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Comparative Historical Analysis of Mediterranean Sponge Fishing Communities: Adaptability and Effects of Global Change

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Abstract

Sponges (*Spongia* and *Hippospongia*) have been harvested in the Mediterranean basin for thousands of years, with demand sharply increasing during the industrial revolution in the nineteenth century. However, since the mid-1980s outbreaks of epizootic events that regularly destroy sponge populations have brought this resource to the brink of extinction and annihilated sponge fisheries of several countries. Using statistical data from a wide variety of sources, we provide a comparative approach to the historical development of the Greek and Tunisian sponge fishing communities including fishing techniques, capitalisation rates, and the place of the sponge in collective representations. While the Tunisian sponge fishery landed large and regular quantities of sponges until the last third of the twentieth century, the tonnages landed by the Greek fleets have been very irregular over the last 150 years. We highlight the importance of small-scale coastal fishing as an adaptive response to global impacts of climate and environmental change.

Keywords Sponges (*Spongia* and *Hippospongia*) · Small-scale fisheries · Fishery structure · Resource depletion · Comparative research · Mediterranean · Greece · Tunisia

Introduction

Mediterranean sponges, including several species of the genus *Spongia* and *Hippospongia*, have been harvested over centuries in the Mediterranean, and from the sixteenth century when sponge fishing has frequently been reported in the Aegean region (e.g., Carlier De Pinon, 1579; De Thevenot, 1727; Sandys, 1673) and more rarely in Tunisia (Raynal, 1792). In the second half of the nineteenth century, the industrial revolution increased the demand for sponges, considerably increasing the size of the harvest and triggering several changes in the practices of Mediterranean sponge fisheries, (Fourt et al., 2020a; Olympitou, 2014).

Modern Mediterranean sponge fishing is characterized by several fishing techniques, some of which were spread by long-term and large scale fishing practices. Some techniques did not require diving underwater and thus allowed collecting sponges from the sea surface. One of the oldest and simplest techniques called *kamaki* consists first of identifying a sponge from a fishing boat, either by smoothing the sea surface with oil or by using a bathyscope (*yali* in Greek, *specchio* in Italian) and using a *kamaki*,[1] a long spear (up to 10–15 m), with three to five prongs to bring the sponge into the boat (Fig. 1). Another surface technique, the *gangava*, is a benthic trawl attached to an iron bar pulled behind boats that scraped sponges from the seafloor of flat continental shelf to a depth of up to 110 m. At greater depths the boats needed to be powerful and heavy (Fig. 1).

Diving is still commonly practiced to collect sponges. The oldest and simplest strategy was freediving, which came to be identified with some fishing communities of

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[1] Also used for fish, octopus, and cuttlefish.

Fig. 1 Left: Photography of Captain Michalis Kapsis' gangava, Symi, Greece around 1945–50. The trawling net attached to the iron bar is moored on the side of the boat (Photography courtesy Giorgos Fotaras, personal collection). Right top: Two hard-hat divers with their helmets, Limnos, Greece around 1960s (Photography courtesy Stratis Liadellis, personal collection). Right bottom: Two sponge fishermen using the kamaki and the yali to spot and collect sponges, Tunisia (Daniel Faget, personal collection)

the Southern Sporades (see Henrichs, 1836; Sandys, 1673). These fishermen, acknowledged for their diving skills, were able to collect sponges at depths of over 40 m (Henrichs, 1836; Langlois, 1853; Olympitou, 2014), and the most skilful were able to hold their breath for several minutes to dive down more than 50 m. These depths were attained due to a rapid descent using a flat stone (*scandalopetra*) attached to a long rope from the boat so the diver could communicate when he needed to be pulled up rapidly. Divers later added a small loose string between their wrist and the rope to increase security in case of loss of consciousness before reaching the surface.

With the industrial revolution in Europe came surface supplied air techniques, such as the use of the hard-hat diving suits, also called heavy gear - a heavy waterproof suit with weighted shoes and a rigid diving helmet providing air through a tube from the surface. This improved fishing efficiency but did not replace other techniques since it required an investment not affordable to most people, and led to severe diving accidents and high diver mortality rates. By the 1960s, the hard-hat equipment was progressively replaced by hookah diving, also using surface-supplied air, but with a simple air regulator held in the diver's mouth.

We examine sponge landings of Greece and Tunisia since the mid-nineteenth century to better understand the impact of the choices of harvesting practices on fishermen's livelihoods and on the development of sponge fishing. We base our reconstructions of sponge landings on data gathered from an extensive review of historical and archival sources (e.g., the Hellenic Statistical Authority, the General State Archives, Department of Rhodes (Greek National Archives), the Centre of Diplomatic Archives in Nantes), and on testimonies from two historical centres of sponge fishing in the Mediterranean Sea: the sponge fishing communities of Tunisia and of the Aegean Sea (including the Greek islands and the Southern Sporades, which came under Greek rule in 1947 after Ottoman rule until 1912 and Italian rule until 1943). Our study sheds light on two different relations to sponges and sponge fishing, which led to different capacities to adapt to regional changes in economy, politics, policies, and environment.

Materials and Methods

Study Area

The study area covers the Mediterranean basin where sponges develop at depths ranging from a few to 110 m (Pérez & Vacelet, 2014). Around 1870, regularly frequented sponge fishing areas were concentrated east of the Sicily strait (Voultsiadou et al., 2011), including the Adriatic Sea (Fig. 2). Since the beginning of the twenty-first century, this area has been reduced to the Eastern Adriatic coast and the Tunisian and Greek Seas (Fig. 6).

Sponges are also present in the Western Mediterranean basin, although not in sufficient numbers to make their harvest profitable. Greek and Southern Sporades sponge fishing boats visited France (Corsica) and Spain two or three crew over two years. Due to limited quantities of sponges, sponge fishermen, in this case divers using

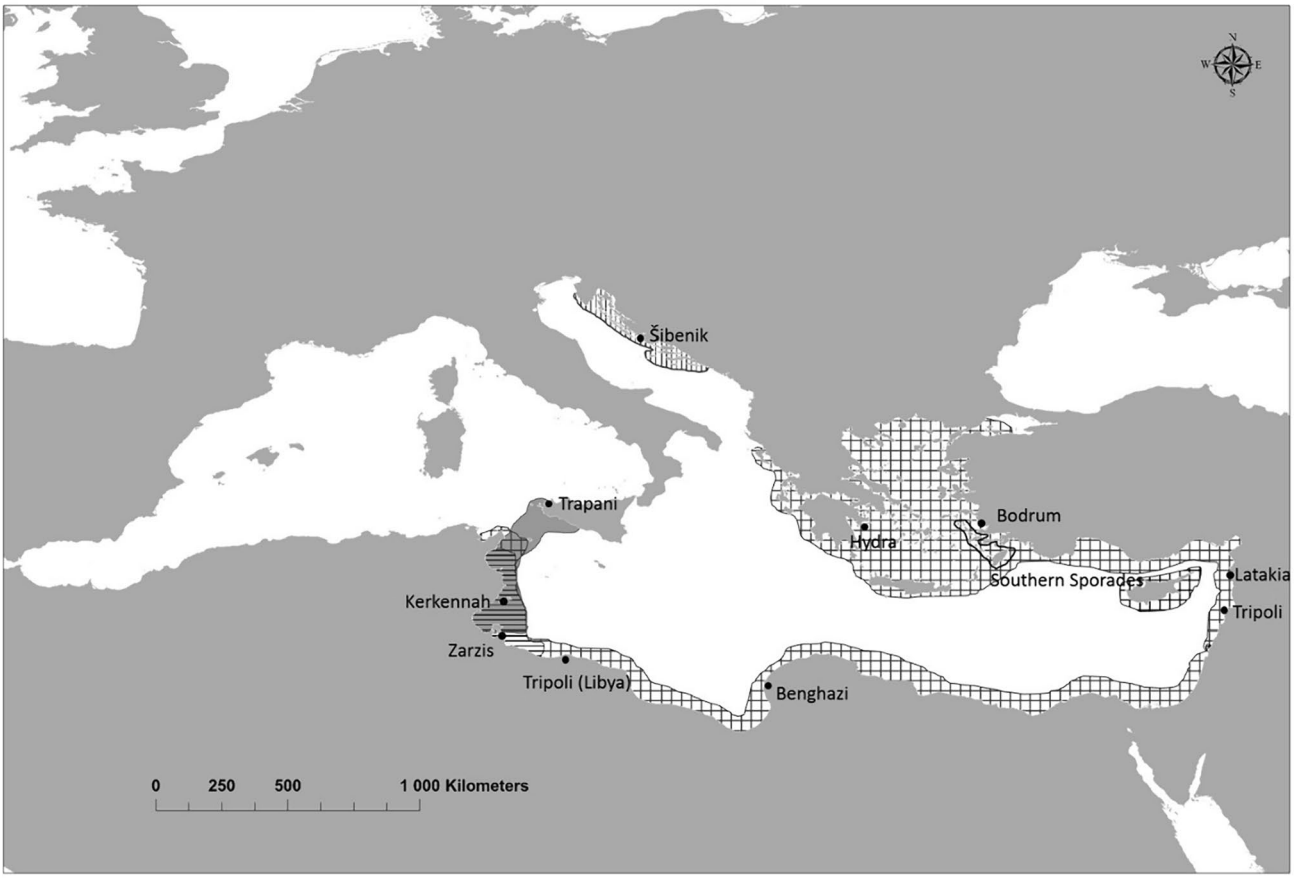

Fig. 2 Study area showing the sponge fishing areas regularly frequented by sponge fishermen around 1870–1880 Mediterranean. Area frequented: by Greek-speaking fishermen in checked pattern; by Syrian fishermen around Tripoli and Latakia; by Tunisian fishermen horizontal lines pattern; by Italian fishermen grey; and by Dalmatian fishermen in vertical lines patterns. Ottoman Turkish fishermen harvested sponges along the coast near Bodrum. During this period, sponge fishing took place down to 150 m depth, but generally not deeper than 80 m

surface-supplied air, often moved to harvest more profitable red coral (Dive, 1904; Flégel, 1912[2]; Grimm, 1902; Moore, 1910). Evidence of occasional local sponge fishing in France is limited to the Marseille and Toulon areas.

Data Collection and Analysis

We consulted published articles, grey literature, historical documents, archives, and official statistical data sources, interviews, and administrations and aggregated the data with corresponding references in a Microsoft Access 2013 relational database. Queries enabled the selection of data and information for e.g., a given country and/or period, which facilitated the contextualization of quantitative data variations. Extracts of the database grouping sponge species distribution, quantitative values of sponge landings and commerce, and fishing efforts are available in PANGAEA Data archive (Fourt et al., 2021). The data we use and their sources are part of this deposit or are specifically referenced here.

The data for this study encompass 600 records originating from 116 documents. Data concerning Greece are from official archives and publications mainly acquired or consulted at the Hellenic Statistical Authority (ELSTAT) website, the Library Civica Attilio Hortis (Trieste, Italy), the Kalymnos municipal library, the Kalymnos municipal archives, the Library of the Hydrological station of Rhodes, Greek National library of Athens, FAO Fishery and Aquaculture Statistics (for the years 2008–2014), and the Port police of Kalymnos for the last three years. For the Southern Sporades, documents and archives were consulted at the Diplomatic Archives in Nantes, the Municipal library of Saint-Raphael, the Library of the Nautical Museum of Kalymnos, the Archives of the National Bank of Greece,

[2] Greek National Archives of Rhodes-Dodecanese, Italian occupation series, 09/13/TM1/1916-17, Charles Flégel "La pesca delle spugne de l'abuso dello scafandro", 3 November 1912, p. 2.

Athens, the French National Library Gallica, Paris, the Library of the Hydrological station of Rhodes, and the Dodecanese Archives of Rhodes. For Tunisia, data originated from documents and archives consulted at the Alcazar inter-regional library of Marseille, the Library and archives of the Oceanographic Museum of Monaco, the library of the Endoume Marine Station, Marseille, the French National Library Gallica, Paris, the open access repository Aquadocs, the University library of Saint-Charles, Marseille, the Library of the University department "Maison Méditerranéenne des Sciences de l'Homme," Aix-en-Provence, the Tunisian National Institute of Statistics/ General department of fisheries and agriculture, and the National Observatory of agriculture (ONAGRI).

Raw quantitative data consist of annual sponge production and/or exports by countries or given area, number of fishing boats and number of fishermen yearly involved in sponge fishing. The survey covers the period from 1851 to 2018 (168 years). For the Greek sponge fishing landings, data cover the period from 1857 to 2017 with a few gaps (1938 and 1941–1946). Data on sponge fishing landings from the Southern Sporades data cover the period from 1851 to 1944 but were not available for several periods (1872–1873, 1875–1876, 1879–1883, 1885–1915, 1917, 1921–1924, 1936, 1937, 1939, 1945, and 1946). From 1947 and on, production from the Southern Sporades (that became the Dodecanese) is included in Greek production since the islands were united with the Kingdom of Greece in 1947 (Paris Treaty). Tunisian sponge production values were available from 1884 to 2018, although data for four of these years appeared unrealistic. Since only one source of production values was available for each year, we were unable to verify these values, which could have been due to typographic errors or an incorrect transcription. We used Grubbs's test[3] to identify if these production values could be considered as outliers (errors) under RStudio on the Tunisian sponge production values of respectively 1931 to 1950 (Grubbs' test for two outliers), 1950 to 1960 and 2000 to 2010 (Grubbs' test for one outlier). The tests indicated that the values of 841,000 kg for 1942, 846,000 kg for 1943, 312,000 kg corresponding to the production of 1956 and 100,800 kg corresponding to the production of 2006, are outliers (p-value < 2.2e-16 for the 2 outliers, p-value = 0.00084 and p-value = 0.00039 respectively). Therefore, values of these years (1942, 1943, 1956 and 2006), were considered invalid and were not used for this study. Also, for Turkish sponge landings data after Wold War II, we included data published by Yürekli (2012) that originate from the Turkish administration archives rather than the estimated production values published by FAO. In order to obtain qualitative information on sponge fishing techniques, fishing areas, sponge population distribution, sponge mortality events, and fishermen's perceptions of its temporal evolution, we conducted unstructured interviews with both retired and active sponge fishermen, sponge fishing boat captains and merchants between 2016 and 2019 in Tunisia (Zarzis), in Greece (Kalymnos and Limnos), and in Cyprus, and with the assistance of a local colleague, basic questions were also addressed in Lebanon (Batroun). [4]

We use the term "annual sponge landings" here to refer to the best estimation possible of the total weight of dried sponges landed annually by sponge fishermen, of all sponge species, categories, and qualities combined. In general, these values correspond to the sponge production quantities, but in some cases we used global annual export values as an approximation of landings. Exported quantities of sponges are an approximation of the annual landings, since as non-perishable products, sponges are not necessarily exported the same year they are harvested. Sales of sponges intended for local markets, which could also contribute to a difference between export and production values, is in this case insignificant. Thus, for Greece, fishing statistics on production are globally available from 1928 on, after the establishment of the second Hellenic Republic in 1924. Therefore, to supplement the lack of available fishing statistics on sponge landings before 1928, we considered the annual sponge export values for the years 1870 to 1872 and 1887 to 1927, and the quantities exported to Trieste for the years 1873 to 1887, as the best available estimation of the annual sponge landings. For the Southern Sporades, we used mainly exportation values until 1925, and production values from 1925 and on. For Tunisia, we used exportation values as the best approximation of sponge landings only for the years 1886 to 1888, and 1891. For all years and production areas, when an annual production quantity could be obtained from more than one source, we computed a mean value.

For Tunisia, dried sponge weights were originally always expressed in kilograms, but in other areas such as the Aegean, they could be expressed in okas. Although many definitions indicate that one oka is approximately equal to 1.24 kg (e.g., Collins Dictionary), nineteenth century commercial dictionaries (e.g., Librairie de Guillaumin et C^{ie}, 1861) indicate that the oka was very variable between and even within countries. For instance, the weight of one oka varied from 1.20 kg in Crete to 1.29 kg in Constantinople. In Greece, the "old" oka still used in 1861 was

[3] This is designed to test the hypothesis that the maximum or minimum value of a dataset is an outlier (Grubbs' test for one outlier), or that they are two outliers (Grubbs' test for two outliers).

[4] Dr. Michel Bariche from the American University of Beirut kindly proceeded to the interview of a sponge fisherman for us in Batroun.

1.28 kg, whereas the "new" oka (supposedly used after 1836) weighed 1.25 kg. In our data set, we converted the few values originally expressed in okas to kilograms using a mean equivalence of 1 oka = 1.27 kg.

Annual numbers of boats and fishermen involved in sponge fishing were identified for Tunisia between 1890 and 1965, with data lacking only for 1964. The number of Tunisian boats and fishermen for the most recent period (2013–2017) is a mean estimation based on partial data and interviews with Tunisian administration officials and fishermen. For Greece, such data were scarcer and basically available only for the years after World War II. We used numbers of boats and sponge fishermen to calculate two annual productivity values of Catch Per Unit Effort (CPUE), one by boat (kilograms by boat) and one by fisherman (kilograms by fisherman).

To assess and compare productivity between Greek and Tunisian fisheries in two different periods (after World War II and recent), we represented five statistical indicators summarizing each dataset (minimum, first quartile, median, third quartile and maximum) of the sponge landings, number of boats, number of fishermen and the CPUEs by boxplots for a better visual rendering (see Online Resource 1). We applied the Mann-Whitney U test to compare the two periods for the different variables for each country and to determine whether they are significantly different or not. All figures and statistical calculations were computed with RStudio[5] version 1.3.1093.

Results and Discussion

Sponge fishing in the Mediterranean at the end of the nineteenth century (1870–1900) took place mainly along the eastern coast (Fig. 2). Some sponge fishing communities, such as those in the Aegean, organised two to six months-long fishing harvests around the south-eastern Mediterranean basin, whereas others, such as Tunisians and Syrians, harvested locally on a daily basis.

Greek sponge fishing communities, either from Greece or the Southern Sporades under the Ottoman Empire, travelled throughout the Aegean Sea and since the beginning of the nineteenth century to the North-African coast of present-day Syria, Egypt, Libya, and Tunisia (Fig. 2). This extended fishing area necessitated large boats and navigation knowledge. Harvesting trips lasted from two to six months (Fourt et al., 2020a). In 1895 the Greek sponge fishing boats harvesting in Tunisia had a mean tonnage of 8.9 tons, whereas the Tunisian boats had a mean tonnage of only 1.6 tons (Dubois et al., 1897). Prior to the 1880s, both Greek and Tunisian sponge fishermen frequently used the *kamaki* harvesting method, although the Greeks loaded their small fishing boats on larger ones to sail to the North African coasts. Greek fishermen also used *gangavas* which were particularly efficient in the Gulf of Gabès in Tunisia. In 1897 Greece had up to 150 *gangavas* of all sizes active in the eastern Mediterranean (Godefroy, 1898). Before the 1860s sponge fishermen from the Southern Sporades used free diving with a stone weight, although hard-hat suits were used as early as the 1860s and rapidly spread throughout all Greek sponge fishing communities, which improved harvesting efficiency but also resulted in hundreds of crippled and dead divers by the end of the century. By 1883, Greece had 183 sponge fishing boats equipped with hard-hat suits (Apostolidès, 1883), although the dangers associated with their use created local uprisings. Long term data on the Southern Sporades landings for the nineteenth century were available only for the period between 1851 and 1869, with average annual reported landings of 122,095 kg. Between 1890 and 1900, the Greek sponge fishery from Greece produced average annual landings of 53,023 kg.

By the end of the nineteenth century, Greek sponge fishermen from Greece and the Southern Sporades had diversified sponge fishing techniques adapted to the various sponge habitats they encountered throughout their large fishing area. For example, free divers often harvested on rugged rocky seafloors over 15 m in depth, unsuitable for *kamaki* or to *gangavas*, since the rocks would tear the trawling nets, and too dangerous for hard-hat divers who were not very mobile and could entangle their air tube in the rocks.

By 1880, sponge fishing along the Dalmatian coast was practiced mainly by fishermen using the *kamaki*[6] method of harvesting (Faber, 1883) from the island of Krapanj (near Šibenik), which remains the centre of the activity in the Adriatic. Harvests took place in summer, generally lasting from a few days to a few weeks. Between 1880 and 1900, about 100 Dalmatian *kamaki* boats were active (Faber, 1883; Gourret, 1900), between 1871 and 1900, an analysis of commerce in Trieste indicates a mean annual value of 2,093 kg of exported sponges.

During the same period, Turkish sponge fishing was centred in Bodrum. The Turkish fleet comprised 30 *gangavas* in 1866 with a total of 240 crew members (Caravokyros, 1895), which expanded to 40 in 1891 (Masse, 1892). This device was particularly adapted to trawling on the narrow but smooth continental shelf off the Turkish coast. The use of hard-hat suits appears in the late 1880s mainly used in the northern part of the coast. In 1895, seven boats using

[5] RStudio Team (2020). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/.

[6] The *Pesca e Piscicoltura Marina* society introduced the use of the hard-hat diving suit only in 1891 (Fortibuoni, 2009).

hard-hat suits for fishing sponges were based near Ayvalik (Drakos, 1895). Ottoman Greeks free divers from the Southern Sporades also occasionally frequented the Turkish coast. We were not able to trace any records of sponge production values of the late nineteenth century.

Along the Levantine coast (present day Syria and Lebanon), sponge fishermen were mostly local or coming seasonally from the Southern Sporades and from Greece. In this area the fishermen from Syria and Southern Sporades were exclusively free divers using a stone weight to depths of about 40 m meters to harvest sponges of the best quality (Henrichs, 1836). The Greeks used the *kamaki* methods to harvest in the area from small boats brought on larger vessels (Henrichs, 1836). This area accounted for 260 local sponge fishing boats in 1877, and 156 in 1890 (France Ministère de l'agriculture et du commerce, 1891). In 1896, Cuinet (1896) reports that 8,000 kg of sponges were exported from the region, mostly by local fishermen, while the Greeks from the Southern Sporades generally took most of their catches to their homeport.

In the late nineteenth century Tunisia was hosting fishermen from many countries. For example, in 1882, out of a total of 847 sponge fishing boats, 500 were Tunisian, 225 Italian, 116 Greek, and 6 Maltese (Hennique, 1888). In 1895, over 1,700 sponge fishing boats from all these countries were harvesting in Tunisian waters (Mattei, 1896; Station Océanographique de Salammbô, 1933). Between 1890 and 1900, 115,407 kg per year on average were landed in Tunisia.

Numerous small Tunisian boats were based in the Kerkennah Islands Zarzis, Sfax, and Djerba. They collected sponges in shallow waters with the *kamaki* and *yali*[7] (bathyscope) from boats manned by two to four fishermen. In the Gulf of Gabès and around the Kerkennah Islands, sponges grew mainly in phanerogam meadows, so local *kamaki* sponge fishermen harvested only during the winter months (December to March) when the leaves are the shortest and sponges can be more easily spotted. During the other months they harvested fish and cephalopods (octopus and cuttlefish). Many Tunisians also harvested sponges by walking on shallow bottoms and identifying sponges with their feet.

In the same area, Sicilians also used small boats and *kamaki* to collect sponges. In parallel, larger boats from Naples, previously used to fish red coral, were used as *gangavas* to trawl sponges at depths between 10 and 70 m (Weil, 1901). In 1882, 40 *gangavas*, mainly Italian and Greek but also six Maltese, were harvesting in Tunisian waters (Hennique, 1888). *Gangavas* would have been introduced in Tunisia by Greeks around 1875 (De Fagès & Pronzevera, 1908; Gourret, 1900). By 1882, 120 Greek sponge fishing boats are also reported in Tunisia (Hennique, 1888), chiefly from the Greek islands of the Saronic Gulf, especially Hydra, for the summer season, and used *kamaki*, *gangavas* or hard-hat suits towards the end of the century, which were also for sponge fishing off the Italian islands of Pantelleria, Lampedousa, and Lampione, where several bodies of sponge divers using hard-hat suits were found buried with their equipment in 1897 (Darboux et al., 1906).

Evolution of the Tunisian and Greek Sponge Fishing Communities

The Tunisian and Greek sponge fishing communities differed in several ways: (i) the extent of their fishing area, (ii) their navigation means, (iii) their organization and use of different techniques, and (iv) the role of sponge fishing in their culture.

Greek and Southern Sporades sponge landings came from harvests in a large fishing area in the eastern Mediterranean that were counted as sponge production of their homeport. This explains the large quantities of sponges landed by Greece and the Southern Sporades during the second part of the nineteenth century (Fig. 3A).Throughout the studied period, Tunisian sponge fishermen primarily practiced in Tunisian waters and during certain periods, extended fishing to the bordering Libyan Sea and more recently, around the most southern Italian islands (Pantelleria and Lampedusa) (Figs. 2 and 6). However, sponge fishing was intense in Tunisia leading to high production values (Fig. 3B).

Greek Landings

Greek sponge fishermen mainly came from islands in the Saronic Gulf, such as Hydra and neighbouring Aegina, and from the Southern Sporades where sponge fishing was the main activity during the nineteenth century for the most of the barren small islands of the archipelago. The Southern Sporades annual sponge landings increased steadily between 1851 and 1862 from 66,000 kg to 184,665 kg, followed by a period of high landings varying from 122,890 kg to 268,000 kg (Fig. 3A). The next long term available data are for 1925 to 1935, when annual landings had decreased to a mean annual value of 33,054 kg.

In Greece, annual sponge landings increased markedly in the period 1870 to 1888 from 22,500 kg to 222,000 kg. Over the subsequent years annual landings regularly decreased and remained low until the Second World War (Fig. 3A). The landings dropped to 10,000 kg in 1904, representing less than 10% of the Tunisian landings at the same period.

[7] De Fagès and Pronzevera (1908) attest that the use of the *yali*, which advantageously replaced the oil spilled on the surface of the sea, had been transmitted to Tunisians by Greek sponge fishermen around 1876.

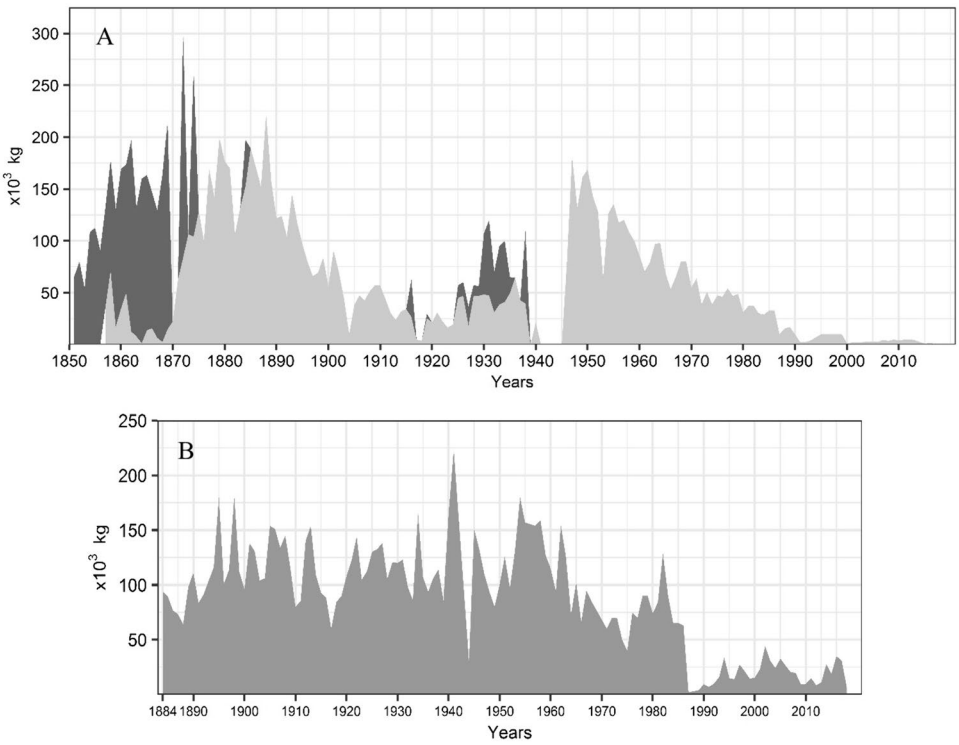

Fig. 3 Mean annual sponge landings for: **A** Greece in light grey and Southern Sporades dark grey (cumulative curves) and **B** Tunisia

Between 1905 and 1938 the landings remained low (Fig. 3A) at 36 500 kg per year on average.

At the end of the nineteenth century, sponge landings were higher in Greece than in Tunisia, but this was followed by nearly 50 years of reduced landings mainly due to economic but to some extent political influences (Fourt et al., 2020a). Greek sponge fishermen had to sail long distances requiring large boats and annual financial investments. Investments were the highest for hard-hat divers since they required payment before departure because of the high mortality rates. While use of hard-hat divers increased productivity, these fishing expeditions were much more speculative and risky for investors and merchants, especially since frequent prohibitions of hard-hat use were proclaimed in different areas, including the Ottoman Empire (Fourt et al., 2020b). Likewise, large fishing expeditions using simpler fishing techniques, such as *kamaki*, were also costly because sailing distance to North Africa required equipping large vessels and large numbers of crew members. Consequently, when the country became bankrupt and economically isolated in the 1890s (Petmezas, 2013), lack of funds consequently reduced sponge landings (Fourt et al., 2020a), and fishing livelihoods depended on sponge fishing methods needing little investment, such as family organised free diving or the regional *kamaki* sponge fishing (Fourt et al., 2020c). In the early twentieth century, there was massive migration from Greece and Southern Sporades in search of better opportunities (Maratou-Alipranti, 1988). For example, in 1907 1,500 Greek sponge fishermen moved to Tarpon Springs, Florida to work in the local sponge fishery (Bucuvalas, 2016).

The Greek sponge fishery recovered after the Second World War when the Greek Agricultural Bank started offering loans with low interest and the fishing fleet was expanded by the addition of the Southern Sporades sponge fleet (Fourt et al., 2020a), and sponge production peaked at 182,000 kg p.a. in 1947 (Fig. 3A). However, sponge landings began to drop again during the 1950s to 1970s, mainly because of the progressive loss of fishing areas due to the progressively nationalization of Egyptian, Libyan, and Tunisian sponge beds. Some of the oldest interviewed Greek sponge fishermen spoke of their trips to the Libyan and Egyptian coasts, indicating that bath sponge populations were much denser there than in Greek waters. The lack of access to these rich sponge beds caused many Greek fishermen to turn to other fishing targets or even to abandon fishing for other jobs (Damer, 2004; Olympitou, 2014). Consequently, sponge fishing disappeared in many islands easily accessible to mass tourism, such as Hydra and Symi, together with the large boats used for earlier distant and long expeditions to the North African coast. Where sponge fishing persisted after the 1960s, hard-hat diving was progressively replaced by lighter hookah diving equipment that remains the main practice today, reducing crews to only two to four fishermen on smaller fishing boats.

Our Greek sponge fishing informants also reported the well known mass mortality event that affected all sponges in late summer 1986 (see Gaino et al., 1992; Vacelet, 1991),

at the end of the Greek sponge fishing season, although affecting the northern Aegean much less. In 1987 landings decreased, although fishermen were authorized to harvest in Italian waters where sponges were less affected. From this first ecological crisis to the end of the studied period, landings were irregular and remained under 20,000 kg p.a. Indeed, unpredictable mortality events, although more localised, have been regularly observed by sponge fishermen since 1986, even in the northern Aegean. Without a reliable supply, sponge fishing throughout the Greek seas became economically too risky even though sponge prices are very high (110–130 euros/kg in 2019). During the interviews, Greek informants stated that to make a steady living, they were progressively turning towards other targets that can be collected by using hookah diving, such as holothurians (sea cucumbers), or turning to other occupations entirely. They also expressed a preference to continue fishing for sponges if they were available. However, sponge fishing in Greece has practically ceased altogether.

Tunisian Landings

During the eighteenth century Tunisia sponge landings averaged 10,000 kg/p.a. (Faget & Carroll, 2016), which had increased to 90,000 kg/p.a. in 1884, and continued to rise sharply to an average of 105,621 kg/p.a. in the last years of the nineteenth century, with peaks at 180,000 kg in 1895 and 1898 for unknown reasons (Fig. 3B). The demand for sponges in industrialized countries at this time was high (Bernard, 1976). From 1881 to 1956, Tunisia was under French protectorate, thus guaranteeing Tunisian sponge exports. Between 1890 and 1939, sponge fishermen landed 115,407 kg/p.a. on average from the Gulf of Gabès and its surroundings. Throughout this period, CPUEs (Catch Per Unit Effort) remained relatively stable, with 133 kg by boat and by year on average, which thus appears sustainable while the Greek productivity was collapsing the. However, the Second World War paralysed the sponge market and access to Tunisian waters.

Until Tunisian independence in 1956, foreign sponge fishermen were permitted to collect sponges by acquiring a license. After 1956, the progressive closing of Tunisian waters by the government reduced fishing pressure to only Tunisian sponge fishermen, mainly using the traditional *kamaki*, which may explain the recorded decrease in sponge production after mid-1950. In the 1960s synthetic sponges started flooding the sponge market (Bernard, 1976). Decreased demand for sponges further eased fishing pressure. The short increase of landings observed in Tunisia between 1976 and 1986 is due to both reduction in Greek sponge production opening new markets for Tunisian sponges, despite the introduction of synthetic sponges, and the opening of a national professional fishing training centre (CFPP) in Zarzis (South Tunisia) in 1968, which was upgraded in 1975 to train professional hookah divers for sponge fishing. The first divers graduated in 1976, and annual sponge landings reached 80,000 kg/p.a. on average between 1976 and 1986 (Fig. 3B), a dynamic that was ended, as in the Aegean, by the 1986 sponge mortality event, which decimated bath sponge populations at depths shallower than 40 m in Tunisia (Vacelet, 1991).

Tunisian sponge landings dropped drastically from 62,000 kg in 1986 to 2,000 kg in 1987, but seem to have somewhat recovered a few years later. Landings down to 2,000 kg in 1987 increased by 2002, to 44,000 kg, indicating the relative resilience of the main bath sponge species harvested in Tunisia, *Hippospongia communis* (Lamarck, 1814). But our informants among *kamaki* sponge fishermen and free divers from the Kerkennah islands reported that sponges have become scarce in shallow depths where they used to be dense. The traders indicated that the landings of recent years are mainly from the hookah divers from Zarzis who collect sponges in the Sicily strait at depths between 30 and 45 m but also from *kiss* boats (shallow trawlers that illegally scrap the sea bottom). Since 2017, new sponge mortalities events have recurrently affected Tunisian sponges obliging fishermen to increase fishing pressure on their other targets to sustain their livelihoods.

Communities

Settled on islands that did not allow prosperous agricultural development, Greek communities have forged a privileged relationship with marine resources over thousands of years. In the past, in the Southern Sporades, sponge fishing was used to distinguish the bravest men, for whom were reserved the best matrimonial unions. It was also sponge fishing that organised the year's calendar of activities, as people set off on more or less distant campaigns. This central role of the resource has permeated local mentalities to the extent that many statues celebrate to this day the adventures of sponge-fishing crews. Marked by this mono-activity, the Greek communities are radically different from the coastal populations of Tunisia. The latter have always benefited from the extremely rich waters of the Gulf of Gabès, but also from the highly fertile nature of the crops grown on the coastal plains. Although sponge fishing is part of Tunisian fishing culture, it never takes on the role of a unique activity as it does on certain Greek islands. The sacrificial and tragic dimension of the perilous existence of Greek fishermen is not to be found in Tunisia. The mono activity/polyvalence opposition observed in the two areas is also coupled with distinct technical and organisational characteristics.

The Greek sponge fishing communities were early on integrated into a cycle of capitalisation initiated by European companies keen to regularise their supplies. This outside

investment, which explains the existence of costly long-distance campaigns on powerful ships, and also the rise of the use of hard-hat diving, had two major effects.

- On the one hand, it helped to wipe out any desire on the part of Greek fishermen to diversify the resource. Reduced to a status of indebtedness or wage labour, they continued until the mid-twentieth century to regard sponge fishing as their only available resource. If there was a shortage, or if markets shrank temporarily, they had no choice but to put their children to work as slave labour in the factories of Russia, or to emigrate to America to continue their work on the rich sponge beds of Florida or in the factories of the Great Lakes (Yerakis, 1999; Kalafatas Mitrofanis in Kalafatas, 2003).
- The highly capital-intensive nature of Greek activities, by marginalising traditional fishing techniques, did not created optimal conditions for the local conversion of fleets when the resource disappeared.

During the colonial period and throughout the decades of independence, Tunisia maintained a fleet of modest boats belonging to the fishermen themselves, equipped to alternate fishing targets according to the season. This enabled the fishermen of the Gulf of Gabès to withstand the hazards affecting sponge populations until the beginning of the twenty first century. Western investment companies have been modestly involved in sponge fishing in Tunisia for two centuries. These investments have been limited essentially to the late fitting out of vessels using the *gangava* technique. In fact, the lack of major investment in Tunisian fleets is due to the extreme local abundance of sponges. The shallow depths in this area allowed everyone to harvest sponges using rudimentary techniques, fishing on foot or using *kamaki*, and then to sell directly from the quayside to foreign traders.

Free to organise their fisheries in the waters of the Gulf of Gabès, with little debt, Tunisian fishermen have thus maintained throughout these decades a versatility that seems to be the key to adaptability to regional change.

The different sponge fishing practices impact the marine ecosystems at various degrees. Freediving, hard hat and hookah diving and the use of *kamaki* are selective techniques. Nonetheless, because of their efficiency, the surface supplied air technics (past hard hat and current hookah diving) could eventually lead to sponge overfishing as denounced by Weil (1901) in Syria at the beginning of the twentieth century. Further, as a blind technique, bottom trawling (past *gangavas* and the current shallow trawling *kiss* boats in Tunisia) severely impacted not only sponge populations but also all benthic ecosystems. At the end of the nineteenth century, the extensive use of *gangavas* in the golf of Gabès was already considered as largely contributing to the decrease of sponge availability and size (Mattei, 1896). When restrictions were imposed to *gangavas* in 1954, this fishing method became less profitable and was therefore progressively abandoned. Yet, in Tunisia, sponge fishing continued throughout the twentieth century with rather constant landing values before the first epizootic event in 1986 that seems to have affected sponge populations independently of the resource exploitation.

However, regional change now seems to have taken its toll on sponge fishing in the two areas studied as well as throughout the Eastern Mediterranean Sea. The resource, which has been decimated by epizootics occurring in close succession over the last four decades, has completely disappeared from certain 'historic' fishing grounds. Bath sponges have virtually disappeared from the southern Aegean Sea and the south-eastern Mediterranean, and it has not managed to make a lasting recovery in the Gulf of Gabès either where the extent of environmental damage caused by industrial and urban pollution appears to be an aggravating factor in the disappearance of sought-after species and their habitats (Béjaoui et al., 2019; Darmoul & Vitiello, 1980; El Zrelli et al., 2019; Zaouali, 1993). However, the maintaining of rather large fishing communities in Tunisia, while they have collapsed in the Dodecanese islands, seems to demonstrate the resilience of multi-purpose artisanal fisheries, which are the only ones capable of rapidly modifying their targets and techniques of activity.

The Collapse of Mediterranean Sponge Fishing

Comparing 1947–1951 to 2013–2017 (Fig. 4, Online Resource 1) Tunisian annual landings, number of boats and fishermen have significantly decreased (Mann-Whitney *U*-test, $p < 0.05$). Average Tunisian landings diminished by a factor of 4, from 102 to 25 tons per year, the number of sponge fishing boats fell by a factor of 7, and the number of sponge fishermen by a factor of 6. However, comparing CPUEs between the two periods (Fig. 4D, E), although the mean values appear to have increased, the difference is not significant (Mann-Whitney *U*-test, $p > 0.05$) and productivity remains relatively comparable, although comparing CPUE by boat and by fisherman reveals high variability of the CPUEs in the period 2013–2017, reflecting the variable availability of the resource in this period.

Greek landings, number of boats, and fishermen significantly decreased as well (Mann-Whitney *U*-test, $p < 0.05$). The average landings divided by 75, collapsing from a mean value of 157,000 for 1947–1951 period to 2,000 kg per year for 2013–2017, while the number of boats divided by 77, and the average number of fishermen by 353. If for 1947–1951 only sponge fishing in Greek waters is considered, then the decrease in landings appears less abrupt. Such detailed data are available only for 1955, when annual landings were 29,500 kg, Greek sponge fishing boats numbered 56, and

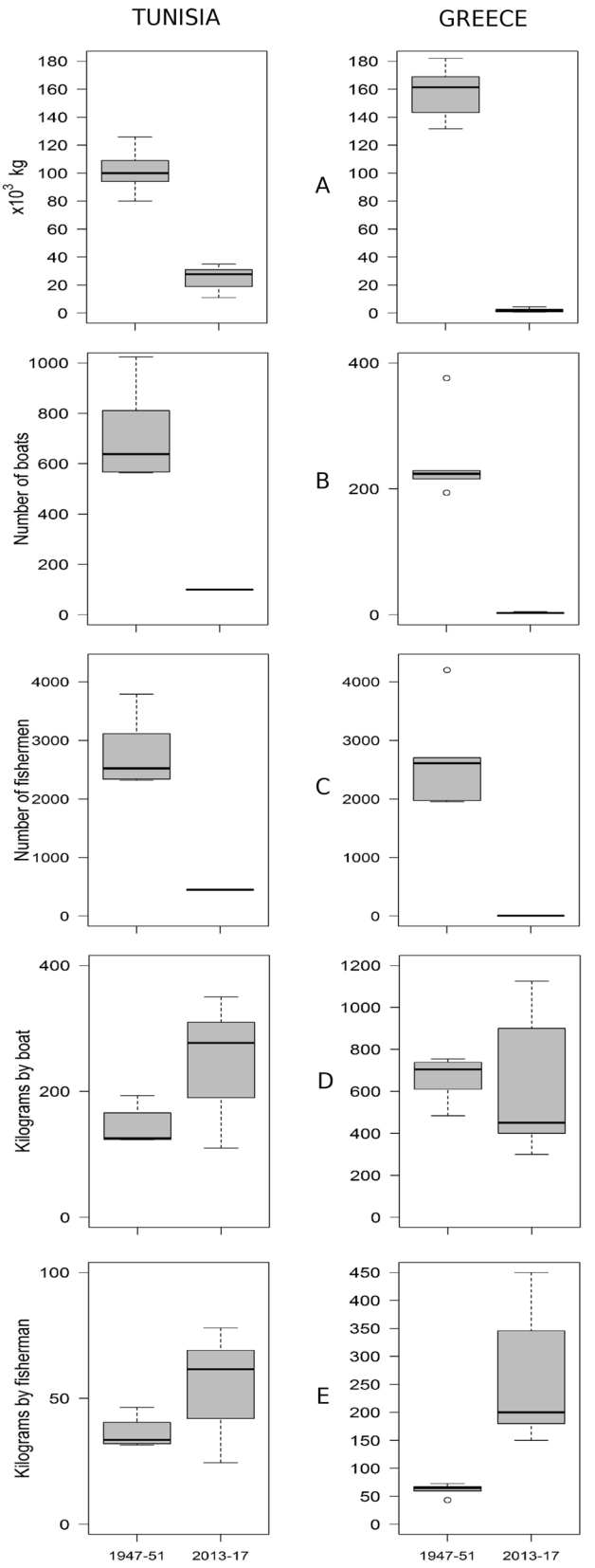

Fig. 4 Boxplots for the post-war period (1947–1951) and the recent ▶ period (2013–2017) for Tunisia and Greece. **A** annual sponge landings, **B** annual number of sponge fishing boats, **C** annual number of sponge fishermen, **D** annual CPUE by boat, **E** annual CPUE by fisherman

sponge fishermen 407. If these values are considered for the first period, the landings have been divided by 14, the number of boats by 17.5 and the number of sponge fishermen by 53.5. Overall, in Greece as in Tunisia, the mean CPUE by boat has not significantly changed between the after-war and the recent period (Mann-Whitney *U*-test, $p > 0.05$), although it appears much more variable in the recent period. However, the CPUE by fisherman has significantly increased (Mann-Whitney *U*-test, $p < 0.05$), as it is now 4 times higher than during the post-war period. Thus, the main difference between these two countries is number of boats and fishermen during the first period, the mean number of sponge fishing boats in Tunisia was 721 with 2,315 fishermen (average 3 per boat), while Greece had three times fewer boats all with about the same number of fishermen (average 10 to 11 per boat).

CPUEs by boat and by fisherman were significantly different (Mann-Whitney *U*-test, $p < 0.05$) in both periods, Greece had higher CPUEs reflecting the efficiency of hard-hat and hookah diving used by Greeks compared to the *kamaki* used in Tunisia. Greek sponge fishermen generally relied solely on sponge fishing for their livelihoods, whereas in Tunisia, sponge fishing represented only part of fishermen's annual income.

At a broader scale, we assembled data from other Mediterranean sponge fishing countries for 1947–1956, 2009, and 2013–2017 for comparison (Fig. 5).[8] During the post-World War II period, the Libyan coast produced 106,000 kg/p.a. on average, but only 26,000 kg were landed by local fishermen (Anderson & Blake, 1982; Milanese et al., 2008). Tunisian fishermen reported that they still fished in Libyan waters in 2010, before the Arab spring. FAO Fisheries Department[9] indicates that Libya had a mean annual production of only 2,200 kg between 2013 and 2017, with no production at all

[8] Data for Croatia come mainly from Rančić et al. (2010) and included references, for Cyprus from the report Economou and Konteatis (1990), for Libya from Anderson and Blake (1982), and for Turkey from Yürekli (2012).

[9] See FAO FishStat Global production by production source Quantity (1950–2021) for "Libya", "sponges", "Capture production" and the concerned years. Accessed in 2023. https://www.fao.org/fishery/statistics-query/en/global_production/global_production_quantity.

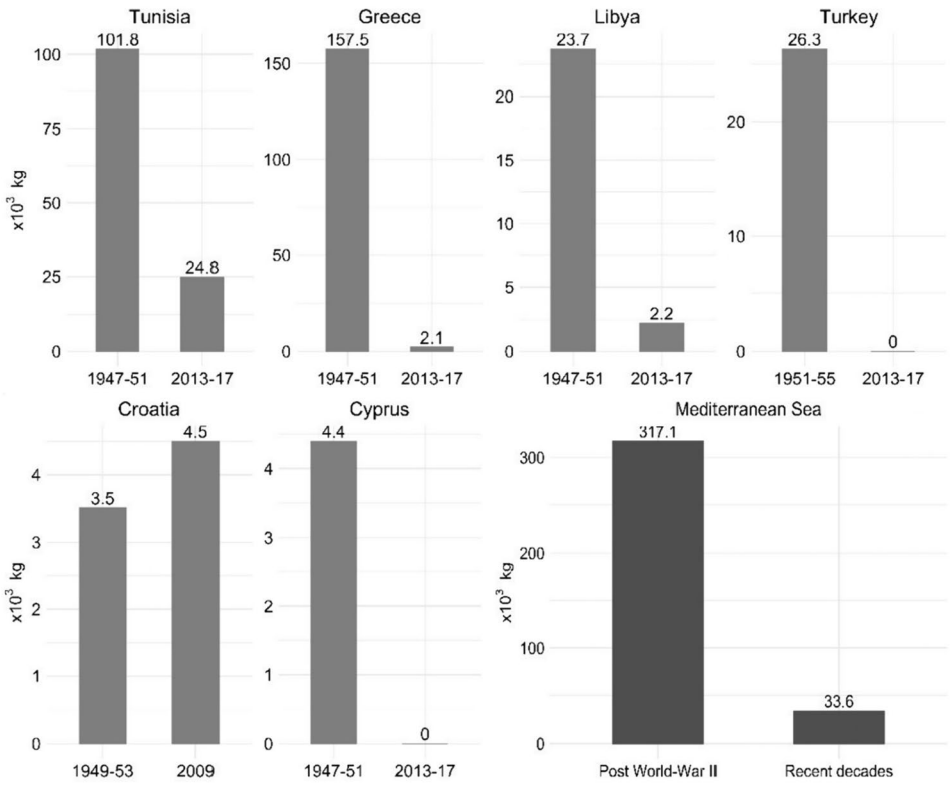

Fig. 5 Post-war and recent mean annual sponge landings of the Mediterranean sponge producing countries

in 2017 and 2018. Turkish annual sponge landings were over 25,000 kg at the beginning of the 1950s (Yürekli, 2012) but landings no longer exist, as is also the case in Cyprus and Libya. No data were available for the post World War II period for Egypt, Lebanon and Syria. As of 2009, Croatia is the only Mediterranean country that shows a small increase in average annual sponge landings (Fig. 5) (Rančić et al., 2010), since the north-eastern Adriatic has practically not been affected by the sponge mortality events.

Current Mediterranean sponge landings are only 11% of the post-World War II production (34,000 kg against the previous 317,000 kg). The sponge fisheries of Egypt, Syria, Lebanon, Turkey, Cyprus, and Libya have disappeared in a few decades and by 2018, only Tunisia, Greece, and Croatia support sponge fisheries (Fig. 6). The most recent data available indicate that latest Tunisian sponge landings amounted to 10,000 kg in 2019 and 3,000 kg for 2020[10]. Our informants in the only remaining Greek sponge fishing centre, Kalymnos, reported that although sponge fishing licences are still acquired, no one has been harvesting sponges in the past two to three years.

The first epizootic event severely affected all bath sponge species throughout the Eastern Mediterranean Sea and undeniably marked a critical point for this fishery. As reported by the Tunisian, Greek and Cypriote sponge fishermen, mortalities devastated bath sponges in 1986–87. This mortality event spared the Northern Aegean and Adriatic Sea probably due to cooler sea temperature regimes. Sponge diseases had already been registered in the past, as in 1905–1906 in Tunisia (Allemand-Martin, 1906), but landings had not been impacted (Fig. 3B).

Further, more or less localised mortality events have been reported in the interviews conducted with fishermen specifically for the years 1991, 1996, 1999, 2003, 2005, 2013 and 2017 in various areas of the Mediterranean Sea including the Northern Aegean. Lately, a marine heat wave that occurred at the end of the summer 2022 in the North-Western Mediterranean, resulted in mass mortalities of several species, including bath sponge monitored populations that were simply wiped out down to 25 m (Grenier et al., 2023). Where sponge fishing subsisted after 1986, quantities of sponges annually landed as well as CPUEs are irregular, with an important inter-annual variability (Fig. 4D, E). This is due to the erratic and decreasing availability of bath sponges resulting from the increasing frequency of mass mortality events that have been affecting sessile species in the Mediterranean these last decades (Crisci et al., 2011; Grenier et al., 2023; Lejeusne et al., 2010; Pairaud et al., 2014; Pérez et al., 2000; Rivetti et al., 2014).

[10] See *Annuaire Statistique de la Tunisie 2016–2020* published in 2021 Fisheries and aquaculture department of Tunisia available here.

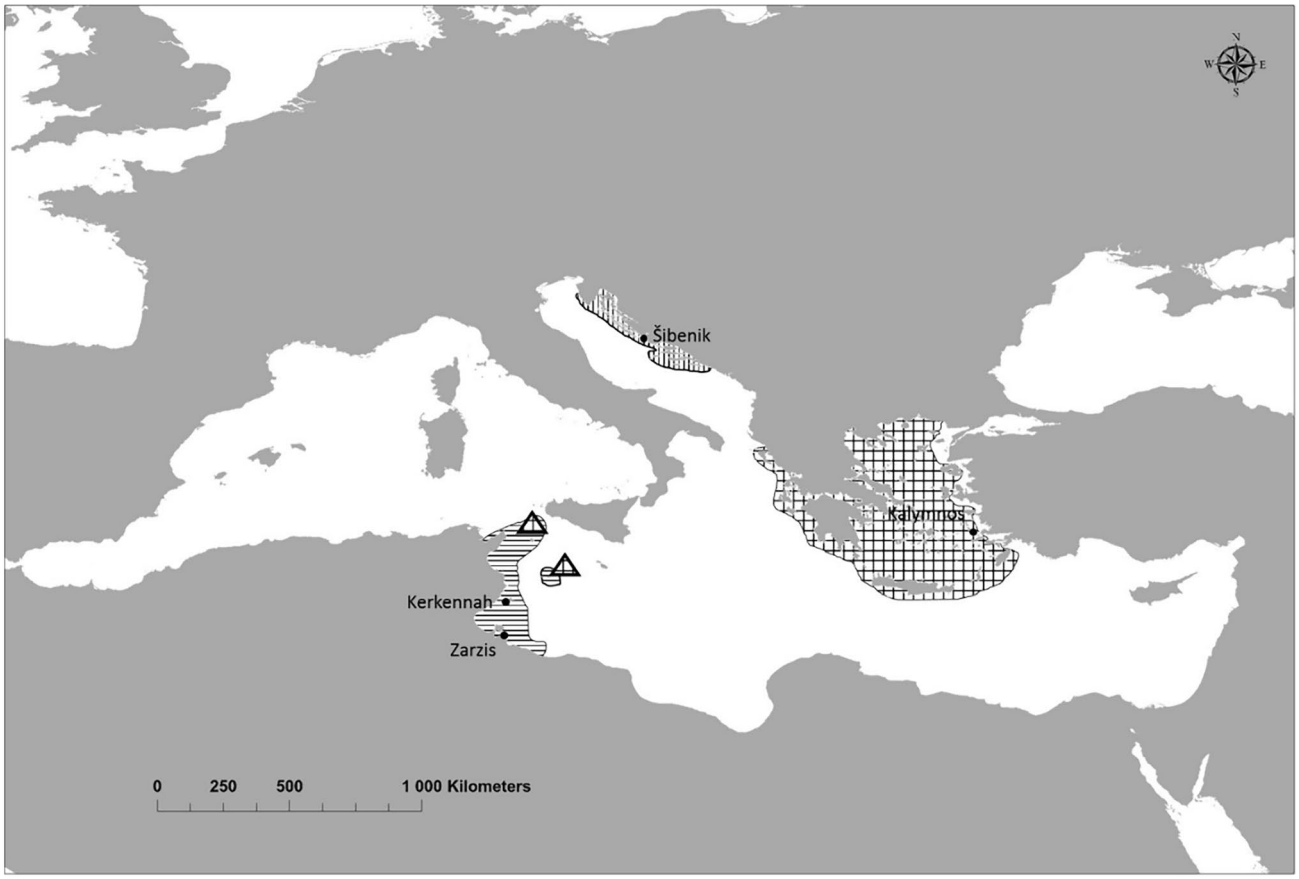

Fig. 6 Sponge fishing areas reported since 2010. Sponge fishing areas of Greeks in checked motif, Tunisian in horizontal lines and Croatian in vertical. Triangles indicate areas occasionally frequented by Greek sponge fishermen

Conclusion

Mediterranean coastal fisheries play an essential role in feeding and structuring coastal communities in the Mediterranean (FAO, 2020; Tzanatos et al., 2005) which are highly vulnerable to climate change and other anthropogenic impacts that have considerably altered the marine environment in recent decades. Conservation measures and sustainable management plans at a regional level are urgently needed to mitigate cumulative anthropogenic impacts on marine resources. Average sponge landings between 2013 and 2017 represented only 11% of average landings in the post-war period and 7% of their height at the end of the nineteenth century. Nonetheless, there is significant and possibly increasing demand for natural sponges and prices remain high as confirmed by Greek fishermen and merchants during interviews. Faced with a highly uncertain future for this sector, the evolution of sponge fishing can serve as a model illustrating the threats and the alternative futures facing small-scale Mediterranean fisheries in general.

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Author Contributions TP and DF supervised the project. MF created the database and managed the data. All authors contributed extensively to the final manuscript.

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Declarations

Ethical Approval Not applicable.

Competing Interests The authors declare no competing interests.

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