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Jelly surge in the Mediterranean Sea: threat or opportunity?

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Abstract

The rise in water temperature in the Mediterranean Sea, and associated migrations of temperate marine biota, are occurring in the context of a global warming causing an expansion of the tropical jellyfish range, exacerbating jellyfish outbreaks linked to coastal development, nutrient loading, and overfishing. The gelatinous component of plankton is considered as 'the dark side of ecology' capable of appearing and disappearing at unpredictable times. In the last decade an increasingly high number of gelatinous plankton blooms are occurring and this makes us wonder if 'a Mediterranean Sea full of jellyfish is a probable future'. The reasons for rising jellyfish blooms are, probably, manifold. Current studies are aimed to highlight how climatic change is interacting with the Mediterranean ecosystem favouring entrance, abundances and success of alien species and triggering 'regime shifts' such as from fish to jellyfish. Jellyfish damage the economic success of power plants, fish farms, tourism, and affect fisheries consuming larvae of commercial fish species. On the other hand, several studies were also taken into account on uses for jellyfish as biofuels and foods but more experimentation is needed to improve the first encouraging results.

Keywords: Jellyfish; threat; opportunity; climate change; alien species; Mediterranean Sea.

Introduction

The Fever of the Mediterranean Sea

Since the mid-1980s a pronounced warming trend has characterised the Mediterranean Sea temperature with extensive mass mortalities of organisms characterized by cold-water affinities whereas species well-adapted to high temperatures show a positive feedback (Rivetti *et al*., 2014).

Shaltout and Omstedt (2014) analyzed data about Mediterranean Sea surface temperatures and their response to global change observing a significant annual warming. The basin represents, indeed, a 'model basin' for all oceans as it is characterized by several traits and a peculiar history (Templado, 2014) being much smaller than any ocean, almost closed, and with a high rate of endemism. For these reasons, it can be used as 'a Climate Test Basin' (Garrett, 1994) and is the subject of changes of its biota responding quickly to climate change (Bianchi, 2007; Boero & Bonsdorff, 2007; Lejeusne *et al*., 2010; Boero & Gravili, 2013; Gravili *et al*., 2013; Boero, 2015). In addition, climate change may favour some jellyfish species through increased availability of flagellates, a jellyfish food source, in surface waters. Furthermore, temperature change can interact in many ways with global biogeographic changes (Hughes, 2000; Gravili & Boero, 2014) inducing the 'tropicalization' of the Mediterranean basin, a phenomenon characterized by success and abundances of sub-tropical species in warm-temperate waters (Bianchi & Morri, 2004; Bianchi, 2007), and on global scale is forcing temperate marine biota towards the poles (Boero *et al*., 2016). In addition, alien species invasion is closely linked to opportunities provided by anthropic activities such as shipping transport, the Suez Canal (opened in 1869 and, recently, double), and escape of tropical species from culturing grounds (Boero, 2002; Galil *et al*., 2015).

Moreover, scientists are also concerned that warmer water could alter the system of global currents that regulates the Earth's temperature changing gyres and ocean currents around the world (Anonymous, 2010b), forcing migrations and species extinctions (Hughes, 2000; Hoegh-Guldberg & Bruno, 2010; Boero & Gravili, 2013; Gravili & Boero, 2014; Gravili *et al*., 2015).

Jellyfish Surge

In this paper, the term 'jellyfish', refers to gelatinous zooplankton that includes medusae of the taxa Hydrozoa, Scyphozoa, and Cubozoa. Jellyfish are a component of marine ecosystems, relatively little studied but conspicuous that shows population fluctuation characterized by sudden outbursts (blooms) followed by crashes (Purcell, 2005). Jellyfish are a natural presence in natural ecosystems and have bloomed in the past too (Hagadorn *et al*., 2002; Young & Hagadorn, 2010; Brotz *et al*., 2012).

The first signs of a possible change in the frequency of jellyfish blooms worldwide were recognized by Mills (Mills, 1995, 2001) and numerous localized increases are reported by subsequent reviews of jellyfish populations in several world seas (Black Sea, Baltic Sea, the Northern Benguela Current off Namibia, Sea of Japan, East China and Yellow Seas), as well as in the Mediterranean Sea off the coasts of Spain and France and coastal Middle Eastern area (Purcell, 2005; Boero *et al*., 2016; Brotz *et al*., 2012; Mills, 2001; Brodeur *et al*., 2002; Uye & Ueta, 2003, 2004; Kawahara *et al*., 2006; Link & Ford, 2006; Purcell *et al*., 2007; Chudnow, 2008; Cho, 2011; Boero, 2013; Pitt & Lucas, 2014).

In the Mediterranean Sea several scientists reported a surge in the number of jellyfish that threatens the biodiversity of the basin and also the health of thousands of tourists (Tremlett, 2013; De Donno *et al*., 2014). Therefore, the Mediterranean biota is undergoing a process of 'jellyfication' (Roux *et al*., 2013). Similar trends in jellyfish populations have been observed on a global scale too (Brotz *et al*., 2012; Brotz & Pauly, 2012). Although many jellyfish populations fluctuate with oceanic climate (see Purcell, 2005, 2012), the proliferation of jellyfish appears in large part to be related to human impacts (global warming, eutrophication, habitat modification, overfishing, aquaculture, ocean acidification) on the marine environment. Gelatinous species, in fact, are adapted to develop large populations through asexual reproduction and being opportunistic are favoured against species that, on the contrary, require predictable environmental conditions (Boero *et al*., 2016). In addition, sea warming influences species phenology: life cycle might be altered leading to changing of phenological relationships between species (Hughes, 2000). Warm-water scyphozoans are liable to lengthen the time-window of medusae production as answer to temperature increases leading to a probable expansion of the period of jellyfish growth and reproduction (Boero *et al*., 2016). On the other hand, cold-water species could be negatively affected by temperature increases as reported by case studies about *Aurelia* and *Cyanea* species (Lynam *et al*., 2004). In addition, climate change may improve winter survival of tropical species expanding to temperate waters, and broaden the mid-latitude jellyfish reproductive periods and, as a consequence, enhancing both native and alien outbreaks (Boero *et al*., 2016). Furthermore, with the disappearance of predators, jellyfish blooms are increasing in frequency, intensity, and duration worldwide, as well as in the Mediterranean Sea (Hughes, 2000; Purcell & Uye, 2007; Boero *et al*., 2008a; Richardson *et al*., 2009; Boero, 2013; Duarte *et al*., 2013; Guilford, 2013; Tremlett, 2013; Canepa *et al*., 2014; Boero *et al*., 2016). Overfishing, in fact, forced trophic networks causing the increase of jellyfish populations through elimination their predators and competitors (Purcell *et al*., 1999, 2001; CIESM, 2001; Daskalov, 2002; Parsons & Lalli, 2002; Bilio & Niermann, 2004; Lynam *et al*., 2005; Purcell, 2005; Tatsuki, 2005; Xian *et al*., 2005; Hay, 2006; Boero, 2013; Benedetti-Cecchi *et al*., 2015) with a 'top-down control of marine food web' by gelatinous predators (Mills, 2001; Gershwin, 2013): short-lived invertebrates (such as jellyfish) and planktivorous fishes increase disfavouring large and long-lived predators (Pauly *et al*., 1998). Moreover, jellyfish are favoured when forage fish (as herring and sardines) are harvested for aquaculture fishmeal as they have fewer competitors for zooplankton. For the above reasons, a challenge for researchers is to separate normal jellyfish fluctuations from those for which anthropic impacts may be responsible (Schrope, 2012; Boero, 2013; Boero *et al*., 2016). Could jellyfish blooms be as a 'miner's canary' that bellwether of change when the ecosystem is disturbed?

To answer that, further studies are required to monitor jelly bloom phenomena: research on this topic is lacking, probably, for a number of reasons, among these several problems that the scientific community has to detect them. To eliminate the scarcity of gelatinous plankton long-term monitoring, a Citizen Science campaign began in 2009 (Boero, 2013), along the Mediterranean coasts, allowing the creation of a long-term database. There have been numerous Mediterranean records of jellyfish species: the tropical scyphozoan *Phyllorhiza punctata* Lendenfeld, 1884 (Boero *et al*., 2009), the Atlantic species *Catostylus tagi* (Haeckel, 1869) (Boero, 2011), the new species *Pelagia benovici* Piraino, Aglieri, Scorrano & Boero, 2014 (Piraino *et al*., 2014), *Cotylorhiza erythraea* Stiasny, 1920 (Galil *et al*., 2016), and two *Aurelia* species (Scorrano *et al*., 2016). However, alien species often characterize recurrent jellyfish outbreaks in the Eastern Mediterranean (Galil, 2008), whereas blooms phenomena consist of indigenous species in the Western-Central Mediterranean colonizing several unique habitats such as coralligenous assemblages, *Posidonia oceanica,* and vermetid reefs and exhibiting strong Atlantic affinities (Harmelin & d'Hont, 1993; Green & Short, 2003; Boudouresque, 2004; Sardà *et al*., 2004; Ballesteros, 2006; Galil, 2008; Gravili *et al*., 2013). Moreover, in recent years, numerous alien species, previously confined to the eastern basin, showed an expansion of their distribution area to the central-western basins of the Mediterranean due to the effects of climate changes (Richardson *et al*., 2009; Occhipinti-Ambrogi & Galil, 2010; Zenetos *et al*., 2012; Tsiamis *et al.*, 2018). Several studies reported the effects of alien species invasions on native populations, communities, and whole ecosystems, increasing in spread and in dominance through the success of a few invasive species that might be mediated by physical change (Galil, 2015; Galil *et al*., 2015). On the other hand, while numerous species spread to new habitats, others are in decline or even in extinction due to overexploitation and loss of their habitats (Boero & Gravili, 2013; Gravili *et al*., 2015).

Animal waste and agricultural often loads coastal waters with nutrients, which cause eutrophication where algal proliferation impoverishes the water of oxygen. Furthermore, eutrophication provides more food for jellyfish polyps favouring both jellyfish and polyps more than fish because they are low oxygen levels tolerants (Cho, 2011). Waters around aquaculture, where fish waste produce eutrophication, support jellyfish blooms and their structures and pens often provide polyp habitats.

But how we can define the term increase of jellyfish?

Brotz *et al.* (2012) reported as the detection of jellyfish true trends could be influenced by several factors. First of all, the scarcity of historical information on jellyfish, because these organisms were usually damaged or not recorded during zooplankton surveys (Pugh, 1989; Hay, 2006) that, often, use methodologies that recommended their removal through plankton-gear designed to exclude jellyfish from samples (Dovel, 1964; Heinle, 1965).

Another factor is the extreme variability on both spatial and temporal scales, due to their ecology that contribute to why jellyfish tend to be understudied too (Brotz *et al*., 2012).

Many hydrozoans and scyphozoans, and all cubozoans, have a life history consisting of a sessile polyp phase and a planktonic medusa phase. A few species have their polyps that may asexually bud more polyps or form dormant cysts capable of overcoming unfavourable environmental conditions and rapidly reproduce when conditions are favourable (Boero *et al*., 2008a; Richardson *et al*., 2009; Arai, 2009). On the other hand, studies on the dynamics of jellyfish populations are often based on records of the location, relative size, and blooms timing (Mills, 2001; Purcell, 2005; Boero *et al*., 2008a; Dawson & Hamner, 2009; Brotz & Pauly, 2012) unlike researches about finfishes that use analytic models (Palomares & Pauly, 2009). In this complex framework, jellyfish have natural cycles of abundance and their pulses determine the cycling spatial and temporal diversity of plankton as 'the dark side of ecology' (Boero & Mills, 1997; Boero *et al*., 2008a). This scenario could be explained by the bentho–pelagic cycles (Boero *et al*., 2008a), typical of most jellyfish, where the presence of an asexually reproducing polyp stage in the life cycle could determine long time intervals characterized by absence of some jellyfish that might, then, reappear suddenly such as the endemic *Drymonema dalmatinum* Haeckel, 1880 in the Adriatic Sea and *Rhizostoma luteum* (Quoy & Gaimard, 1827) in the Gibraltar Strait (Bayha & Dawson, 2010; Prieto *et al*., 2013). Moreover, for a long time researchers have considered the stages of polyps and medusae separately creating several classification systems for them. On the other hand, the reconstruction of their full life cycle is a pre-requisite essential for a unified classification (Boero *et al*., 1997), and for a complete knowledge of the jellyfish ecology and their evolutionary patterns. Finally, but not less important, there are taxonomic concerns linked to the term 'jellyfish' may refer to different phyla such as Cnidaria, Ctenophora, and Chordata. The use of such a term that ignores taxonomy as such organisms are phylogenetically distant, without proper taxonomic resolution, prevents a knowledge of the mechanisms and consequences involved (Haddock, 2004: Brotz *et al*., 2012). The latter problem is aggravated by the 'loss of taxonomic expertise' characterized by the retirement of taxonomy experts replaced by new researchers in molecular biology or ecology (Boero, 2001; Gravili, 2017).

Global Threats

The jellyfish aggregations are becoming a serious problem: fisheries and nuclear power plants could undergo further losses. Jellyfish in large numbers can devastate power stations by clogging the cooling systems (Gershwin, 2013).

Further problems derived from nets full of jellyfish with consequent disruption of fisheries. The profit of the fishing industry is reduced due to delays in the fishing process because the net clogging, rips of fishing nets caused by the excessive weight of water-filled medusae (Moffett, 2007), and suffocation of desirable species essential to the fishing industry (Purcell *et al*., 2000).

Jellyfish blooms are often negatively perceived because they may affect fishery through competition for food or direct predation resulting in reduction of fish stocks (Lynam *et al*., 2006; Purcell *et al*., 2015). Furthermore, jellyfish populations can cause mass mortality in caged fish aquaculture, produce negative impacts on coastal tourism and human health due to painful stings, and block cooling pipelines (Purcell *et al*., 2007; O'Rourke, 2013; Bosch-Belmar *et al*., 2016). In particular, blooms of gelatinous cnidarian stingers are associated to a wide range of neurotoxic, cytotoxic, and hemolytic effects on farmed fish, such as the case study of the species *Pelagia noctiluca* (Forsskål, 1775) (Fig. 1) that is a direct causative agent for several fish mortality events in Northern European and Mediterranean aquaculture farms (Bosch-Belmar *et al*., 2016). Other potentially harmful species for aquaculture facilities are the hydromedusae *Phialella quadrata* (Forbes, 1848) and *Solmaris corona* (Keferstein & Ehlers, 1861) (Baxter *et al*., 2011), and the siphonophore *Muggiaea atlantica* Cunningham, 1892 (Fosså *et al*., 2003).

Moreover, swarms of jellyfish have disrupted power generation everywhere in the world: power plants out-

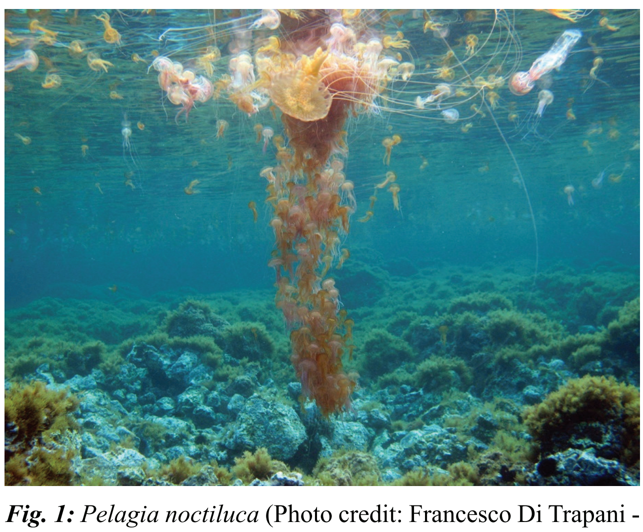

Fig. 1: *Pelagia noctiluca* (Photo credit: Francesco Di Trapani - MED-JELLYRISK project).

side (Scotland, Japan) and inside the Mediterranean Sea (Israel) were victims of the jellyfish threat causing power reductions or shutdowns (O'Rourke, 2013), and fish stocks were destroyed in Ireland and Tunisia by tearing nets and harming fish (Schrope, 2012). In the fishing business, the situation is worse with clogged trawl lines and burst nets. In addition, jellyfish reduce the population of the commercial fish by eating their eggs, larvae and juveniles, consuming the zooplankton they eat, and transmitting parasites on fish. Jellyfish have seemed to fill the empty niche in conjunction with fish species decline (Pauly *et al*., 1998; Jackson, 2008) and their peculiar biology means that once their populations increase may be impossible to turn getting off the food network (Gershwin, 2013).

Brotz *et al.* (2012) examining 45 major marine ecosystems found that 62% saw an increase in blooms since 1950. Jellyfish have often invaded numerous beach holidays. Tourism is severely damaged by jellyfish blooms along the Mediterranean coastline shortening swimming season for tourists: about 150,000 people are treated for jellyfish stings in the Mediterranean each summer (Guilford, 2013). In addition, the "dead zones", created by what scientists call 'eutrophication', contribute to the jellyfish bloom (Gershwin, 2013). Farming pesticides and sewage pumped into rivers and poured into the seawater affects phytoplankton, forming algal blooms that float to the bottom, impoverishing the water of oxygen. This phenomenon, threatening the survival of most creatures, may favour the expansion of jellyfish colonies. Gershwin (2013) wrote as human impacts are helping jellyfish reproduction: their sessile stage (polyp) is the "key to their ability to bloom in such incredibly rapid fashion and shocking numbers." In fact, the proliferation of anthropic structures such as boats, platforms, offshore wind turbines, are some of the new surfaces where polyps can cling to and proliferate. Moreover, a number of invasive species of jellyfish are thriving in the Mediterranean basin impacting on fishing and other industries (Öztürk & İşinibilir, 2010).

As mentioned above, the main vector of introduction of alien species is shipping (Galil, 2009). In particular, benthic phase of most jellyfish have been transported on ship hulls, while hydromedusan and scyphozoan ephyrae are often found in ballast water. Numerous species can overcome adverse seasonal conditions in the form of encysted stages in ballast waters or attached as 'fouling' to the ships-hulls (Boero, 2002). On the other hand, the jellyfish *Pelagia noctiluca*, usually considered to be the most important jellyfish species in the Mediterranean Sea due to its widespread distribution and ecological role, can be considered 'invasive' when it spreads out from offshore to coastal waters with periodic occurrences of extraordinary abundances (Sabatés *et al*., 2010; Canepa *et al*., 2014). Climatic conditions, probably, also determine optimal conditions for this species both speed reproduction and extend the reproductive season with the appearance of more frequent blooms (high temperature and atmospheric pressure, low rainfall, mild winters) causing negative interaction on tourism (Molinero *et al*., 2005; Purcell *et al*., 2007; Anonymous, 2010c; Canepa *et al*., 2014; Rivetti *et al*., 2014). Goy et al. (1989) detected for *P. noctiluca*, through a long-term dataset, a cyclic trend of about 12 years in the western basin of the Mediterranean. In the late 1990s, persistent blooms occurred almost annually (Malej *et al*., 2004; Anonymous, 2008; Mariottini *et al*., 2008; Anonymous, 2010a; Daly Yahia *et al*., 2010), and *P. noctiluca* records began more frequent also in areas such as the Adriatic Sea where this species was relatively rare until the last 1970s (Zavodnik, 1987).

Other jellyfish species appear to exhibit sustained increases in the Mediterranean Sea, such as the cosmopolitan species *Chrysaora hysoscella* (Linnaeus, 1767) that appears to be in expansion in the Aegean area in recent years (Öztürk & İşinibilir, 2010). Furthermore, in the Mediterranean Sea there are several examples of non-indigenous jellyfish species: two species of the *Cassiopea* genus *C. andromeda* (Forsskål, 1775) and *C. polypoides* Keller, 1883 (Brotz & Pauly, 2012; Schembri *et al*., 2010); *Carybdea marsupialis* (Linnaeus, 1758), Mediterranean cubomedusa widely distributed in the tropical waters of the Atlantic (Boero & Minelli, 1986). More alien jellyfish species were recorded in the Mediterranean Sea: *Rhopilema nomadica* Galil, Spanier, and Ferguson, 1990 (Deidun *et al*., 2011; Daly Yahia *et al*., 2013), one of the most successful invasive species of jellyfish in the eastern Mediterranean that is causing significant economic losses; the tropical invasive scyphozoan *Phyllorhiza punctata* Lendenfeld, 1884 (Boero *et al*., 2009; Galil *et al*., 2009; Galil *et al*., 2010; Çevik *et al*., 2011; Gülşahin & Tarkan 2012); the scyphozoan *Marivagia stellata* Galil and Gershwin, 2010 (Galil *et al*., 2010).

Change seen as opportunity

As seen above, in the Mediterranean Sea every year an increasing number of jellyfish blooms are recorded as a consequence of climatic and anthropic causes that are shaping changes in marine biodiversity and food sources (Leone & Piraino, 2015).

Big blooms may be the new normality but with new technologies we could turn they into an economic opportunity as valuable resources. Jellyfish create shelter for fish in their tentacles and in a few Countries provide an important source of food; their toxins, their tissues and the green fluorescent protein (responsible for their bioluminescence) are being studied for medical uses (Cho, 2011).

Recent researches suggest methods of turning proteins, carbohydrates and lipids into ethanol alcohol (Hsieh *et al*., 2001). On the other hand, in order to obtaining ethanol production from jellyfish requires washing them in fresh water to remove most of the salt that could be marketed as jelly salt (Lee *et al*., 2014). Finally, ethanol can be converted into a drink or used as fuel vehicles (Huo *et al*., 2011).

In the Mediterranean Sea, nutraceutical value and antioxidant properties of a few of the most abundant and commonly recorded jellyfish species [*Aurelia* sp.1, *Coty-*

lorhiza tuberculata (Macri, 1778) and *Rhizostoma pulmo* (Macri, 1778)] (Figs 2, 3) were subject to investigation (Leone *et al*., 2015). Marine organisms, in fact, still represent a largely unexplored reservoir of natural products (source of potential healthy food, bioactive compounds and, even, new drugs) due to the presence of secondary metabolites (Mayer *et al*., 2013). For this reason, recent researches (Gates, 2010; Guérard *et al*., 2010; Leone *et al*., 2013; Mariottini & Pane, 2013; Mayer *et al*., 2013) have focused on many bioactive molecules extracted from marine organisms with potential anti-inflammatory, antimicrobial, and anticancer properties. In particular, cnidarians are an important source of physiologically active compounds (Leone *et al*., 2013; Mariottini & Pane, 2013). The collagen, the main structural protein in the jellyfish body mass (Hsieh & Rudloe, 1994; Addad *et al*., 2011), is a structural protein family component of extracellular matrices in connective tissues (Aouacheria *et al.*, 2006; Ricard-Blum, 2011) characterized by low immunogenicity and high biocompatibility sharing several features with their human counterparts (Meena *et al.*, 1999; Esposito *et al*., 2010). These marine invertebrates are becoming an engaging source for collagen better tolerated than that extracted from other organisms as porcine and bovine skins that is more and more rejected for religious reasons or disease risks.

Jellyfish are used in the cosmetics for the skin as well as in the pharmaceutical and biomedical industry for their therapeutic value in the treatment of hypertension, ulcers, arthritis, bone pain, digestion problems, as softening skin (Hsieh & Rudloe, 1994; Omori & Nakano, 2001; Leone *et al*., 2015).

Projects such as 'The EU-project 'GoJelly project' (see https://www.geomar.de/en/service/kommunikation/singlepm/article/jellyfish-disgusting-useful/) aims to change the perception that jellyfish are regarded as annoying and dangerous proposing their use as source to produce microplastic filter, fertilizer or fish feed. Another project such as The EcoJel project (see http://ec.europa.eu/regional_policy/en/projects/ireland/ecojel-assessing-jellyfish-increase-in-the-irish-sea), for example, is helping the EU to become a smart, sustainable and inclusive economy by 2020, as set out in the EU 2020 growth strategy, identifying and managing the threats and opportunities on sectors such as tourism, aquaculture and fisheries presented by the predicted increase in jellyfish blooms in the Irish Sea. Indeed, it is a priority to identify and manage threats and opportunities of jellyfish increase: jellyfish might lead to the closure of some beaches and at the same time can also present business opportunities around diving with jellyfish; blooms, cause of mass mortality in fish farms, could present a chance for harvesting jellyfish as food to export to Asian markets. In China and in Japan jellyfish are appreciated as food for their composition [high content in omega-3 and omega-6 fatty acids, low content in cholesterol, fat and salt decreasing incidence of coronary heart diseases (Hsieh & Rudloe, 1994; Hsieh *et al*., 2001; Omori & Nakano, 2001)]. On the other hand, the cnidarian lipid composition may vary considerably depending on their diet or symbiotic association with unicellular algae (Papina *et al*., 2003; De Souza *et al*., 2007; Dunn *et al*., 2012; Leone *et al*., 2013). In this framework, there could be positive aspects to an sea full of jellyfish (called "Jellyfish Apocalypse" by Lee *et al*., 2014) as scientists have looked into using jellyfish in several ways: age reduction powers in one type of jellyfish (Rich, 2012) (life-cycle reversal in *Turritopsis dohrnii* (Weismann, 1883) medusa (Piraino *et al.*, 1996; Martell *et al*., 2016), proteins used for disease control purposes (Hsieh *et al*., 2001), and biomarkers used in medical diagnostics (Stepanenko *et al*., 2008). On the other hand, jellyfish as new food sources must be fully characterised from nutritional, nutraceutical, biochemical, microbial and toxicological point of view. Furthermore, any potential risks for health must be carefully evaluated in order to increase consumer confidence. These new perspectives require the development of appropriate processing technologies for extraction of some bioactive compounds from jellyfish ensuring to avoid bio-accumulate chemical contaminants.

Several jellyfish species show nutritional and biological features resulting good candidates as feed sources and/or bioactive compounds. What we have therefore is, similarly to the Asiatic edible species, the potential possibility of Mediterranean jellyfish as natural biological resources for different food, industrial and pharmaceutical sectors (Leone & Piraino, 2015).

Humans could exploit the increase of jellyfish by de-

Fig. 2: *Cotylorhiza tuberculata* (Photo credit: Gianluca Romano).

Fig. 3: *Rhizostoma pulmo* (Photo credit: Gianluca Romano).

veloping new benefits. The 'Jellyfish Apocalypse', therefore, can be converted to an opportunity through their use as food, as it already happens in the eastern countries in Asia where business have already developed for jellyfish products, and biofuel (Lee *et al*., 2014).

Future perspective

In the framework of a rapid changing of the Mediterranean pelagic ecosystem structure, from one dominated by fish to a gelatinous state, management actions are necessary to stop such trend through the coupling of tactical strategies and longer-term research managing the marine environment in a precautionary and holistic way (Brotz & Pauly, 2012; Coll *et al*., 2012). On the other hand, jellyfish may be regarded, due to their high abundances-reproductive and regenerative potentials, as a new source of nutraceutical, pharmacologic and food/feed compounds, providing the opportunity of several potential use medicine, tissue engineering, and food industry (Boero *et al*., 2002, 2008a; Piraino *et al*., 2004; Boero, 2013; Doyle *et al*., 2014; Lee *et al*., 2014; Leone *et al*., 2015). More research is necessary to perfect the technology, still at the experimental status, using yeasts and bacteria to turn jellyfish protein into alcohol: this plan must be taken into consideration for the future.

Finally, further studies are also needed to clarify aspects related to insufficient scientific knowledge, food safety assessment, and data access.

Conclusion

Jellyfish are ancient creatures that together to other organisms evolved into a balanced and calibrated ecological puzzle. Anthropic actions continue to disrupt these interdependent relationships seeing profound effects on our environment. Jellyfish blooms are, probably, the result of just one of countless habitats we have destroyed. On the other hand, adaptation strategies and management have been developed in order to prevent negative impacts (Matsushita *et al*., 2005; Lucas *et al*., 2014) as well as mitigation measures against jellyfish proliferation impacts in the context of research projects such as Med-JellyRisk (see www.jellyrisk.eu) (MED-JELLYRISK, 2015).

In conclusion, it is clear that our lifestyle is not compatible with a healthy ecosystem (Boero, 2015). Policy decisions made in the past continue to have profound impacts on ecosystems and global climate, not just for this century, but also for the next millennia (Clark *et al*., 2016). According to Gershwin (2013), the future of the marine ecosystems is, probably, starting now by facing the problems created by past mistakes and being proactive in solving them.

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