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# The Ghosts of the Sea

We look out to sea from the shore, but can't see anyone in the water. We swim far out, alone, and there are hardly any waves. It promises to be a great day, but when we glance back to the beach we see that a flag has just been hoisted, and curse those strange organisms that seem to want to ruin our holiday. The beach guard has raised that flag to indicate jellyfish and, though we cannot see them, our instinct tells us that it would be better not to stay in the water. Perhaps we can paddle a bit to wet our feet, but no more, because we all have a cousin, friend or acquaintance who has been stung by a jellyfish, and it is annoying, painful and, in some cases, deadly.

Jellyfish are a form of gelatinous plankton and are composed almost entirely of water—more than 99%, in some cases—which gives them a very peculiar semi-transparent and ghostly appearance. They are fascinating creatures: beautiful, mysterious ghosts of the sea, some of the most simple yet misunderstood on our planet. They have spent the winter offshore, but come in with the winds that blow from sea to the shore from April. Now is the time when you notice them. Their life cycle is, in general, between one to two years, depending on the species, of which there are some four thousand, from giant size (Nomura's jellyfish) to the tiny hydromedusa, whose umbel (cap) is less than a centimetre across. Speaking of 'jellyfish' is as vague as saying 'mammals', as there are about five thousand species.

In 1990, I was fascinated by a talk given by a colleague of mine, now sadly gone, Francesc Pagés, on the life and miracles of the jellyfish. Among other things, he told us that jellyfish have been on the plant for more than 600 Ma years (about 400 Ma more than mammals), thus have managed to survive all the upheavals that the planet has delivered: there have been several



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near extinctions that have barely changing them, lacking any brain and with an extremely basic morphology. They are primitive beings that have witnessed the evolution of other without flinching, living a simple, effortless lifestyle that is nonetheless highly effective.

Why are there so many? Has there really been an increase in these organisms? Time-series studies to follow-up jellyfish are scarce. However, in places such as Villefranche (French Mediterranean), it has been shown that from 1979 to 1989 there was indeed a progressive increase in jellyfish and that since 1990 the numbers have soared. In other places as varied as the Bering Sea, Israel, San Francisco Bay, Chesapeake Bay, la Manga on the Mar Menor and the Norwegian fjords, the trend is the same, despite the different circumstances. This represents an increase in the mass of gelatinous plankton at the expense of fish and other organisms.

Scientists and authorities have gradually come to realize that this is a global problem, not just a fluke or localized to a certain area that is isolated from the rest of the world. 'We have come a long way during the last decades in the understanding of the biology and ecology of gelatinous organisms,' says Robert Condon of the Department of Biology and Marine Biology of the University of North Carolina, 'but the road ahead of why these changes are happening will be long.'

When they find highly favourable conditions of light, nutrients, food, currents, and so on, jellyfish can 'bloom', in an accelerated proliferation through reproduction or agglomeration, forming great concentrations in a specific place in a matter of days or weeks. As practically passive bodies, the creatures are carried by sea currents towards the shore, where the fresh water from rivers acts as a barrier to their advance. When it rains heavily in spring, the rivers create a front that prevents the jellyfish reaching the shore, but when there is drought, or when the rivers have reduced flow rates due to agricultural or industrial use of their water, this front is absent and the ghosts of the sea appear on beaches en masse.

The jellyfish can adapt well to various conditions of salinity and turbidity of the water, but are mostly animals that live in the sea. It is not true that the presence of jellyfish is associated with pollution such as sewage (look at the waters of Corsica or Menorca, crystal clear yet full of jellyfish). In general, they can also survive low concentrations of oxygen, which favours their presence in where there is a high concentration of organic matter due to decomposition. However, by itself, pollution never explains the presence of jellyfish. What is certain is that some species especially enjoy waters rich in inorganic nutrients or suspended matter, and this makes them proliferate. This is the case for those jellyfish that have algae in their interior, as one

source of medusa's nourishment, and are at ease in such areas. 'When the waters are polluted diversity decreases, but those species of jellyfish that resist can grow without control', affirms Mary Arai of the Pacific Biological Station in British Columbia, Canada. In the Florida Everglades, the inability of the system over much of its surface to absorb the nutrients and organic matter in suspension, coming from deep degradation, has dramatically increased a species of medusa, *Cassiopea* sp., to the extent that you can spot more than 42 individuals per cubic metre. But this is nothing compared to places like some Scandinavian fjords, where the concentration of the medusa *Aurelia aurita* reaches 300 individuals per cubic metre. The increased turbidity and organic nutrients in the Adriatic seems to be one of the key factors behind the expansion of both this and species such as *Pelagia noctiluca*. Conversely, in some areas along the Japanese coast, where fish farming imposes a heavy organic load on the environment, the closure of particular fish farms has been a trigger for *Aurelia aurita*'s disappearance,.

What is the chief culprit? One of the main triggers of the expansion of jellyfish is overfishing, without a doubt. 'In the region of Bering, where there is intense fishing, 5% of all that on the entire planet, the drastic reduction of the stocks has been accompanied by a significant increase of *Chrysaora melanaster*', says Claudia Mills of the Friday Harbor Laboratories of the University of Washington. In this and in other places, the disappearance of fish has been accompanied by an increase in jellyfish and other gelatinous plankton. The major predators of these organisms are tuna, mackerel, swordfish and sunfish, and some turtles. It has been demonstrated that mackerel are an effective predator of ephyrae, the jellyfish in their first stages of life in the open sea. As we have seen in previous chapters, these and other agents are still victims of a means of extraction that has decimated their populations and diminished their role in the pelagic and benthic systems. Already in the 1980s, academic papers warned of the extinction of various types of predators, but at that time no one linked the increase in gelatinous plankton with the impoverishment of fishing grounds. This trend has been increasing, to the extent that currently there is discussion on a ban on fishing for some species so that they regenerate. The solution, undoubtedly, is a landmark for those fish that devour jellyfish. But in the case of turtles, for example, there is little hope: excessive human pressure has reduced the extent of the shore environment needed by these reptiles, which have nowhere to go. Can you imagine turtles laying their eggs on the beaches of Benidorm or Salou?

Most jellyfish are voracious feeders and some eat fish larvae, among other things, which has led to an acceleration in the collapse of fish stocks across the planet. Moreover, their diet often includes small crustaceans and detritus,

which are sources of food for other fish, so jellyfish compete for food with their potential predators and prey. On the other hand, jellyfish themselves may be eaten by fish larvae and young, or be caught by fishing vessels.

Another major problem related to the proliferation of jellyfish is the introduction of invasive alien species. There are species that have largely moved from site to site in the ballast water of merchant shipping, carrying millions of organisms (algae, crustaceans, jellyfish, etc.: see chapter on invasive species). If they are comfortable in the habitat into which they have been relocated, these organisms reproduce and come to replace native species. The number of trade routes has increased with the growth in maritime traffic.

An example that has been known for decades illustrates the successive invasions of a marine system. Over the past fifty years, eutrophication, overfishing and pollution have altered the Black Sea. At the end of the 1960s, it had intense blooms of a typical of Mediterranean jellyfish, *Rhyzostoma pulmo*, with more than two or three per cubic metre, but these stopped suddenly as the sea became a more saline environment, giving way to the medusa *Aurelia aurita*. The development of this second species is related to the lack of fresh water, since agricultural irrigation had taken water from and thus reduced the flow of the major rivers flowing into the Black Sea. But the situation became dramatic when, in the 1980s, the accidental introduction as another invasive species of gelatinous plankton interfered in the already precarious balance in the trophic chains of this sea. The alien ctenophore *Mnemiopsis leidyi* (sea walnut), which tolerates high salinity, quickly proliferated in a disproportionate way, reaching a concentration of 300–500 specimens per cubic metre. This organism was devastating, since it feeds on the larvae of anchovies, a fish that, at that time, was still a significant source of wealth in Turkish and Russian waters. The introduction of another ctenophore (*Beroe ovata*), specialized in eating other ctenophores, could regulate the concentrations of the harmful *Mnemiopsis leidyi*, but the results are unknown, to date. What is clear is that, of the 26 exploitable types of fish that once swam in the Black Sea, there are now five fewer.

*Mnemiopsis leidyi* settled in the Mediterranean 'officially' only recently. Scientists from ICM-CSIC in Barcelona confirmed the arrival of this invasive species on Spanish coasts in summer of 2009, where it has been found in certain areas such as Denia, Salou and Mataró, sometimes in extremely high densities. It originated on America's Atlantic coast: *'Mnemiopsis* is a very adaptable to different environmental conditions, and can withstand a temperature range of 0–30 °C and a salinity of 2–38‰', says Veronica Fuentes, from the ICM-CSIC in Barcelona. 'They often live at shallow depths,' says Dr Fuentes, 'between 2 and 30 m deep. We have detected dense banks close

to the surf break of beaches, from breaking waves to beyond 200 m offshore.' The ctenophore is harmless to humans but has been shown to have a serious impact on fishing stocks, especially when in the absence of predators, such as small fish, that can feed on the first stages of life of this gelatinous component. In the Caspian, Baltic and North Seas, where it has also been detected, it also has serious implications for the food chain and the survival of stocks of pelagic fish. The aggravating circumstance in this case is that it is a non-native species thus has no natural predators.

In the Mediterranean Sea we feel increasingly that the jellyfish will begin to join us on the beach. We can consider four species as the most colourful in the Mare Nostrum, as the Roman's termed it. The first, *Pelagia noctiluca* (purple-striped jellyfish), is pink and semi-transparent, with long and tentacles that are barely visible. It is the most dangerous. Then there is *Chrysaora hysoscella* (compass jellyfish), opaque with brown stripes, which can measure more than 50 cm in diameter; it, too, has long tentacles. The other two, *Rhizostoma pulmo* and *Cotylorhyza tuberculata*, are common in less clear waters and their tentacles are short. They are less dangerous. Finally, there is a siphonophore, rare but highly dangerous: *Physalia physalis* (the Portuguese man-of-war) has long, nearly invisible tentacles and its sting is fearsome. But, as we have said before, the phenomenon of jellyfish is not restricted to the Mediterranean: they have expanded, around the globe.

The examples mentioned above are just the start of it. A changing sea is the optimal breeding ground for jellyfish, and they are taking full advantage of the reduced diversity of different aquatic systems. In many of the Scandinavian fjords, fishing now catches nothing but large jellyfish, which eat the small crustaceans and other food that had sustained fish fauna. In the San Francisco Bay, a small hydromedusa that was introduced accidentally has unbalanced the system in its favour, and its polyps and its young are ubiquitous and displacing competitors that cannot grow as fast. Other instances of expansion of these simple creatures are perhaps not so visible, by virtue of being in areas around the world that are less frequented by tourists.

It has been argued that an increase in temperature, especially in shallow water, is the trigger for their uncontrolled increase. However, by itself this does not guarantee the proliferation of any animal, nor even jellyfish. 'We need to better understand the life cycles to be able to relate cause effect', says Giacomo Milisenda of the DiSTeBA of the University of Salento in Italy: '*Pelagia noctiluca*, for example, has a cycle related not only temperature but also the availability of food.' We need to consider both warmth and food, therefore, or the cycle will accelerate in a way unlike how experts believe.

Recent studies carried out by several studies are beginning to provide the keys to questions that so far have been in the air. For example, it does seem that jellyfish now appear on our shores earlier in the year. 'Data series that we have so far cannot tell us if the increase in temperature or salinity in the Mediterranean Sea has caused an earlier appearance of jellyfish', says researcher Veronica Fuentes. Temperature and salinity, along with the availability of food, are known to influence the life cycles of these planktonic organisms, but at the moment the effects are unknown. Some groups, for instance that of Professor Jennifer Purcell of the Department of Marine Biology at the Western Washington University in the United States, have already seen that increases in temperature, nutrients and sunlight, which favour the proliferation of single-celled algae, are behind the increase in benthic substrate fixed polyps, releasing small jellyfish to the environment —'but not all jellyfish species behave in the same way,' Purcell continues, 'elsewhere, the environmental factors that affect them are different and otherwise affect their reproduction and growth'. Purcell and Stefano Piraino of the DiSTeBA of the University of Salento have also researched other species and have come to the conclusion that proliferations are on the rise, especially in cosmopolitan jellyfish that can find optimal conditions that they did not enjoy previously. Wind is another factor that interacts with the presence of jellyfish. *Pelagia noctiluca* arrives on our coasts due to currents and sea breezes, from sea to shore.

Now that our accumulated information is becoming more consistent, one of the questions asked by both visitors and permanent inhabitants of coasts is whether or not there are areas where these animals tend to become concentrated. This is because one of the main victims of the jellyfish is, without a doubt, tourism. In 2008, a report indicated that 150 million people are exposed to these ghostly bodies every year. In Chesapeake Bay, more than 500 thousand people are stung by these gelatinous beings annually. In Florida it is 200 thousand people and in Australia more than 10 thousand. Taking into account the density and population of these places, this is an extremely high number. This makes for uncomfortable swimming, sometimes even dangerous. The worst aspect is that tour operators are tending to 'map' jellyfish risk, discouraging visits to certain areas, although this is sometimes completely unfounded. Many millions are lost, because beach tourism depends on the millions who generate it—the tourists.

Jellyfish effects are also present in other sectors, chiefly perhaps fisheries, either indirectly or directly, as we have seen. On the coast of Namibia in Africa, up to 90% of the catch may constitute jellyfish. Losses in aquaculture can also be high: an eloquent example is that more than 250 thousand

salmon were killed by a bloom of *Pelagia noctiluca* in Ireland in just a few days. Less well known but more disturbing is that large proliferations can clog cooling ducts. In Tokyo Bay, a species of large size (Nomura's jellyfish, up to 2 m across its umbel) blocked the port, as vessels could neither leave nor enter as their refrigeration systems were put out of order due to the immense numbers of these animals. This problem has been experienced at various plants, such as thermal desalination and nuclear pumping systems, yet only in Japan has it changed in the last few decades from being an interesting issue to a 300% increase in the cost of repairing systems. More and more jellyfish can become a serious problem and pose a huge economic cost.

What can we do? The easy (and obvious) answer is to stop fishing in the way that we do, pollute less and foster a more controlled transformation of the coastal system. However, there are people who have taken the time to think laterally: if you cannot join them, take advantage of them. For hundreds of years, jellyfish have been considered a delicacy by the Chinese and the Vietnamese. The body contains only 2–5% of protein and only 0.2% of lipids, but to transform it into food is quite simple: just dehydrate it and add flavour. According to the Food and Agriculture Organization, the jellyfish market is worth more than €120 million and is growing. This is nothing compared to fishing, but it is a market that many may explore, in time. 'The jellyfish can provide many interesting products, from an economic point of view, as pharmaceuticals, beauty products or substance stabilizers for the food industry', says Antonella Leone of the Institute of Sciences of Food Production of the Italian CNR: 'We might have to start to look to these organisms as a food source rather than a nuisance.'

Yes, while we do need to think how to reduce the pressure on the potential predators and competitors of jellyfish, the market is the market, and if we now abound in jellyfishes there will always be those who won't hesitate to take full advantage. By 2050, the human population is projected to increase by 46% from current figures, meaning ever more demand for marine fish-shaped protein—cephalopods, bivalves or crustaceans—and if we continue at this rate, maybe it will have to be… medusa.

## A Small Sea of Jellyfish

Perhaps one of the places where most people have gained first-hand experience of the jelly problem is la Manga, on the Mar Menor, Murcia. This huge coastal lagoon is one of the largest in the Mediterranean, at some 135 $km^2$. No more than 6.8 m deep, it has been the perfect breeding ground for three

species for the past twenty years. Swimmers have had to share the 610 million cubic metres of water with over 100 million *Cotylorhyza tuberculata* ('fried egg' jellyfish) and *Rhizostoma pulmo* (barrel jellyfish). What has happened to put these two species, introduced before the mid-1990s), and *Aurelia aurita* (the native species) so much at ease?

The circulation of water, the sediment, the concentration of nutrients and organic particles and even the fauna and flora have changed dramatically in the Mar Menor in recent decades, for many reasons. These are overfishing, the opening of the inlet from the Mediterranean (the Estacio canal), a rise in the concentration of mineral salts and urban waste. Besides contributing a much-increased level of nautical activity, Murcia is now an urban sprawl along the coast with a consequent proliferation of hard surfaces (anchorages, breakwaters, artificial reefs, etc.), and these factors together create the ideal habitat for certain species. The removal of the fish has opened the way for a jellyfish increase (as noted before), especially of species whose diet includes small crustaceans, vertebrates and invertebrate larvae. One of the three species (*Cotylorhyza tuberculata*) is greatly benefited by the huge contribution of nutrients from the crowds from the developments along the coast of the Mar Menor and from agriculture in the area. The 'fried egg' jellyfish carries inside it symbiotic algae, small plant cells that convert nutrients (nitrates, phosphates and carbon dioxide) into carbohydrates, which are, in part, transferred to the jellyfish for growth, respiration and reproduction.

But the changes that favoured the proliferation of certain species in the Mar Menor did not end here. In 1970, most of the primary production of the lagoon came from a marine plant, the seagrass *Cymodocea nodosa*. When the Estacio canal was opened, a benthic alga (*Caulerpa prolifera*) was introduced, and this began to displace *Cymodocea*. Microscopic algae such as diatoms also began to increase in concentration. Only a few patches of seagrass were left, because nutrient levels had climbed and climbed, favouring algae over seagrass. The entire system was shaken, but the final insult was still to come. One of the businesses being developed in the area a few decades ago was oyster farming. Besides the wealth of phytoplankton in that closed environment, the venture rested on the convenience of operation due to the shallow waters of the lagoon. But oysters need a hard substrate for the larvae ('seeds') to germinate and become established—as do the polyps of the three species of jellyfish, if they are to become established and grow into the future generation. The developers established the oysters and many other species by erecting artificial structures. However, oyster culture had to be discontinued due to the high levels of heavy metals that were found in the prized oyster flesh, yet it had never been agreed who would remove artificial structures.

Subsequently, the construction of piers, docks, marinas, and so on, due to the development of tourism, increased the amount of substrate available for the establishment of yet more polyps.

Both the profound transformation of the habitat and its actors favoured the proliferation of jellyfish in the Mar Menor. The hire boats that went out of San Pedro de el Pinatar to drag for fish now caught gelatinous plankton: in 2000 they caught around 2,000 tonnes of jellyfish, and in 2003 about 5,000 tonnes (96% of the 'fried egg' type). The residents of the area are divided. Almost half consider that the jellyfish damage tourism, although these species are not particularly dangerous. The majority perceived urbanization, agricultural management and overfishing as the real problem in the area, but it is symptomatic that 37% confessed to having no idea why, in a few years, there had been such a spectacular increase of jellyfish in one of the country's most important tourist destinations. The jellyfish have become the actual regulatory system, as the main 'capturer' of nutrients and particles, dead or alive. In various parts of the area, the regional government has already installed 43 km of a network to prevent the arrival of gelatinous intruders. Nevertheless, as usual, there are implications due to the other agents… and you can be sure that pieces of jelly or small jellyfish will continue to reach the Mar Menor's beaches.

## Giant Jellyfish (*Nomura nomurai*)

At the end of 2009, a Japanese fishing boat sank from being overloaded by a jellyfish known as *nomura* by the locals of the area. The boat was not very large, about 10 tonnes, but the story grabbed the world's attention as it was highly alarming. Apart from this shock, the giant jellyfish *Nomura nomurai* has become a real problem on the Japanese west coast. It has been estimated that in times of population explosion or bloom there may be 500 million jellyfish in the waters lapping the coast between Korea, China and the Japanese archipelago and the area south of the coast by the Yellow River. What has happened to make the presence of this species in these waters a nightmare for fishermen since the beginning of 2000? *Nomura* is perhaps the largest jellyfish ever to exist, with an umbel that can measure more than two metres across and a body that sometimes exceeds 200 kg: a queen of a medusa.

In recent decades, two main factors may have triggered its appearance. The first is overfishing (as always), in a sea where, for example, catches have been reduced to 95% in recent years off the coast of China, despite it being one of

the places on the planet where the extraction is concentrated, at no less than 11% of global fishing activity (with 9–10 million declared tonnes of extracted fish). The Sea of Japan and the surrounding areas have always been highly productive, but during recent years the level of nutrients has soared due to industrialization and intensive agriculture, as well as aquaculture-related activities, especially off the Chinese coast.

Jellyfish were the first beneficiaries of this food glut, because organic particles in suspension are an important part of their diet and there are no competitors to share it with. But there are other possible causes. According to specialists, the construction of the Three Gorges Dam on the River Yang-Tse could represent another transformation, changing the dynamics of the currents in this sea and promoting the arrival of material from the mainland to the island of Japan. 'This change in currents and an increase in the surface temperature of 1.7 °C on average since 1976–2000 are factors that help the proliferation of' the medusa, along with overfishing', argues Shin-Ichi Ows from Hiroshima University, Japan. When there is an explosion in jellyfish numbers, reaching densities of approximately 2.5 individuals per 1,000 cubic meters at about 10–30 m deep, their bodies become less robust and more watery, as if they had grown rapidly. 'In only 28 days they can pass from weighing barely 1.5 g to more than 29 g', comments Ows.

But there is another factor that, it is clear, has been decisive, apart from changes in temperature, currents and available food: the increase in substrate available for nomura polyps. As in the Mar Menor and other places, the transformation of the (in this case, mostly Chinese) coast in the past two decades appears to have been a key factor behind its abundance. 'The construction of large ports, dams, artificial reefs, aquaculture farms and other artificial structures could be benefiting the formation of new young from the polyp or the "flower" which settles on the bottom and is essential for its reproductive cycle step', noted Yoon's National Fisheries Research and Development Institute of South Korea. When they reach the Japanese coast, the nomura's gonads are ripe, ready to start life over again. Polyps can survive swings in temperature between 0 °C and 27 °C, which is a very wide range, and even manage to do without food for a long time. 'It is clear, however,' adds Ming Sun of the Key Laboratory of Marine Biological Resources and Ecology of the Liaoning Ocean and Fisheries Science Research Institute in China, 'that if they have temperatures between 15 and 27 °C and much food, proliferate uncontrollably and form large blooms, that can be a huge problem year after year'.

The year 2005 was a particularly difficult year for Japanese fishermen due to an invasion of *Nomura nomurai*. There were more than 100 thousand

formal complaints, losses of up to 80% of income from inshore fishing catches and considerable public alarm. There have been many selective screens devised to catch fish but not let the immense gelatinous creatures past. There are desperate measures to use nomura for food, as the Chinese did hundreds of years ago. In 2007 the Japanese government promoted a book on ways to prepare jellyfish—biscuits, salad dressing, fries—as a counter-attack to an invasion against which it felt powerless but which, together with those of other countries of the environment, it was first responsible.

## *Carybdea marsupialis*, Mediterranean Cubomedusa

The dreaded cubomedusa is typical of tropical seas, such as around the Australian Great Barrier Reef or the Philippines. Cubozoans, or 'box jellyfish', are considered to be the cnidarian group's most dangerous, with an extremely painful sting that has changed the lives of dozens of Australians every year. It is mostly found in shallow areas near estuaries and lagoons, and the largest does not usually measure more than 20 cm by 20 cm across. Its umbel is a curious cube with tentacles of about three metres long coming out of each corner. These corners feature an optical system that is well developed for such a primitive animal, so it is able to perceive changes in both light and form, despite lacking a brain (as do all jellyfish). The venom of many cubomedusas acts immediately and may be deadly: the pain is so intense that it can cause shock, preventing the swimmer from reaching shore, and neoprene is not always sufficient protection against their sting. There are only about forty species known, and they are apparently restricted to tropical seas. Until now.

During the summer of 2008 there was a great abundance of a cubomedusa along the Spanish coast, spotted off the beaches of Denia, Alicante: *Carybdea marsupialis*, a small species. It is rare in the Mediterranean Sea, so had never been considered to be a species that would form a major proliferation, yet during the summer of 2008 the Red Cross reported a high number of stinging incidents in this area due, no doubt, to this almost imperceptible, transparent and seemingly harmless jellyfish forming dense swarms in the breakers. 'During that summer we could confirm that such assistance was due to the presence of these small jellyfish,' says Dacha Atienza of the ICM-CSIC, 'and repeatedly during the summer we made surveys and collected samples, both alive and dead.' Their sting is more serious than that of *Pelagia noctiluca*, but less so than its feared Australian relatives. It is possible that the species

may reappear on another occasions, because nothing is known about its distribution or of what factors influence in its life cycle. Atienza concludes, 'Its recovery is slower than that of other common species in our waters'. Like many other species of gelatinous plankton, its life cycle has not yet been described, and much remains to be understood of its biology and ecology.