biodiversity is, however, under serious threat. Its waters are inhabited by nearly 1000 alien species, being considered the biggest biological invasion of the planet (Bourdouresque, et al., 2017). Alien species are not the same as invasive species. The former might be an intentionally or unintentionally introduced non-native species (animals or plants) that has established population and spread into the wild in the new host region. Meanwhile, Invasive Alien Species (IAS) are those alien species which become agents of change in the structure of other ecosystems, increasing in abundance and distribution and threatening autochthonous biodiversity (IUCN, 2018). Currently, more than 5% of the marine species in the Mediterranean are considered to be allochthonous or non-native, whilst about 13.5% of those are classified to be invasive (Otero et al., 2013).

It is difficult to predict when alien species will become invasive, as it does not always happen (Otero et al., 2013). However, they are one of the main causes of biodiversity loss in the Mediterranean Sea along with habitat degradation, displacing autochthonous species, reducing community biodiversity and producing trophic chain shifts. In the following section, we will analyse the principal anthropogenic factors triggering biological invasions in the Mediterranean Sea:

Suez Canal

The Canal of the Pharaohs was already designed in ancient Egypt as a corridor to connect the Red Sea with the Nile, and therefore, with the Mediterranean Sea. However, it was not until 1869 when the Suez Canal was constructed in order to shorten the maritime trade routes between Europe and Asia. Since that moment, the Canal has been continuously expanded and deepened. Until 1966, there was a natural water barrier with a lower percentage of salt impeding migration of species from one side of the canal to the other. Notwithstanding, when salinity started to level and the barrier faded, many invasive species started migrating.

There is a minimum amount of Mediterranean native species moving to the Red Sea, while most of them have done in the other direction. Among the reasons underpinning this

situation reveal that the Red Sea is higher than the Mediterranean, so water flows towards the latter, which is also richer in nutrients and has less salty waters. In addition, the Mediterranean, thanks to its warm waters it is ideal for all types of foreign living organisms.

Since then, Lessepsian species, as these invasive species caused are named on behalf of Ferdinand de Lesseps, the builder of the canal, have been recorded to be more than 80 (Otero et al., 2013). Initially, they were concentrated on the Levantine Basin, but some of them have gradually escalated westwards and northwards (Bourdouresque, et al., 2017).

Ballast water

The introduction of steel-hulled vessels at the end of the 19th century implied the use of water as ballast to stabilize vessels at sea and compensate for weight in cargo loads. Despite being essential for modern shipping, this system requires water to be pumped in and out, relocating a plethora of marine species from one ecosystem to another. These include bacteria, microbes, small invertebrates, eggs, cysts and larvae that provoke serious ecological, economic and health problems (International Maritime Organization, 2020).

Although Mediterranean ships have carried these alien species for centuries, its harmful effects are beginning to be disturbing due to the growth of shipping routes and habitat degradation (2005 FLAGELLA). In an effort to limit the impact of ballast water, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) in order to manage ship's ballast water and remove, render harmless or avoid the uptake or discharge of aquatic organisms and pathogens within ballast water and sediments.

Marine biofouling

It refers to the accumulation of algae and invertebrates on ship-immersed surfaces such as hulls or propellers as well as on other in contact with water such as anchors and water pipes. Once the vessel has arrived at its destination, the stowaways and their offspring may colonise new areas (Jackson, 2008).

Besides, if not cleaned frequently from organisms, the surface may become rough and impose additional resistance and therefore, increasing fuel consumption and greenhouse gases emission. Apart from that, the continuous concentration of organisms also favours the deterioration of coatings and hulls as a whole, what entails further economic costs (Global Invasive Species Programme (GISP), 2008)

Other important causes of biological invasions in the Mediterranean are assigned to **shellfish farming, aquarium trade, fishing baits and waterways crossing watersheds** (Bourdouresque, et al., 2017).

4.4. DISTURBANCES ON THE FISHERY MODEL

The mentioned externalities have strong implications for Mediterranean fisheries and there are no indications that the situation in most of them will reverse. In fact, it will exacerbate with greater intensity if measures are not taken. For this reason, the previous models for European hake and small pelagic are expected to be subject to changes:

- The maximum size of the stocks depends on the particular environmental circumstances of the particular environmental circumstances that happen to prevail (Perman, Ma, McGilvray, & Common, 2003). Nonetheless, the rise in sea water temperatures and ocean acidification would impair the marine milieu and, hence, **dwindle the stocks' carrying capacity, *SMAX*.**
- Likewise, the demise of shelters in the seafloor induces higher predation and more vulnerable habitats, coupled with the loss on biodiversity would incur again in a reduction in the carrying capacity, and a **decrease in the intrinsic growth rate, *g*.**

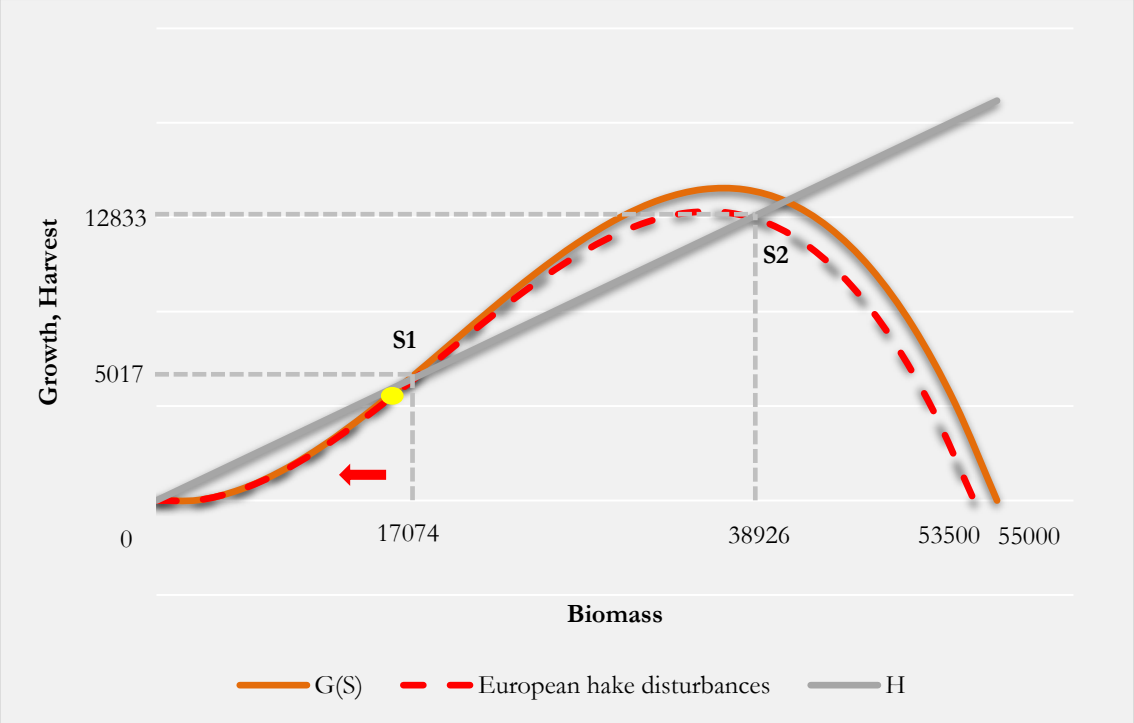
All the same, these shocks have different implications depending on fish species, Mediterranean subregions and other factors.

Although European hake might not be the most susceptible species to climate change, temperatures in certain parts of the western subregion such as the Balearic Islands have been identified as one of the regions with the maximum increase (MedECC, 2019). As a demersal species, seabed destruction might imply the demise of the hake's habitat and bycatch wreak havoc for them. Additionally, the expansion of plants and algae due to eutrophication would cause an overlap in the food chain in favour of herbivorous species against predators such as the European hake. Thus, this would aggravate the already delicate situation of the species previously observed in Figure 5.

Now, Figure 7 gathers the effects of these externalities. The carrying capacity and the intrinsic growth rate have decreased from 55,000 to 53,500 and from 0.099 to 0.097 respectively. As a result, with the initial level of biomass of 16326, the fishery is no more at the unstable steady equilibrium, but below it. Harvest for the next period will continue being 6286, however, population growth has decreased to 6085. If effort levels are, thus,

maintained at E=55, the population of European hake, with great economic importance in the western Mediterranean, will go to extinction in few periods

Figure 7. Disturbances for European hake in the western Mediterranean subregion



Source: Own calculations

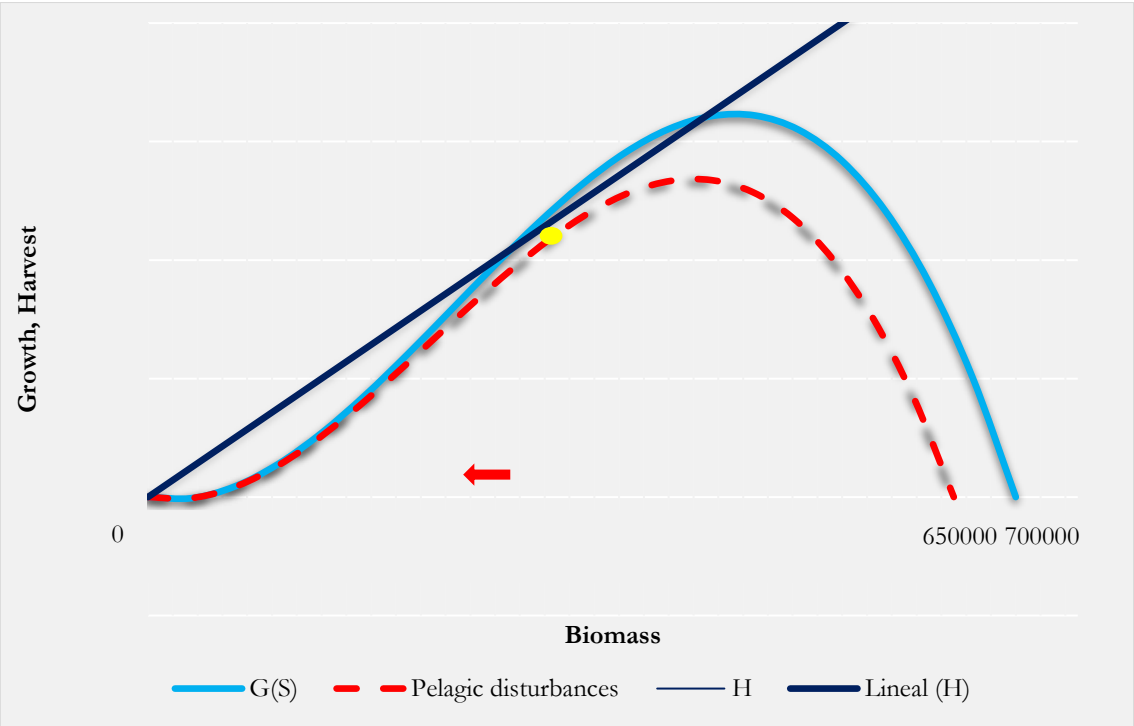
Moreover, a study conducted by (Corrales, et al., 2018) in the western Mediterranean, where climate change and biological invasions are most present, states that reducing fishing effort could not be enough to preserve this Mediterranean species.

On the other hand, Small pelagic such as sardine and anchovy are very vulnerable to extreme temperature changes. This affects their whole biological process through spawning, migration patterns, interactions between fish populations and even fish growth and survival (ClimeFish, n.d.). Besides, even though the short lifespan of sardine and European anchovy allows them grow faster, their reproduction could be compromised by the destruction of spawning areas. Landings of sardine and anchovy have dropped during last decades by common action of overfishing with climate change and acidification (MedECC, 2019) and its effects are expected to deepen.

Figure 8 collects the predicted model gathering these disturbances for sardine and anchovy in the Adriatic. Small species require less time to grow and become mature and, in situations of food shortage, they have also more facilities to find survival. However, it also leads to shorter reproduction periods that could become increasingly unsuccessful as a result of the spawning grounds destruction and thus, reduce the population growth rate. In

this light, the carrying capacity of the fishery would dwindle from 700000 to 650000 and the intrinsic growth rate would decrease from 0.1 to 0.097.

Figure 8. Disturbances for small pelagic in the Adriatic Sea



Source: Own calculations

On the whole, the logistic growth function of small pelagic would decrease in such a way that the harvest function would not intersect at any point with the new growth function considering such ecosystem disturbances. This means that, at the current level of effort E=47, harvest would be higher than growth for any period and therefore, the stock biomass would be depleted in few periods, entailing that the most important species in terms of catch volume around the Mediterranean would disappear, with all its consequences it brings about.

To avoid this, the next section tries to alleviate these disturbances through the introduction of private property resources for the Mediterranean fisheries.

5. PRIVATE PROPERTY

Private property entails **well-defined and enforceable property rights** in a fishery. Owners can control access to the fishery and appropriate any rents that it is capable of delivering (Perman, Ma, McGilvray, & Common, 2003). There is a twofold purpose in introducing private property regimes in fisheries: the conservation of fish stocks and marine biodiversity and the reassurance of economic efficiency.

Historically, measures to restrict fishing have been directed towards **input/effort controls**, by specifying how much, how hard and what fishing equipment can be used or **output/catch controls** on the number of individuals that can be taken in a certain fishery and period of time. In the Mediterranean Sea, fisheries management has been mainly focused on limiting effort control; closing seasons to protect juveniles and spawning beds; establishing minimum conservation reference sizes; technical measures such as mesh size and gear dimensions; banning of more active gears such as trawlers and purse seines from spawning grounds or the creation of Marine Protected Areas.

In this sense, the only quota implemented so far in the Mediterranean has been for bluefin tuna. Every year, the International Commission for the Conservation of Atlantic Tuna (ICCAT) establishes for each Mediterranean country a Total Allowable Catch (TAC) based on a series of historical catches. Each country can determine how to distribute this quota among vessels and fishing practices (Lucchetti, et al., 2014). Even though considerable improvements in the stocks of Atlantic bluefin tuna have been produced, it is still too early to assert the population has completely recovered. After years of unprecedented harvest during the 2000s, the blue fin tuna stock biomass was about to deplete. In light of this, a quota was introduced so as to decrease fishing pressure. With the years, it seems to be recovering and fishermen are being allowed to increase their harvest.

Assigning yearly quotas to fishermen does not give them the property of the resources, but an exclusive right to harvest them. If these TACs are divided among individual catch quotas for fishers, it allows them to rent, sell or mortgage the quotas, or just the contrary, depending on if they suppose high or low costs for fishermen to sell or make use of them. Now, owners choose effort to maximise economic profit from the fishery. There is a large number of competitive fishermen, each behaving as a price-taker and so regarding price as being equal to marginal revenue.

$$G(S) = H \qquad [7]$$

$$Max\ NB \qquad [8]$$

Transferable quotas encourage technological progress, what may reduce bycatch, but is very difficult actually. In addition, in the case the government was willing to reduce the number of existing quotas, it could buy them back from those willing to sell them.

In the following section, we will analyse how the joint efforts with the GFCM multiannual plans and the new 2020 EU regulation, are contributing to ensure the social and economic

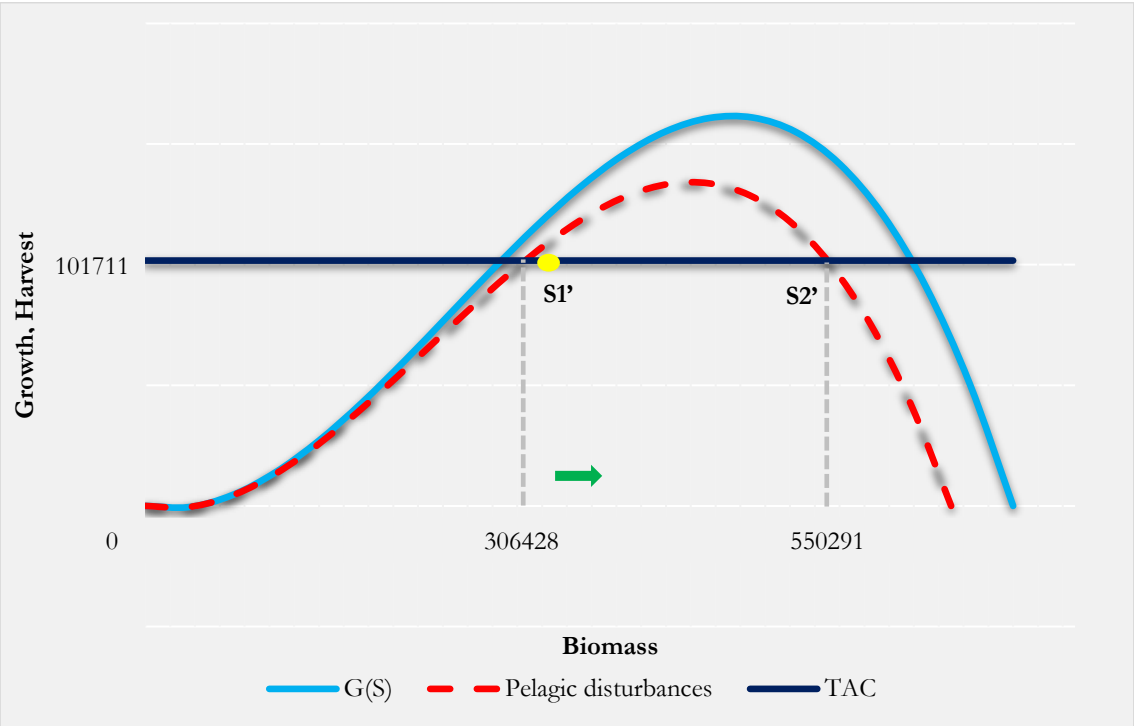
viability for the fishermen operating in the region by restoring and maintaining certain stocks at sustainable levels.

5.1. TAC for small pelagic stocks in the Adriatic Sea

Following the measures adopted by the GFCM for the conservation and control of sardine and anchovy species in the Adriatic (GSAs 17 and 18), the EU implemented in November 2019 a TAC for its Member States. The quota sets out a maximum level of 101,711 tonnes live weight that fishermen from Croatia, Italy and Slovenia could harvest, although the catch from the last one should not either exceed 300 tonnes. The procedures followed by the EU have also included other measures such as closure periods, in which fish populations are let recover and reproduce during the spawning season, essential for their conservation. In this sense, fishing days in the Adriatic are limited to 180, within which a maximum of 144 will be deployed for pursuing sardine and another 144 for pursuing anchovy. Altogether, catches of small pelagic in the Adriatic are expected to steadily decrease in a 5%.

Figure 9 below translates this information to the previous model with a horizontal line defining the new harvesting behaviour of fishermen, whose captures will not exceed 101,711 tonnes during the next years.

Figure 9. TAC for small pelagic in the Adriatic Sea



Source: Own calculations

For the initial biomass of 320000, the stock growth is 107,237 for the next period, whilst harvest will not exceed 101,711 tonnes. Accordingly, the biomass of the stock will keep increasing and harvest will remain constant. In the long, biomass is expected to reach 544438 tonnes at the stable steady-state equilibrium S2'. This would entail not just the conservation of sardine and European anchovy in the Mediterranean at biologically sustainable levels, but also the economic benefits of Mediterranean fishermen whose livelihood depends on these species.

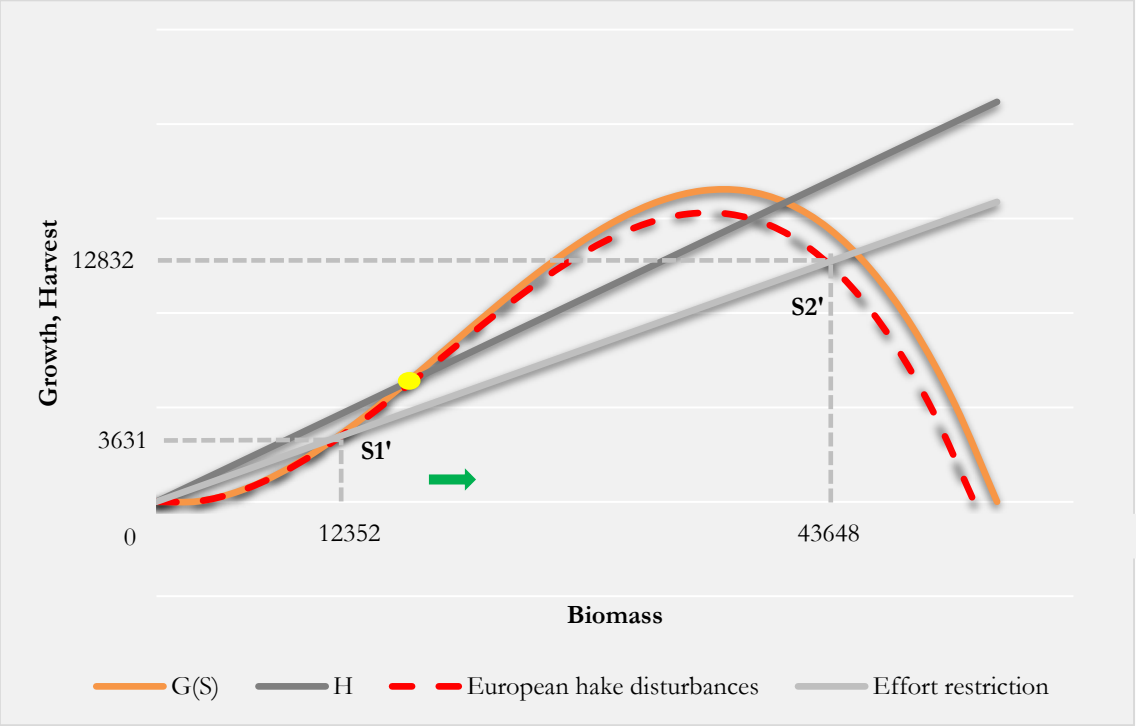
5.2. Effort restriction for demersal in western Mediterranean

Similarly, the state of European hake and other demersal fisheries in the western Mediterranean pressured the EU to take action following the path outlined by the GFCM multiannual management plan of 2019. Notwithstanding, instead of imposing a restriction over a maximum allowable catch as for sardine and anchovy, this time, the EU has established the maximum allowable fishing effort (in fishing days) exerted by all kinds of trawls (See Table 2 from the Annex). The concerning species are the most overexploited in the Mediterranean and particularly, western subregion, those are red mullet, deep-water rose shrimp, Norway lobster, giant red shrimp, blue and red shrimp and obviously, European hake. Thus, the next step is to include in our model the expected result of the new measure for the western stocks of European hake that could be extrapolated to the rest demersal species with lower threat.

In this way, measures taken should be enough to diminish fishing effort by 10% during the first year and achieve a reduction of 40% for 2025. However, limitations do not end here. Trawling activities should not exceed 15 hours per day and five days a week. The use of trawls shall be also prohibited within six nautical miles from the coast except in areas deeper than 100m isobath during a consecutive period of three months each year and in other areas considered appropriate, in order to protect again spawning fish, fish below the minimum conservation reference size, non-targeted fish species or minimise the negative impact on the ecosystem. Member States may establish other closure areas, aiming a reduction of at least 20% of catches of juvenile hake in each geographical subarea. Besides, the Temporary cessation of activities with the support of the EMFF, could occur in the case of the obligation to implement some emergency measures to ensure the conservation of fish species regarding their biological recovery periods or if a reduction of fishing effort is required (Council of the European Union, 16 December 2019).

Unlike for small pelagic, no maximum harvest is allocated to Mediterranean fishermen Now, there is a smoother harvesting function after a reduction in the effort deployed from E=55 to E=42. This gives more time for the European hake populations to recover and grow and, hence, distance from extinction. As it can be obtained from Figure 10, the initial level of biomass 16300 is situated above the unstable steady-state equilibrium and therefore, the fishery grows (6085) faster than it is harvested (4800). In the long-run, the fishery will go to the stable steady-state equilibrium, S2', where biomass and harvest are 43648 and 12832 tonnes respectively. In light of this, although during the subsequent periods the amount of fish extracted is lower than if no effort limitation is applied, it is worth reducing pressure in the short-run. As a result, in the future, the fishery would be fished at a sustainable level and, with a lower effort, fishermen would harvest a larger amount of hakes in the Western Mediterranean.

Figure 10. Effort restriction for European hake in Western Mediterranean



Source: Own calculations

The reduction in the Total Allowable Catch (TAC) or effort applied could produce certain short-run costs for some stakeholders of the fishing industry and not only fishermen. For instance, fisheries may lose in terms of profits and jobs during the early period of the reform. Therefore, the money obtained from the allocation of quotas could serve as a compensation mechanism for these new costs, as already proposed for Bluefin tuna in some cases (Hanoteau, 2012).

6. CONCLUSIONS

Even though as it is observed, the model might not be able to gather all factors intervening in the fishing activity and depict reality with total accuracy, it provides a faithful representation of the Mediterranean fisheries situation, either as a whole or differentiating among species.

The results have shown that implementing private property in Mediterranean fisheries could not only combat overfishing and overexploitation, but also cushion the effects of habitat degradation and loss on biodiversity, among others. Notwithstanding, the only feasible solution requires nurturing a Mediterranean common governance to effectively monitor and control fishing effort and deter IUU fishing or environmental degradation in order to overcome the sea particular hurdles and implement successful enforceable property rights.

Additional challenges for the immediate future would be reducing inequalities within the region, provide useful and sustainable subsidies, establish more MPAs, putting end to the massive biological invasions or educating consumers to make appropriate elections.

Finally, it is expected that the overall state of the Mediterranean stocks continues moving towards more biologically sustainable levels and trigger higher economic yields. The issue at stake here is not only the conservation of certain species with economic importance, but also the life of the Mediterranean and its people. **FOR A SAFE MEDITERRANEAN IN ANIMAL AND HUMAN LIFE, WE ARE ALL IN THE SAME BOAT.**

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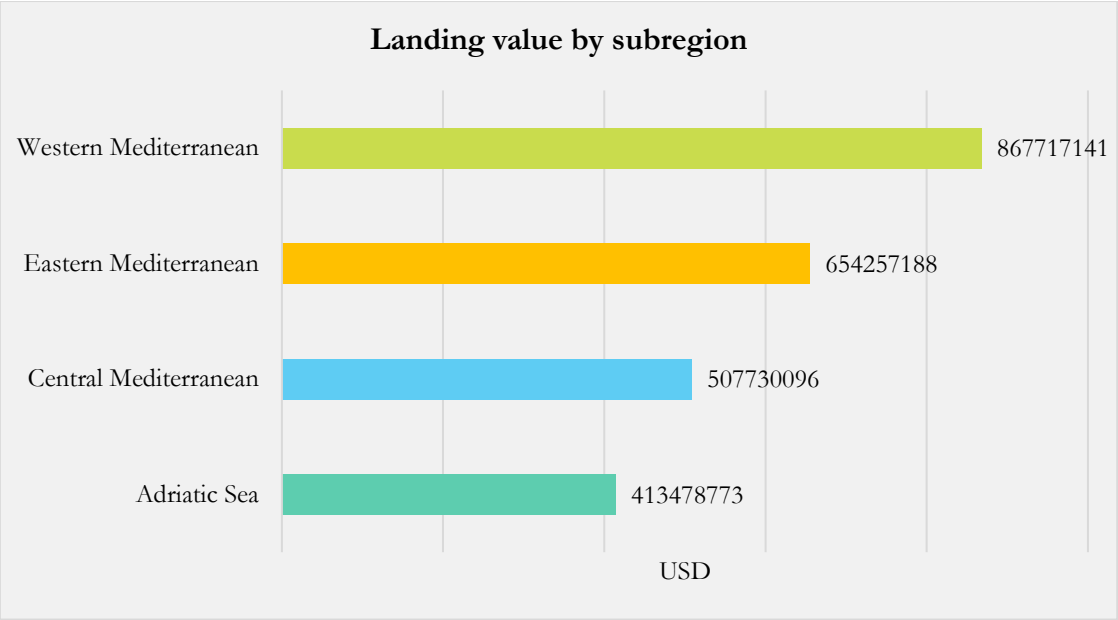
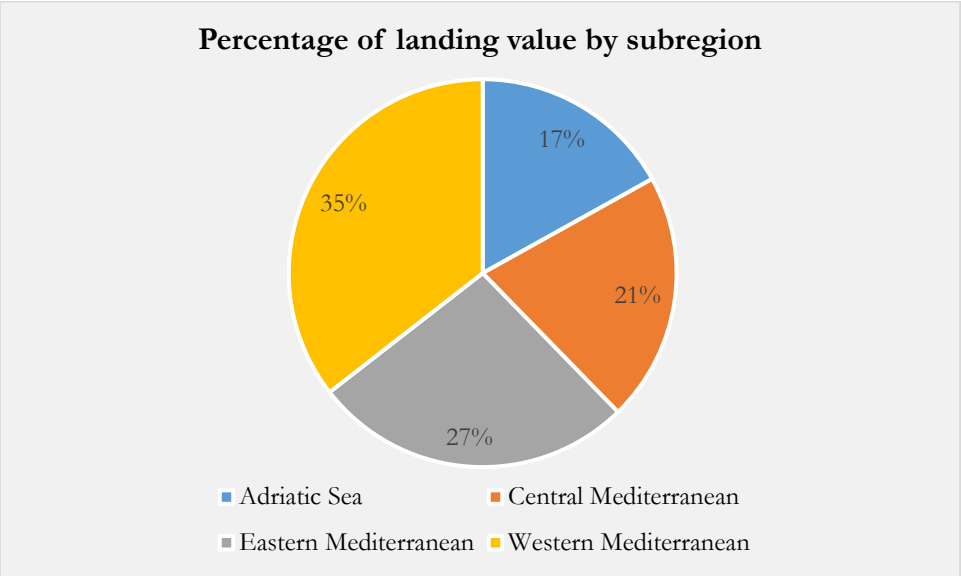
8. ANNEX

Figure 1. Landing value by subregion



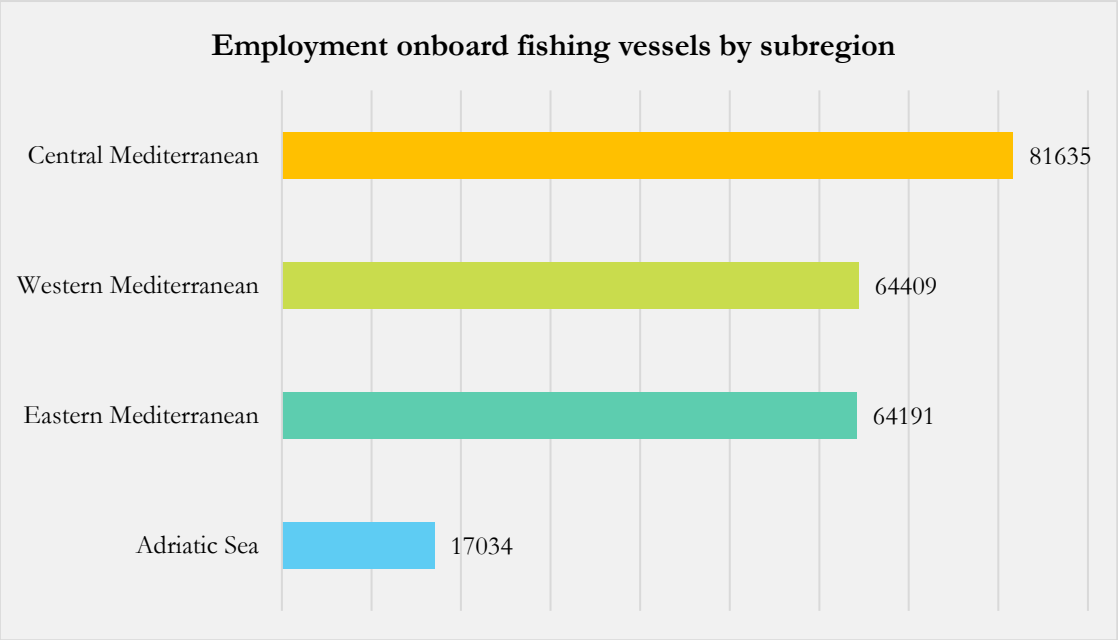
Source: Adaptation from GFCM 2018

Figure 2. Percentage of landing value by subregion



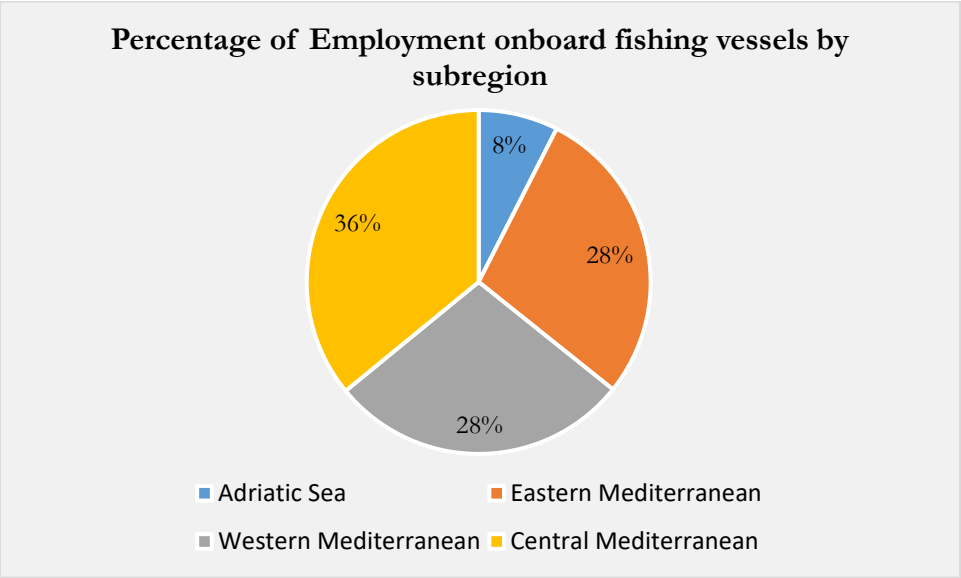
Source: Own calculations based on GFCM 2018

Figure 3. Employment onboard fishing vessels by subregion



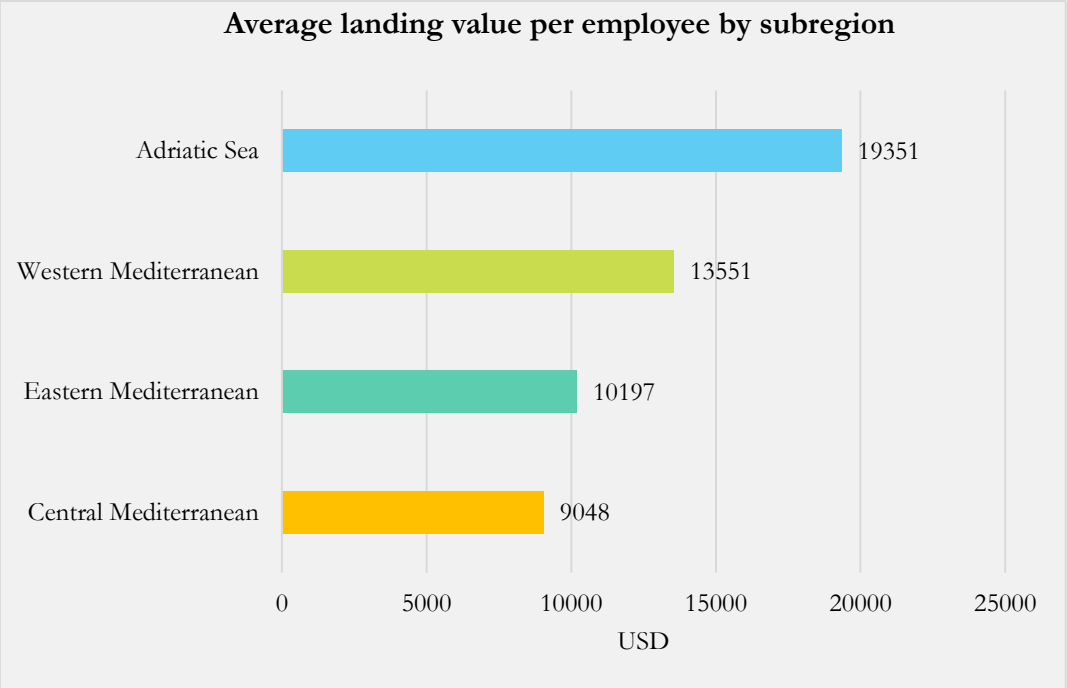
Source: Adaptation from GFCM 2018

Figure 4. Percentage of Employment onboard fishing vessels by subregion



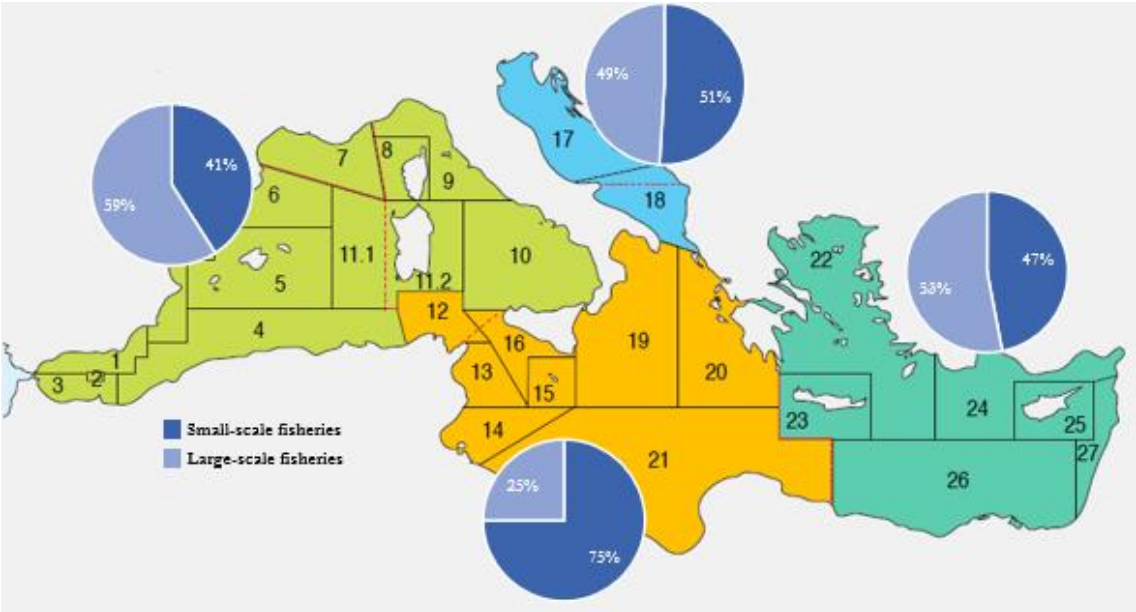
Source: Own calculations based on GFCM 2018

Figure 5. Average landing value per employee by subregion



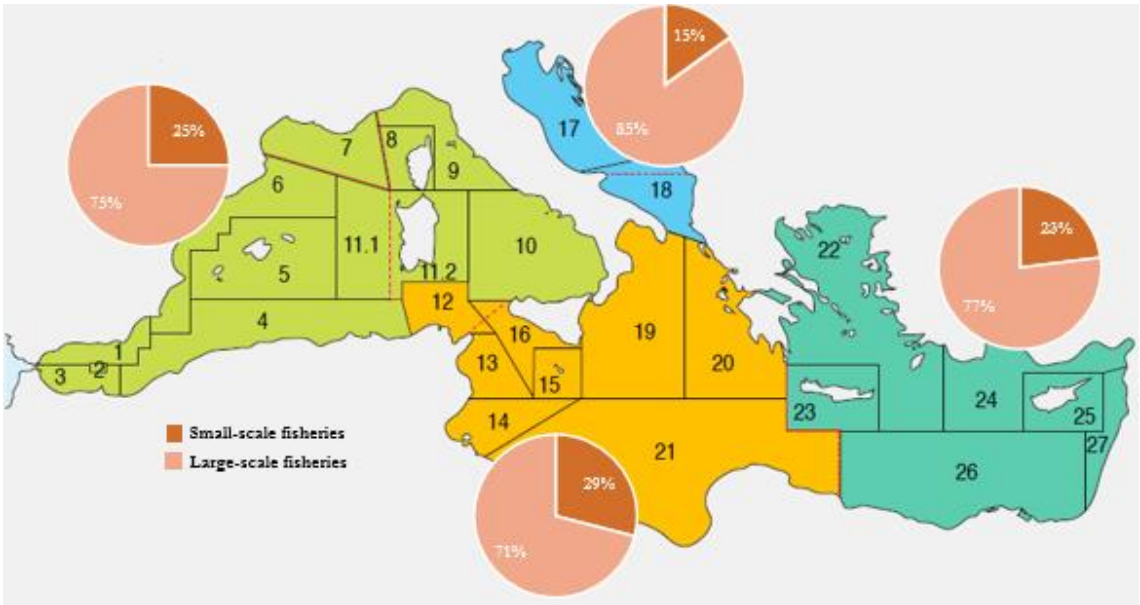
Source: Adaptation from GFCM 2018

Figure 6. Percentage of on-vessel employment from small- and large-scale fisheries by subregion



Source: Adaptation from GFCM 2018

Figure 7. Percentage of landing value from small- and large-scale fisheries by subregion



Source: Adaptation from GFCM 2018

Table 1. Mediterranean Stock status and current average overexploitation ratio by species[3]

a) Western Mediterranean

Species	Western Mediterranean								
	1	3	4	5	6	7	9	10	11
Anchovy (p)									
Sardine (p)									
Blue and red shrimp (d)	1,8			2	1,94		1,47		
Deep-water rose shrimp (d)					2,67		0,9	2,36	
European hake (d)	8,5	8,5		8,71	9	12,73	1,92	4,62	
Giant red shrimp (d)							1,53		
Red mullet (d)	3,42	3,42	3,42	6,64	1	3,37			
Striped mullet (d)									
Average subregion	4,28								

[3] **Stock status:** Red indicates low biomass; Yellow indicates intermediate biomass; Green indicates high biomass.
Average overexploitation trend: number of times that fishing mortality is higher than the targeted level.

b) Central Mediterranean

Species	Central Mediterranean					
	12	13	14	15	16	19
Anchovy (p)						
Sardine (p)						0,53
Blue and red shrimp (d)						
Deep-water rose shrimp (d)	1,71	1,71	1,71	1,71	1,71	1,53
European hake (d)	3,65	3,65	3,65	3,65	3,65	
Giant red shrimp (d)						
Red mullet (d)		2,47	2,47	1,2	1,2	3,08
Striped mullet (d)						
Average subregion	2,31					

Source: Adaptation from GFCM 2018

c) Adriatic Sea and eastern Mediterranean

Species	Adriatic Sea		Eastern Mediterranean			
	17	18	22	24	25	26
Anchovy (p)	2,23	2,23				
Sardine (p)	2,77	2,77				
Blue and red shrimp (d)						
Deep-water rose shrimp (d)	0,48	0,48				
European hake (d)			3,55			
Giant red shrimp (d)						
Red mullet (d)	0,36	0,48	0,87	1,28	0,81	
Striped mullet (d)						
Average subregion	1,48		1,63			

Source: Adaptation from GFCM 2018

d) Average species overexploitation in the whole Mediterranean

Species	Average	Average by habitat
Anchovy (p)	2,23	2,50
Sardine (p)	2,77	
Blue and red shrimp (d)	1,80	3,04
Deep-water rose shrimp (d)	1,54	
European hake (d)	5,83	
Giant red shrimp (d)	1,53	
Red mullet (d)	2,22	
Striped mullet (d)		

Source: Adaptation from GFCM 2018

Table 2. Maximum allowable fishing effort (in fishing days) by demersal stock groups in the western Mediterranean.

a) Alboran Sea, Balearic Islands, Northern Spain and Gulf of Lion (GSAs 1, 2, 5, 6 and 7)

Stock group	Overall length of vessels	Spain	France	Italy
Red mullet in GSAs 1, 5 and 7; European hake in GSAs 1, 5, 6 and 7; Deep-water rose shrimp in GSAs 1, 5 and 6; Norway lobster in GSAs 5 and 6	< 12m	2260	0	0
	≥ 12m and ≤ 18m	24284	0	0
	≥ 18m and ≤ 24m	46277	5144	0
	≥ 24m	16240	6208	0
Blue and red shrimp in GSAs 1,5, 6 and 7	< 12m	0	0	0
	≥ 12m and ≤ 18m	1139	0	0
	≥ 18m and ≤24m	10822	0	0
	≥ 24m	9066	0	0

Source: European Union, 2019

b) Corsica Island, Ligurian Sea, Tyrrhenian Sea and Sardinia Island (GSAs 8, 9, 10, 11)

Stock group	Overall length of vessels	Spain	France	Italy
Red mullet in GSAs 9, 10 and 11; European hake in GSAs 9, 10 and 11; Deep-water rose shrimp in GSAs 9, 10 and 11; Norway lobster in GSAs 9 and 10	< 12m	0	208	3081
	≥ 12m and ≤ 18m	0	833	46350
	≥ 18m and ≤ 24m	0	208	31170
	≥ 24m	0	208	4160
Blue and red shrimp in GSAs 1,5, 6 and 7	< 12m	0	0	510
	≥ 12m and ≤ 18m	0	0	3760
	≥ 18m and ≤24m	0	0	3028
	≥ 24m	0	0	405

Source: European Union, 2019