35 Effect of Climatic and Anthropogenic Disturbances on Sponge Fisheries

Thierry Pérez and Jean Vacelet

Abstract

The commercial sponge industry is a fascinating cultural heritage of several Mediterranean countries, where it continues to represent an important economic activity. Mediterranean bath sponges are of the highest quality and the commercial demand for them is still significant, however, sponges are suffering from environmental disturbances that seem to be occurring more frequently in recent decades. Here we present some general data about commercial sponges of the Mediterranean Sea, and examine probable consequences of both overfishing, which has been occurring for many centuries on most sponge beds, and the effects of climatic change, which appears to be responsible for increased disease outbreaks and mass mortality events. Together these disturbances may alter the species distribution. We also examine the potential future of sponge cultivation under these conditions.

Keywords

Porifera • Bath sponges • Biology • Ecology • Population • Global change

Introduction

Sponge fishery has a long history in the Mediterranean Sea, where it represents a fascinating cultural heritage (Pronzato and Manconi 2008). Commercial sponges have been used for domestic purposes since high Antiquity, especially in Greece (Arndt 1937; Voultsiadou et al. 2011). Traces of sponge use have been found in the Minoan civilization in Crete dating back to approximately the nineteenth century BC. Sponge harvesting was undertaken for a long time by free divers (Castritsi-Catharios 1998; Warn 2000; Voultsiadou et al. 2011). It became more intensive with the development of diving techniques, and improvements in dredging technology in the late nineteenth century. At the same time, demand has increased worldwide, which has been satisfied by an extension of exploitation to other seas such as the Caribbean Sea and the Pacific Ocean. Simultaneously there has been severe depletion of Mediterranean sponge grounds. Overfishing was already occurring in the first half of the twentieth century, causing the emigration of many Greek sponge fishermen, especially to Florida. Comparisons of ancient and recent sponge populations in Cyprus, Crete and Sardinia show dramatic falls of sponge abundance in recent decades (Pronzato et al. 1999). Furthermore, several instances of diseases and mass mortality events have severely affected sponge fisheries in the twentieth century. Nowadays, although commercial demand is declining due to the use of cheaper artificial sponges, bath sponge stocks face serious decline in the Mediterranean due to the combined effects of overfishing, diseases and climate change. In this chapter, we aim to present the current status of Mediterranean commercial sponges and how it will be affected by environmental disturbances.

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Fig. 35.1 Underwater photographs of (**a**) *Hippospongia communis*, (**b**) *Spongia officinalis*, (**c**) *Spongia lamella* (Photos T. Pérez/CNRS)

Fig. 35.2 Treatment of sponges in Tunisia (Photo Nicole Boury-Esnault)

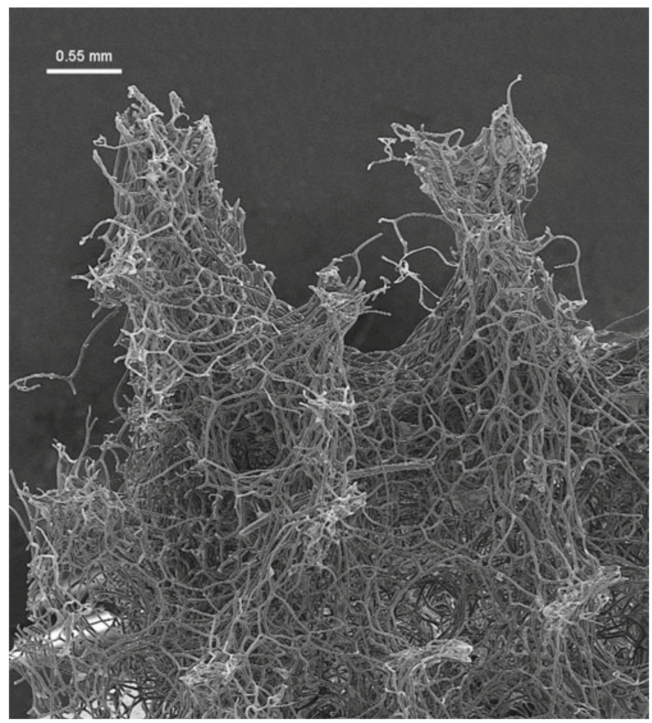

Fig. 35.3 Scanning electron microscope view of the skeleton of *Spongia* (*Spongia*) *officinalis*

The Mediterranean Commercial Sponges

Among the numerous species of sponges currently reported from the Mediterranean Sea, only five species of the genera *Spongia* and *Hippospongia* (Fig. 35.1) are presently used for domestic purposes. These commercial sponges are classified in the Class Demospongiae, Order Dictyoceratida in which the skeleton consists only of a reticulation of fibres, without the siliceous spicules found in most other demosponges.

The commercial sponge is the cleaned skeleton of the species of the Spongiidae family (Fig. 35.2). The skeleton is a dense network of two types of fibres (Fig. 35.3). The primary fibres, 40–100 µm in diameter, are rather scarce. They generally contain a small amount of foreign bodies, sand grains or foreign spicules. They ascend towards the surface, where they generally protrude in small conules. The secondary fibres, 6–35 µm in diameter, build a very dense reticulation (Fig. 35.3). These fibres consist of a collagen named ‘spongin’. The reticulation made by these fibres is remarkable by its softness, elasticity, resistance and high water retention capacity, which are all of top quality and clearly superior to that of artificial or plant ‘sponges’.

Five species are commonly harvested in the Mediterranean (Pronzato and Manconi 2008): *Spongia* (*Spongia*) *officinalis* Linnaeus, 1759; *Spongia (Spongia) mollissima* Schmidt, 1862; *Spongia* (*Spongia*) *lamella* (Schulze, 1879); *Spongia* (*Spongia*) *zimocca* Schmidt, 1862; *Hippospongia communis* (Lamarck, 1814). The distinction between *S. mollissima* and *S. officinalis* as distinct species (Pronzato and Manconi 2008) is still under discussion, and Voultsiadou et al. (2011) and Dailianis et al. (2011) still prefer to maintain its classification as a subspecies of *S. officinalis* together with the subspecies *adriatica*. They are known by different commercial names by the sponge traders, sometimes depending on local varieties and local traditions. Their respective abundance is variable in the diverse areas of the Mediterranean, as well as the depth to which they may occur in sufficient abundance to permit profitable exploitation. Most of the productive sponge banks are located in the eastern basin of the Mediterranean Sea (Tunisia, Libya, Greece, Egypt), and there is also a significant production in the Adriatic Sea (Croatia). In other countries such as Spain, France or Italy, the sponge fishery is trivial, with small amounts of sponges being sold mainly on local markets.

All Mediterranean commercial sponges are included as protected species in the Appendix III of the Bern Convention on the Conservation of European Wildlife and Natural Habitat.

Spongia (*Spongia*) *officinalis*, 'Greek bath sponge' (English), 'Fine Grecque' (French), 'Matapas' (Greek), is massive, spherical or lobate. The primary fibres contain foreign bodies, the secondary fibres, 20–35 μm in diameter, are free of inclusions. It is common throughout the whole Mediterranean, from 0.5 m (under overhangs) to 40 m depth, but may occur at greater depths, especially in the Aegean Sea where it has been recorded as deep as 100 m (Kefalas et al. 2003). This species is of excellent commercial quality and is highly regarded, especially for bath use. It constitutes a large part of the Mediterranean production, for instance 37.3 % of the Kalymnian sponge fishing fleet production in 1996 (Castritsi-Catharios 1996; Castritsi-Catharios et al. 2007).

Spongia (Spongia) mollissima, 'Turkey cup' or 'Levantine' (English), 'Melati' (Greek), 'Fine Syrie' (French), is roughly cylindrical or in the shape of an inverse cone with an enlarged flat or depressed summit, or cup-shaped with thick walls. The fibres are similar to those of *S. officinalis*, with slightly thinner secondary fibres (10–25 μm in diameter). The species is recorded only from the eastern Mediterranean, generally 10–30 m in depth, although there are records deeper than 120 m in the Aegean Sea (Kefalas et al. 2003). It is considered as the best bath sponge in the world, but represents only a small part of the Mediterranean production; for instance 15.3 % of the Kalymnian sponge fishing fleet production in 1996 (Castritsi-Catharios 1996; Castritsi-Catharios et al. 2007).

Spongia (*Spongia*) *lamella*, 'Elephant Ear' (English), 'Oreille d'éléphant' (French), 'Lagophyto' or 'Psathouri' (Greek) has been called *Spongia agaricina* Pallas, 1766 for a long time due to a confusion with an Indian Ocean species (Pronzato and Manconi 2008). This sponge is lamellar, most often forming a more or less regular cup up to 1 m in diameter, exceptionally up to 3 m in diameter (Castritsi-Catharios et al. 2011a). The primary fibres are cored by foreign bodies, the secondary fibres are 20–40 μm in diameter. The species is found in the whole Mediterranean area. Its depth distribution, however, differs in the two Mediterranean basins. In the western basin, it is present from a few metres to 110 m in depth, whereas in the eastern one it is generally found in depths from 50 to 110 m. Its commercial quality is considered to be very good, with a higher resistance to tearing than other commercial sponges (Castritsi-Catharios et al. 2011b). Due to its lamellar shape, it is mainly used for cosmetic and for polishing glasses or pottery, and there is still a significant demand according to a French sponge trader (C. Cypreos, personal communication, www.sponges.fr). Its production, however, is not large, for instance 3.1 % of the Kalymnian sponge fishing fleet production in 1996 (Castritsi-Catharios 1996; Castritsi-Catharios et al. 2007).

Spongia (*Spongia*) *zimocca*, 'Tsimoucha' (Greek), 'Chimousse' (French), 'Leather sponge' (English), 'Zimoukha' (Arabic/Tunisian), is a massive sponge, generally irregularly lobate but rather variable in shape, up to 25–30 cm in diameter (Castritsi-Catharios et al. 2011b). The primary fibres are uncored; the secondary fibres are generally of two size classes, the thinner being 5–18 μm in diameter. The skeleton is rather rough and harsh when compared to the other Mediterranean commercial sponges, with the lowest elasticity and resistance to tearing (Castritsi-Catharios et al. 2011b). Accordingly, its commercial value is relatively low. The sponge is recorded at depths of 25–85 m, and is harvested only in the eastern basin. Its presence in the southwest of the western basin is possible, but not confirmed. This species constitutes a small part of the sponge production in the Mediterranean, for instance 4.4 % of the Kalymnian sponge fishing fleet production in 1996 (Castritsi-Catharios 1996; Castritsi-Catharios et al. 2007).

Hippospongia communis, 'Honey Comb' or 'Horse sponge' (English), 'Eponge commune' or 'Eponge cheval' (French), 'Kapadiko' (Greek), is massive, most often subspherical, with few conules. It is characterized by very large internal cavities. The primary fibres are reduced and contain foreign bodies. The secondary fibres are 20–30 μm in diameter. The commercial value is good, but its skeleton is less soft than that of *S. officinalis* and *S. lamella*, which are preferred for bath use. The species is widely distributed throughout the Mediterranean, often occurring in seagrass beds, sometimes very shallow especially in Tunisia, but also on rocky substrates up to 40 m deep and possibly more. It constitutes the main part of the Mediterranean sponge production, for instance 40 % of the Kalymnian sponge fishing fleet production in 1996 (Castritsi-Catharios 1996; Castritsi-Catharios et al. 2007).

There are two other species of *Spongia* in the Mediterranean, which are not, or rarely, collected for domestic use. *Spongia (Spongia) virgultosa* (Schmidt, 1868) is a small, encrusting sponge (Pronzato et al. 1998) with a rather harsh skeleton. *Spongia (Spongia) nitens* (Schmidt, 1862), with a massive lobate shape is generally smaller than the five commercial species. It has a very soft skeleton and a high water retention capacity, but is very fragile.

Biology and Reproduction of the Commercial Species

Nutrition and Filtering Activity

Commercial sponges are regarded as among the most efficient benthic suspension feeders of the Mediterranean Sea as they are capable of intense pumping activity. Overall, sponges have already been shown to feed on ultraplankton (<10 μm) and particularly on picoplankton (<2 μm) (Pile et al. 1996, 1997). Savarese et al. (1997) evaluated that the grazing ability of large sponge beds could significantly deplete picoplankton near the bottom. New technologies such as flow cytometry were used recently to determine more accurately which group of planktonic cells constitutes the main source of carbon for a number of sponge species. Most of these studies involved sampling both the inhaled and exhaled waters of sponges living under various environmental conditions in order to estimate the natural filter feeding capacity (see for instance Yahel et al. 2003, 2005, 2007; Pile and Young 2006; Trussel et al. 2006). Only one recent study has aimed to investigate the feeding capacity of a Mediterranean commercial sponge. *Spongia officinalis* was studied under natural conditions in order to assess its efficiency at retaining very small particles (<20 μm), and determine the origin of assimilated carbon by coupling flow cytometry and stable isotope analysis (Topçu et al. 2010). This study showed that *S. officinalis* efficiently retained the main picoplanktonic groups, and it also indicated a size selectivity of particles with significantly lower retention efficiencies for nanoplankton than picoplankton. Whereas picoplankton, such as cyanobacteria and picoeucaryotes, constituted the major food source of *S. officinalis* in terms of particle abundance, most of the carbon retained in term of biomass originated from nanoeukaryotes. Thus, this study demonstrated that even though sponges were known to retain smaller particles than other filter-feeding organisms, which is an adaptive advantage in oligotrophic environments, they are also able to efficiently assimilate carbon from larger organisms such as nanoeukaryotes. This feeding strategy permits sponges to optimize their energy intake. This study also showed a significant increase in retention efficiency in Spring compared to Winter, suggesting an increase in energy needs related to reproduction or growth. Finally, this study indicated that *S. officinalis* excretes faecal pellets as observed in previous studies of other sponge species (*e.g.* Wolfrath and Barthel 1989).

This first novel combination of techniques (Topçu et al. 2010) demonstrated that comprehensive studies of sponge feeding strategies would help to better understand the importance of sponges and their potential role in organic matter recycling. Moreover, by transposing this approach to a selection of other suspension feeders growing on Mediterranean hard substrates, it will be possible to better understand the functional role of sponges in benthic-pelagic coupling. Commercial sponges appear to be highly sensitive to environmental stress related to global climate change (Lejeusne et al. 2010), thus this approach using these species as models, may be useful to assess the potential impact of environmental disturbances, such as the effect of climate change on the function of benthic systems.

Reproduction and Genetics

Knowledge of bath sponge reproductive biology is well advanced. Allemand-Martin (1906) first observed the sexual reproduction of *H. communis* from Sfax and Kerkennah. A second significant study by Tuzet and Pavans de Ceccatty (1958) effectively described its gametogenesis and embryonic development, which was confirmed later by ultrastructural investigations of spermatogenesis (Gaino et al. 1984) and embryogenesis (Scalera-Liaci et al. 1971). Finally, some aspects of the reproductive cycle of the species from the Spongiidae family were investigated in more recent studies of: *Spongia* spp. and *Hippospongia* spp. from the Gulf of Mexico and the Caribbean Sea (Kaye 1991; Kaye and Reiswig 1991a, b), and *Coscinoderma matthewsi* from the Pacific (Abdul Wahab et al. 2012). Some observations have been obtained recently for other Mediterranean species *S. officinalis* (Baldacconi et al. 2007), and *H. communis* (Zarrouk et al. in press).

The general reproductive pattern of bath sponges seems to be similar to those reported for other Dictyoceratida (Scalera-Liaci et al. 1971; Hoppe 1988; Kaye and Reiswig 1991a, b; Baldacconi et al. 2007; Whalan et al. 2007; Chung et al. 2010; Ereskovsky 2010). Sperm cells originate from choanocytes, with choanocyte chambers evolving into widespread spermatic cysts throughout the choanosome, whereas oocytes are derived from archaeocytes. *H. communis* and *S. officinalis* are gonochoric and ovoviviparous. Successive hermaphroditism, with alternate production of oocytes and spermatic cysts in the same reproductive season, has been rarely observed (Baldacconi et al. 2007). Oocytes and embryos are produced all year round, whereas

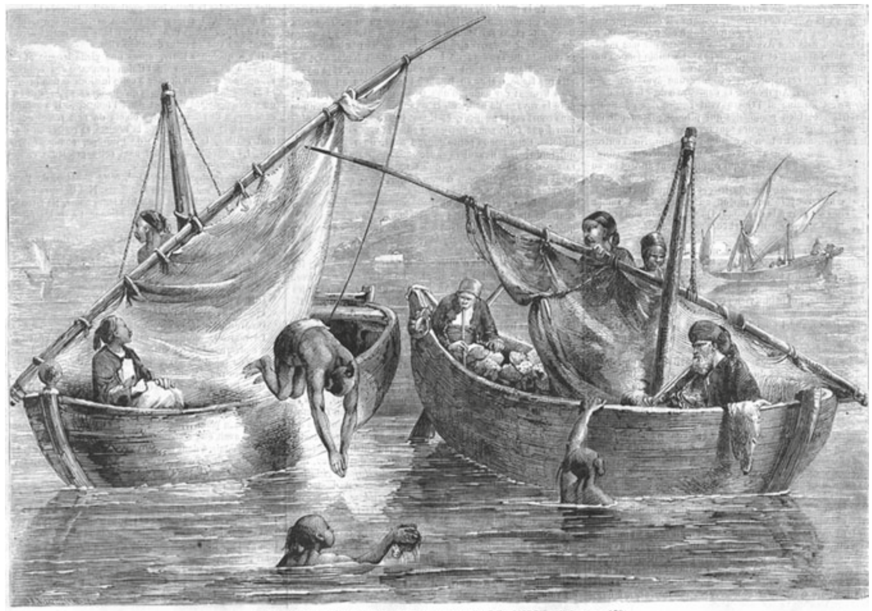

Fig. 35.4 Sponge fishery in Syria (from 'L'Univers Illustré', 13 September 1865). Syria was the main producer of the Levantine sponge, or 'fine Syrie' in the nineteenth century. Its production is now completely stopped

spermatogenesis generally occurs in a shorter period (Autumn or early Winter depending on the Mediterranean species). In females, a given individual is able to develop young oocytes and develop larvae at the same time. Whatever the Mediterranean species considered, the larvae are generally released between May and July (Baldacconi et al. 2007; Zarrouk et al. in press, and unpublished data). However, the most recent study showed a difference in the timing of release of larvae between two locations experiencing very distinct thermal regimes. In *H. communis*, the warmest temperatures tend to increase the reproductive effort, accelerate the embryogenesis and trigger larval release (sooner in the warmest region) (Zarrouk et al. in press). This work indicated that temperature is a key factor controlling the reproductive strategy of bath sponges, as already shown in other demosponges (Fell 1976; Witte and Barthel 1994; Witte et al. 1994; Meroz-Fine et al. 2005; Ereskovsky 2010).

Thus, in the context of global warming of the Mediterranean Sea, some effects on sponge reproduction patterns can be expected, but we do not know yet if these changes would constitute true adaptive responses. Moreover, further investigations of larval biology and the recruitment of bath sponge juveniles are needed to obtain a comprehensive understanding of the population dynamics and establish a conservation plan for sponge beds.

The first studies on the genetic diversity of commercial sponges (Noyer et al. 2009; Dailianis et al. 2011) have shown they have a high level of genetic variability. This suggests that after mass mortalities due to global warming, re-colonization could occur from more tolerant populations. Such studies will also provide a basis for effective management of the species (Dailianis et al. 2011).

Sponge Fishery in the Mediterranean Sea

Most of the Mediterranean sponge production is harvested by divers, using SCUBA diving, or hookah or narghile diving. Free-diving has been the main method for centuries, but is now rarely used (Fig. 35.4). Similarly, hard-hat diving equipment is only used for tourist exhibitions nowadays. Sponge divers rarely work deeper than 40 or 50 m. Decompression tables were ignored or badly respected during most of the twentieth century, and are still sometimes inappropriately followed, resulting in decompression diseases (*e.g.* the so-called 'bends'). There are many paralysed sponge fishermen within these communities (*e.g.* Flégel 1910; Warn 2000). A special dredge named 'gangava', which allows the exploitation of sponges from deeper depths, is still used in the eastern Mediterranean (Castritsi-Catharios et al. 2011b), although it is highly destructive of other benthic fauna. In shallow waters, especially on seagrass beds or shallow rocky substrates up to 15 m depth, *H. communis* and sometimes also *S. officinalis* may be collected by surface visual methods with the fisherman looking from the surface through a cylindrical tube fitted with glass at one end and using a harpoon ('kamaki') to collect the sponge.

The production of commercial sponges has been highly variable, partly due to the occurrence of sponge diseases, which have altered the balance between the Mediterranean and the Central West Atlantic production. The maximum production was in the 1930s. According to Arndt (1937), the world production of sponges averaged 1346 metric ton/year between 1927 and 1936, the Caribbean and Gulf of Mexico being the main producers (998.5 t/year compared to 347.5 t/year from the Mediterranean). The figures were considerably lower in the 1980s, with a global production recorded by

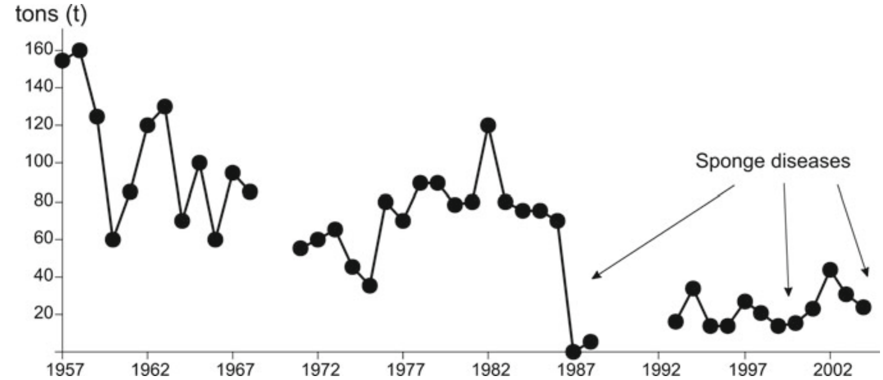

Fig. 35.5 Survey of the Tunisian Sponge fishery between 1957 and 2004. *Arrows* indicate putative effects on catches of successive sponge diseases (Data from the 'Commissariat général aux pêches' (1957–1988) and the 'Direction Générale de la Pêche et de l'Aquaculture' (1993–2004) of Tunisia)

FAO of only 130 t (Wells 1983). This decrease was mainly due to a disease which swept through the sponge beds in the West Atlantic in 1938 and in the following years; there was practically no sponge production for many years. During that time the Mediterranean was the main sponge producer, resulting in severe depletion of the sponge beds due to overfishing. The sponge industry has now somewhat recovered in the West Atlantic, although it has still not fully revived (Storr 1964; Stevely and Sweat 1985), due to the disappearance of local fishermen, most of them being of Greek origin, and possibly also to a decrease in sponge abundance linked to recent climatic change (West et al. 2011).

The Mediterranean sponge fisheries are again facing serious threats of overexploitation, and have also suffered from several episodes of mortality. In Tunisia, which is the main producer of the honey comb (*Hippospongia communis*), production from 1957 to 2002 was highly variable, with severe depletions due to diseases and mass mortality events (Ben Mustapha and Vacelet 1991; and Fig. 35.5). It appears from accounts of old fishermen that the commercial sponges were incredibly more abundant during the 1930s, with more than 200–300 specimens/100 m^2 whereas more recently, the mean density on unexploited sponge banks is often less than 50 specimens/100 m^2 (Pronzato 1999; Pronzato et al. 1999). According to Voultsiadou et al. 2011, bath sponge populations are considerably reduced compared to previous time periods. Sponge beds from the easternmost part of the Mediterranean Sea (Syria, Lebanon, Cyprus), which were famous for the production of the high quality 'turkey cup', now contain very low populations of commercial sponges; a depletion which may be partly due to the influence of the Aswan dam on the Nile River reducing the input of seasonal nutrients.

Sponge Culture

Over-exploitation of sponge beds has long been a problem and is becoming worse with the occurrence of diseases, which appear to be increasing in frequency, possibly due to global warming. It is appealing to combat overexploitation by culturing sponges, which appears at first sight to be easy due to the great regeneration power of sponges. A 'mother sponge' can be cut into several pieces, which when secured on ropes or various substrata in suitable environments, can grow to commercial size in a few years. This method, called culture by fragmentation, has been tried often in the Mediterranean as early as 1862 (Marenzeller 1879), in the Caribbean and in the Pacific (review in Vacelet 1985), and experiments and pilot exploitation are currently being undertaken. Other methods, such as the reorganization of small sponges from dissociated cells or collection of larvae on substrate collectors, were never successful but may be reassessed in the future (Abdul Wahab et al. 2012).

Sponge culture by fragmentation, although simple and experimentally successful, has never been a commercial success in the Mediterranean (Vacelet 1985; Verdenal and Vacelet 1990; Pronzato et al. 1999). The main problem is the rather slow growth rate of the cuttings, which increases risks of destruction of the 'sponge farm' by storms or epizootic diseases, and the variable percentage of mortality. Rapid growth, with explants doubling or tripling in size in a year, has been reported, but rarely occurs on a regular basis in the Mediterranean, especially in areas where the temperatures are rather low (Celik et al. 2011). Some 'sponge farms' in the Pacific (Adams et al. 1995; Croft 1995; Duckworth 2009) have provided the market with productive output for several years. However, their profitability has never been particularly rewarding, although they may be interesting for coastal indigenous communities (Duckworth 2009). Several large-scale experiments, with up to 700,000 cuttings in the Caribbean in 1938, were destroyed by an epizootic disease (Smith 1941), possibly exacerbated by the high concentration of sponges in the farm. However, the profitability and interest in sponge farming has to be reconsidered with the present increase in prices due to the depletion of natural production and an increased interest in natural products (Verdenal and Verdenal 1987). Furthermore, sponge farming, even though not fully profitable by itself, may be interesting in an integrated mariculture system, in which intensive culture of filter-feeders such as sponges has been proposed in order to control increased eutrophication under fish culture cages (Pronzato 1999; Abdul Wahab et al. 2012).

Pollution Effects, Diseases and Mass Mortality Events

It is conceivable that sponges may be highly sensitive to pollution, considering their natural filter feeding activities. Actually, the most productive sponge beds are generally located in areas that are not subjected to heavy pollution. However, Mediterranean commercial sponges are able to withstand some level of urban pollution, provided they are protected from heavy sedimentation. For instance, a large population of *S. officinalis* is present under overhangs some 300 m from the sewage outlet of the city of Marseille. Under these conditions, however, the sponge skeleton is heavily encrusted with particles of iron oxide, decreasing its resistance and commercial value, and culture experiments suffered from high mortality and low growth rates (Vacelet et al. 1988; Verdenal and Vacelet 1990). *Spongia officinalis* appears to have some of the fundamental characteristics of the ideal 'biomonitor' of trace pollutants. It may live in diverse pollution conditions, has a long life span, and filters a considerable amount of water with a rather well known particle retention ability (Topçu et al. 2010). Several studies conducted on this species showed its ability to strongly accumulate metals in higher concentrations than those found in other biomonitor species, to reflect accurately the level of contamination at a given site (Verdenal et al. 1990; Perez et al. 2005), and even to degrade some complex organic compounds (Perez et al. 2002, 2003).

Bath sponges could be affected by the introduction of invasive species, which already play a key role in changes underway in the Mediterranean Sea (Lejeusne et al. 2010). An example is the macrophyte *Caulerpa racemosa*, which has already resulted in a significant decrease in the percentage cover of sponge assemblages (Baldacconi and Corriero 2009). Harmful effects of invasive *Caulerpa* spp. on commercial sponges have not been reported, but have been shown for massive keratose sponges such as *Sarcotragus spinosulus* (Zuljevic et al. 2011).

Commercial sponge mass mortalities occurred in the Mediterranean at the end of the nineteenth and in the early twentieth centuries (Arndt 1937), but as far as we know they were never as devastating as the disease which completely stopped the sponge industry for years in the West Atlantic after 1938 (Galtsoff 1942). It appears, however, that episodes of mass mortality since the 1980s are more frequent and more severe among commercial sponges as well as among other diverse invertebrates; these events are likely linked to thermal anomalies and global warming (Lejeusne et al. 2010). This appears to be a general observation which is not only restricted to the Mediterranean (Webster 2007). Heat stress is often recognized to trigger the disease outbreak, and the frequency of these events has clearly increased over the last three decades because of climate change (Lejeusne et al. 2010). The first signs of sponge disease are often associated with a change in colour or bleaching (similar to 'coral bleaching' in tropical coral reefs), the development of a bacterial white veil on the epidermis, followed by a rather rapid decomposition of the skeleton (e.g. Pérez et al. 2000). Among the best documented events was the severe mortality on the Mediterranean sponge beds in 1986 which dramatically decreased sponge production, especially in Tunisia (Fig. 35.5). This disease outbreak motivated an inquiry mandated by the FAO to assess the incidence and virulence of the phenomenon, and to identify its possible causes (Vacelet 1994). Several studies showed that the disease resulted in a bacterial attack on the spongin skeleton (Gaino and Pronzato 1989; Vacelet et al. 1994). The authors argued that the virulence of this pathogen could have been triggered by high seawater temperatures, an explanation that was also proposed in a case of coral bleaching in the eastern Mediterranean (see for instance Kushmaro et al. 1996). The possible agent of subsequent sponge mass mortality events in 1999 and 2003 remains unknown. After the 1999 Mediterranean multispecies mass mortality, the potential role of pathogenic microorganisms has often been proposed (Cerrano et al. 2000; Pérez et al. 2000; Martin et al. 2002), but the infectious origin of the disease outbreak has been demonstrated only for gorgonians (Bally and Garrabou 2007). In that case, the authors also proposed that the introduction and spread of a pathogenic *Vibrio* might have been promoted by climate warming (Bally and Garrabou 2007).

The context of warming reported around the Mediterranean is probably behind these mass mortality events which have affected the Mediterranean sponge beds. The 1980s corresponded to a succession of positive North Atlantic Oscillations. Both in 1999 and 2003, the analysis of meteorological data and seawater temperature records highlighted exceptional temperature patterns in the NW Mediterranean. Unfortunately, there is a lack of data outside this region, although the 1999 mortalities have been related to similar temperature anomalies in Tunisia and the Aegean Sea (Pérez et al. 2000; Lejeusne et al. 2010). In the NW Mediterranean, seawater temperatures in the summer of 2003 were the warmest in 30 years (Coma et al. 2009; Garrabou et al. 2009). In both years 1999 and 2003, not only were temperatures high, but also the warm and stable conditions lasted for an unusually long time; a positive correlation was observed between mortality rates and exposure to heat stress (Garrabou et al. 2009). The severity of the 1999 event was very high, with for instance about 50 % of *S. officinalis* individuals

Fig. 35.6 Survey of a labeled individual of the *Spongia officinalis* population in the Port-Cros National Park. During the last 10 years, this individual suffered several necroses which affected its shape and made its size highly fluctuate between 3,000 and 7,000 cm^3. Here it is illustrated by underwater photographs of this individual taken in 2007 with no necrosis, in 2009 with a high necrosis rate, and in 2010 with the remaining healed part of the individual (Photos T. Pérez/CNRS)

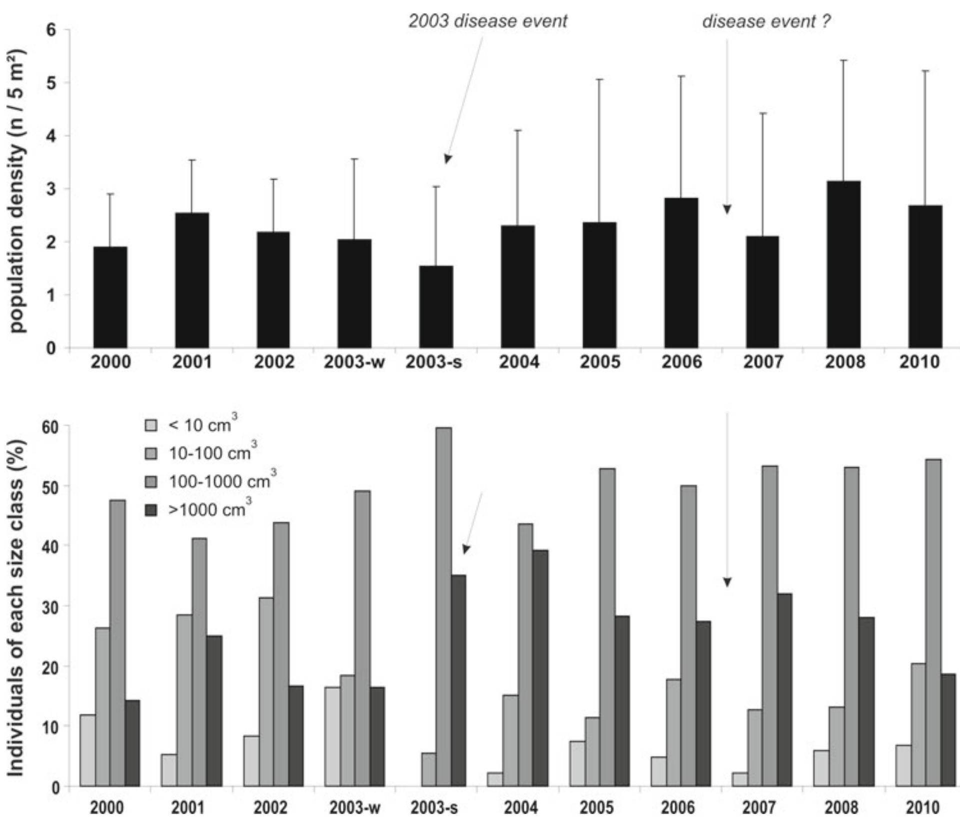

Fig. 35.7 *Spongia officinalis* populations in the Port-Cros National Park were monitored in 1 × 5 m quadrats deployed on a permanent transect. Each year, a minimum of 20 quadrats were studied during winter, with an additional survey in summer of 2003 after the mass mortality event. No surveys were performed in 2009. Sponge volumes were assessed by measuring their three largest dimensions. The resulting indicator of size expressed in cm^3 corresponds to the smallest box where the sponge can be inserted without any squeezing. Size classes: <10 cm^3 correspond to newly recruited individuals; 10–100 cm^3 to individuals of 1–3 previous year classes; 100–1,000 cm^3 to individuals of average size; and >1,000 cm^3 to large individuals

affected in the Port-Cros National Park, and mortality rates of about 90 % in some other locations. The other commercial species that were known in Port-Cros, *S. lamella* and *H. communis*, totally disappeared, and only scattered individuals of *S. officinalis* have survived in this part of the NW Mediterranean. Since then, population monitoring has been implemented in locations where this species is most abundant (Figs. 35.6 and 35.7). The surveys conducted over

10 years showed a population density fluctuating slightly between 2 and 3 individuals per 5 m^2 (on average). The effects of the 2003 event has been detected both in overall incidence (about 25 % of sponges affected, and a decrease in population density to 1.5 individuals per 5 m^2), as well as a change in population size structure (Fig. 35.7). Whereas small sponges of less than 100 cm^3 in size represented about 35 % of the surveyed population before the mortality (38, 34 39, 35 % in respectively 2000, 2001, 2002 and winter 2003), they only represented approximately 5 % after the summer of 2003. The youngest specimens thus appeared to be more sensitive to heat stress; although the mortality was followed by a strong recruitment of new sponges, this category remained less represented in the population than previously (17, 19 and 23 % in respectively 2004, 2005 and 2006). A new drop in population density observed in 2007 (from 2.8 individuals per m^2 in winter 2006 to 2.1 individuals in winter 2007), together with a decrease in percentage of young sponges (from 23 to 15 %), might be related to a new but moderate mortality event that occurred in summer 2006 (Fig. 35.7). Thus, since 2003, some localized mortality episodes have been observed almost every year in different regions of the NW Mediterranean Sea, but the extent of these episodes has been very limited.

Conclusions

The sponge fishery is still an important economic activity in the Mediterranean Sea, although the sponge trade has declined since its peak at the end of the nineteenth century and the beginning of the twentieth. It also represents a valuable cultural heritage, especially in Greece, Tunisia and other countries of the eastern Mediterranean Sea. This activity has been threatened several times by overexploitation and by disease outbreaks. Recent scientific investigations have provided more precise information about the biology of commercial sponges to explain some of the population crashes, which may help to implement more sustainable exploitation with better control and regulation, including harvesting by cutting rather than tearing the sponge loose (Stevely and Sweat 1985), and possibly result in a profitable spongiculture industry. However, it also appears that the global change in the Mediterranean, especially unusual warming episodes, the extension of invasive species, and the global level of pollution, may increase the threats to the traditional sponge beds and the culture of sponge fishing.

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