Chapter 6
Living with Jellyfish: Management and Adaptation Strategies

Cathy H. Lucas, Stefan Gelcich, and Shin-Ichi Uye

Abstract While jellyfish are some of the most ancient multicellular organisms on Earth, man only started to take notice of their impact on human activity and enterprise from about the 1960s. In some regions of the world, jellyfish blooms impose considerable socio-economic hardship to net-based fisheries, aquaculture, power generation and tourism. Blooms are likely to be difficult if not impossible to eradicate, but these industries are striving to develop management strategies that will enable them to successfully coexist with blooms. This chapter reviews the detrimental effects that jellyfish have on society and human wellbeing. We also summarise adaptation and management strategies that are currently being developed and utilised by fishing, power generation and tourism industries to educate and inform the public and manage the actual jellyfish blooms and help ensure the financial viability of these industries in regions that experience blooms.

Keywords Jellyfish blooms • Socio-economic impacts • Net-based fisheries • Giant jellyfish • Salmon aquaculture • Power station water intakes • Mediterranean tourism • Box jellyfish • Irukandji • Citizen science • Jellyfish forecasting

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6.1 Introduction

While cnidarian medusae and ctenophores (hereafter termed 'jellyfish') are some of the most ancient multicellular organisms on Earth, humans only started to pay attention to them from the middle of the last century, and we have now come to realise that jellyfish impact society and human health in a number of ways. They frequently make the headlines around the world with well-known examples such as the dangers of swimming in the sea off northern Australia during the 'stinger season' when the potentially deadly box jellyfish, *Chironex fleckeri*, are present; reports of mass stranding of the mauve stinger, *Pelagia noctiluca*, on Mediterranean beaches; and the impact that giant jellyfish, *Nemopilema nomurai*, have had on the Japanese and Korean set-net fishing industry in recent years. Much of what people perceive about jellyfish and jellyfish blooms in particular is based on somewhat sensationalist headlines, for example, 'Monster jellyfish hit coast' (thesatellite.com.au, 16 Feb 2010), 'Attack of the blobs' (nature.com, 1 Feb 2012), 'Invasion of the killer jellyfish' (mirror.co.uk, 13 Aug 2008) and 'Climate change and the scary jellyfish scourge' (washingtonpost.com, 3 Aug 2009).

Given the predominance of negative headlines about jellyfish, it may be rather easy to assume that jellyfish serve no purpose to man, other than be a nuisance. However, jellyfish have had a surprisingly long and fruitful relationship with man. The Chinese have been eating jellyfish for well over a thousand years and value them for their medicinal properties (Hsieh et al. 2001; Omori and Nakano 2001). The chemical properties of jellyfish are stimulating major advances in biomedical research and providing a host of opportunities for medical and biotechnological applications. Jellyfish toxins are being analysed for their potential anticancer or antioxidant properties (reviewed by Mariottini and Payne 2010), while jellyfish collagen is being considered as a candidate for replacing bovine or human collagens in selected biomedical applications (Addad et al. 2011). In 1991, nearly 2,500 polyps and ephyrae of *Aurelia aurita* were sent up into space in the space shuttle *Columbia*, in an experiment to test the effects of microgravity on development (Spangenberg 1992). Research on jellyfish species has resulted in two Nobel Awards. The first, a Nobel Prize in Medicine, was awarded to Charles R. Richet in 1913 for his discovery of anaphylaxis following experiments on the Portuguese man o' war, *Physalia physalis*. The second, a Nobel Prize in Chemistry, was awarded to Osamu Shimomura, Martin Chalfie and Roger Tsien in 2008 for their discovery and subsequent cloning and development of green fluorescent proteins (GFPs) from the crystal jellyfish, *Aequorea victoria*.

The ecological and societal benefits of jellyfish have been explored in detail by Doyle et al. in Chap. 5. The aim of this chapter is to review the detrimental effects that jellyfish have on society and human wellbeing, from fishing and aquaculture to power provision and tourism. We also discuss the management and adaptation strategies that are being developed to alleviate the impact that jellyfish blooms are having on human activities and enterprise in the sea.

6.2 Detriments of Jellyfish to Society

Predominantly, jellyfish blooms affect the ‘provisioning’ and ‘cultural’ ecosystem services (www.maweb.org/en/index.aspx), in particular fishing and aquaculture (Doyle et al. 2008; Nagata et al. 2009), power and desalination (Daryababard and Dawson 2008) and tourism (Fenner et al. 2010) industries (see reviews of Purcell et al. 2007; Dong et al. 2010). These detrimental socio-economic impacts on humankind are widely reported by the media. The scientific community also tends to focus on the negative impacts of jellyfish blooms on human enterprise and health, although in many cases rigorous analysis is hampered by a lack of quantitative evidence.

6.2.1 Net-Based Fisheries

Jellyfish and commercially important fish species interact in a number of complex ways. Jellyfish feed on the eggs and larvae of fish, are competitors with zooplanktivorous fish for the same food resource (i.e. they are at or near the same trophic level) and may transmit parasites and bacterial pathogens to fish (Purcell and Arai 2001; Delannoy et al. 2011). Commercial fisheries are dominated by pelagic fish and shrimp in coastal regions supported by high primary and secondary productivity (Doyle et al. 2008; Purcell 2012), and there is evidence that jellyfish numbers have increased in regions where fish stocks have declined due to overfishing, for example, the Benguela upwelling (Lynam et al. 2006). Similarly, several marine fishery resources in Chinese waters have been heavily exploited in recent decades (Tang et al. 2003). In the major fishing grounds of the northern East China Sea, *Cyanea nozakii* jellyfish accounted for up to 98 % of the total fishery catch in the bloom years of 2003 and 2004 (reviewed by Dong et al. 2010).

Although the economic costs associated with jellyfish feeding on larval fish stocks are very difficult to assess, direct physical interference by jellyfish on net-based fisheries is without question and financially demonstrable. Blooms of jellyfish cause severe nuisance by (1) clogging and bursting fishing nets, (2) decreasing fish catch, (3) killing and spoiling fish, (4) stinging fishermen as they try to remove jellyfish, (5) increasing the time and labour effort during the removal of medusae from the nets and an in some instances, (6) causing fishing boats to capsize (e.g. Kawahara et al. 2006; Purcell et al. 2007; Uye 2008; Dong et al. 2010; Quiñones et al. 2012). This is particularly so for Japanese and Korean fisheries located in the Sea of Japan, Yellow Sea and East China Sea, where over the last 10 years, most net fisheries have been affected by blooms of the ubiquitous moon jellyfish, *Aurelia aurita*, and giant jellyfish, *Nemopilema nomurai* (Uye 2008). The latter species is one of the largest jellyfish in the world capable of growing to a size of 2-m diameter and 200-kg wet weight and is distributed in the East Asian Marginal Seas (see Uye, Chap. 8 for detail).

According to the Japanese Ministry of Agriculture, Forestry and Fisheries, there are over 4,000 set-nets of various scales around the Japanese coast (http://maff.go.jp/e/index.html), 1,900 of which are located in regions where *Nemopilema* are present. A large-scale set-net consists of a 2–5-km-long 'leading net' heading into a large chamber and a series of two progressively smaller 'trapping nets', which work by herding the fish into the second trapping, or 'harvest net'. The set-net fisheries represent a significant investment in Japan. The installation cost of one net is 300–700 million JPY (US$ 3.8–8.9 million) and provides a livelihood for between 10 and 30 fishermen. The annual revenue from a large net can be up to 100–300 million JPY (up to US$ 3.8 million); thus, it requires a long-term investment in order to make a profit. This type of fishery has been severely affected, in some years by *N. nomurai*. Following the 2005 bloom in Japan, there were >100,000 *Nemopilema*-related complaints registered with the Fisheries Agency of Japan. Of these, 60 % were related to reduced catch, value of catch and suspension of operations, 30 % to increased labour time to remove fish and 10 % to net damage. The financial implications of *Nemopilema* blooms can be severe. The cost of fixing a set-net is between 1 and 10 million JPY (US$ 12,600–126,000), while the cost of physically modifying a net (i.e. larger mesh size and bypass nets; see Chap. 8) to mitigate the impact of jellyfish is 5–10 million JPY (US$ 63,000–126,000). During these periods, fishing is suspended and the fishermen may be laid off work. Following the 2005 bloom, Aomori Prefecture (northernmost prefecture on the largest island of Japan, Honshū) estimated the monetary loss to be two billion JPY (US$ 25 million), while the nationwide loss was estimated to be 30 billion JPY (US$ 380 million) (Uye 2008). In 2009, perhaps a largest bloom year ever, the monetary loss was apparently less than 10 billion JPY (US$ 125 million), thanks to early warning of the approaching bloom.

Japanese and Korean fisheries are not alone in being impacted by jellyfish blooms, although many incidents are not reported. The shrimp fishery in the Gulf of Mexico has experienced US$ 10 million in lost revenue as a result of the invasive rhizostome *Phyllorhiza punctata* (Graham et al. 2003). Several fisheries in South America have also been affected. In southeastern Brazil, for example, the rhizostome *Lychnorhiza lucerna* forms year-round blooms which have affected the shrimp fishery by shortening and displacing hauls, as well as clogging nets (Nagata et al. 2009). *Lychnorhiza lucerna* also causes fishing problems in northern Argentina by reducing total fish captures and catch quality, damaging nets and preventing fishermen from operating (Schiariti et al. 2008). The Peruvian anchovy fishery, one of the largest single-species fisheries in the world, is seasonally affected by the semaeostome *Chrysaora plocamia* (see Chap. 10). Summer blooms of this species appear as by-catch in the seine nets. In the summer of 2008–2009, medusae accounted for >10 % of the catch (by weight) in 10 % of the hauls and >30 % of the total catch in 5 % of the hauls. The fishery factories deduct the weight of jellyfish when the by-catch exceeds 13 % (by weight) and refuse to receive the catch if jellyfish account for >40 % of the catch by weight. It is estimated that in 2008–2009 *C. plocamia* caused an economic loss of US$ 200,000 in just over 1 month (Quinoñes et al. 2012).

6.2.2 *Aquaculture*

While it is well established that jellyfish cause problems for some net-based fisheries, rather less well known is the negative impact that large aggregations of jellyfish and ctenophores have on the aquaculture industry (Båmstedt et al. 1998). For example, when mass numbers of jellyfish such as the holoplanktonic *Pelagia noctiluca* develop, they may get transported into coastal waters and become aggregated around the cages of fish farms by tidal currents (Doyle et al. 2008). Damage to fish may be indirect, through hypoxia and subsequent suffocation when there is insufficient water exchange between the cage and surrounding water column, or direct, via stinging of the skin and gills as jellyfish pass through the mesh of the cages, either intact or becoming broken up into smaller pieces (Baxter et al. 2011a; Mitchell et al. 2012). The pieces still possess their nematocysts that can be discharged, therefore injecting toxin into the fish which is particularly problematic if this occurs around the eyes and gills (Rodger et al. 2011). If tissues containing nematocysts are inhaled, severe lesions of the gills occur, which leads to respiratory and osmoregulatory distress, reduced feeding and sometimes subsequent death (Bruno and Ellis 1985; Baxter et al. 2011a, b; Rodger et al. 2011). In addition, damaged gills may become infected by bacterial fish pathogens, such as *Tenacibaculum maritimum*, which has been shown to be carried by the jellyfish themselves (Delannoy et al. 2011).

Several species of jellyfish have been reported to cause both catastrophic large-scale fishkill events and the more chronic problem of gill damage in marine-farmed fish (Table 6.1) (Rodger et al. 2011). Notable examples of mass mortalities include the 250,000 Atlantic salmon killed by a 26-km^2 bloom of the scyphomedusa *Pelagia noctiluca* in the northern Irish Sea in November 2007 (Doyle et al. 2008) and >100,000 salmon killed by the siphonophore *Muggiaea atlantica* in Norwegian coastal waters (Fosså at al. 2003). Between 2003 and 2005, gill disorders were one of the most significant causes of mortality in the Irish salmon farming industry, resulting in an annual average mortality of 12 % (Rodger et al. 2011). Scottish fish farms have also suffered fishkills and poor health associated with the presence of jellyfish such as *Aurelia aurita*, *Cyanea capillata* and *Solmaris corona* (Fig. 6.1, redrawn from Nickell et al. 2010). Of the specific plankton-related incidents reported to Marine Scotland Science between 1999 and 2005 from around Scotland, including Shetland, approximately 60 % of fish deaths by weight (i.e. 5,700 tonnes) and numbers (i.e. 2.8 million) were due to jellyfish. Using recorded data from a subset of farms in the Scottish region of Skye and the Outer Hebrides during 2002–2005, mortalities caused by jellyfish or plankton accounted for >10 % of total recorded losses in terms of fish numbers and 17 % of fish biomass (http://www.scotland.gov.uk/Topics/marine/marine-environment/species/plankton).

Quantitative data charting jellyfish-associated economic losses for fish farmers are scarce, but costs are related to (1) direct losses caused by fish mortalities and disposals; (2) reduced growth during or after exposure to harmful agents such as jellyfish, harmful algae, parasites and bacteria; (3) increased operational costs; (4) production losses during emergency slaughtering and the resulting reduced prices;

Table 6.1 Summary of damage and death of farmed fish caused by gelatinous zooplankton (hydrozoans, siphonophores, scyphozoans, ctenophores)

Species	Country/region	Damage caused
Apolemia uvaria	Sweden, Norway	600 tonnes salmon killed
Aurelia aurita	Norway, Shetland, Ireland	Farmed salmon affected
	Lake Hachirogata, Japan	Mass mortality of fish and bivalves
Bolinopsis infundibulum	Norway	Farmed salmon affected
Catablema vesicarium	Outer Hebrides, Scotland	Salmon killed
Cyanea capillata	Scotland, Ireland	90,000 salmon killed in Ireland in 2004 1,000 salmon killed in Scotland 1996
Moerisia lyonsi	USA	Killed decapods in mesocosms
Muggiaea atlantica	Norway	>100,000 farmed salmon affected by 2,000 siphonophores m^{-3}
Pelagia noctiluca	Brittany, France	Significant mortalities of salmon and trout
	Japan	Mortality of penned fish
	Northern Ireland	250,000 salmon killed
Phialella quadrata	Shetland	1,500 fished killed
Porpita porpita	Japan	Mortality of penned fish
Rhizostome jellyfish	Goa, India	Shrimp
Solmaris corona	Scotland	650,000 farmed salmon mortalities in 2 days in 2002
Velella velella	Ireland	Skin and gill pathology observed in salmon

Source: Båmstedt et al. (1998), Purcell et al. (2007), Nickell et al. (2010), Rodger et al. (2011)

and (5) increased insurance premiums. In 2007, the Irish salmon aquaculture industry produced 10,000 tonnes of salmon with a market value of €50 million (~US$ 62.6 million) (Browne et al. 2008, cited in O'Callaghan et al. 2011). The major Irish Sea salmon fishkill at Glenarm, Northern Ireland (the only commercial salmon farm in Northern Ireland and the Irish Sea), in 2007 resulted in a loss of ~ US$ 1.2 million. Furthermore, it is suggested that aquaculture pontoons and cages may actually benefit the presence of hydrozoans (Guenther et al. 2009, 2010) and certain jellyfish species such as *Aurelia aurita*, by providing a suitable substrate for settlement and subsequent growth of the biofouling polyp phase of the life cycle (Lo et al. 2008; Duarte et al. 2013), thus exacerbating the detrimental effects of hydroids (Guenther et al. 2009, 2010) and jellyfish blooms on aquaculture operations.

6.2.3 Energy Supply from Power Stations

Coastal regions are the preferred location for nuclear- and coal-fired power stations and desalination plants because of the requirement for large amounts of seawater to cool their condensers and a source of water for desalination. Typically, the seawater

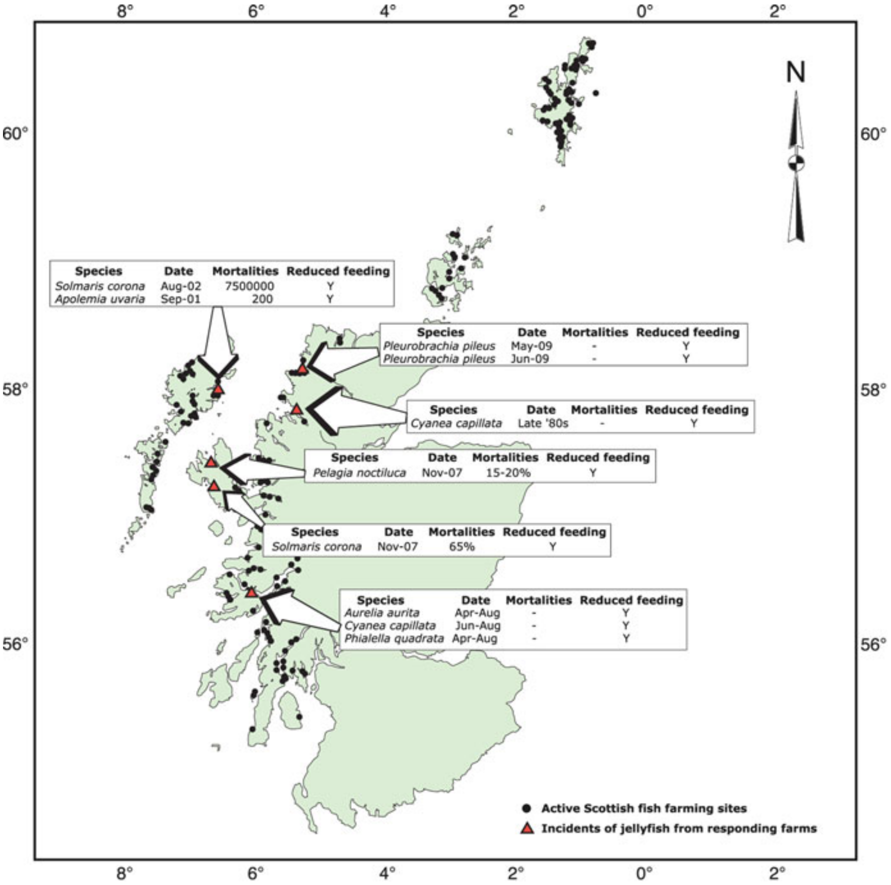

Fig. 6.1 Map showing the location of Scottish fish farms impacted by the jellyfish *Aurelia aurita*, *Cyanea capillata* and *Solmaris corona* (Redrawn from Nickell et al. 2010; base data from Marine Science Scotland; reproduced by permission of The Crown Estate)

intake is located several hundreds of metres from the shore. Large volumes of cooling water extracted by power stations inevitably captures marine flora and fauna, as well as debris (rubbish, sticks, detritus) which then collect on intake screens before entering the cooling system (Purcell et al. 2007). Fish and crustaceans can become impinged on the screens, while smaller, weaker swimmers and plankton can become entrained through the mesh and enter the cooling system. Both impingement and entrainment are detrimental from an environmental health perspective as the organisms are returned to the sea in a physiologically and physically damaged state. When there is a sufficient volume of marine biota and debris, for example, following stormy conditions from a particular wind direction or if there are large blooms or aggregations of marine biota, the screens become blocked, and the flow of cooling intake water significantly reduced (Purcell et al. 2007). Power stations run at reduced efficiency or they may decide to temporarily shut down as a precautionary measure to prevent overheating of the reactors. Provision of power to customers is reduced or even temporarily halted altogether. A 2006 study by the World Association of Nuclear Operators (WANO) reported 44 power outages and load reductions at nuclear plants related to intake blockages since 2004. The most common materials causing blockages were seaweeds and aquatic grasses, mussels, jellyfish, crustaceans (shrimp and crabs) and fish. These materials contributed to 37 of the 44 events.

The clogging of intake screens of power and desalination plants by jellyfish has been a long-standing problem in SE Asia, and in particular Japan, where large seasonal populations of *Aurelia aurita* occur regularly between ~ April and September or November (Yasuda 1998, 2003). The problem is not confined to SE Asia alone, and power stations in India, the Middle East, Europe and North America have been affected by a number of jellyfish species (Rajagopal et al. 1989; Masilamoni et al. 2000; Purcell et al. 2007: Table 4). A study on jellyfish ingress on the Madras Atomic Power (MAP) Station, south-east India, in 1995 and 1996, found that large numbers (up to 17.5 tonnes) of three species, *Crambionella stuhlmanni*, *Crambionella buitendijki* and *Dactylometra quinquecirrha*, appeared on the intake screens between April to July and October, causing reduced flow and head loss (i.e. reduction in vertical drop or pressure). Increased head loss results in increased back pressure on the turbine as well as a reduction in heat transfer efficiency in the heat exchangers. Thus, reduced flow and head produces less electricity. An increase of 10-mm-Hg back pressure in the MAP Station turbine resulted in a loss of ~ INR (Indian Rupees) 0.11 million d^{-1} (~ US$ 2,000 d^{-1}), while damage to the intake screens caused INR 0.4 million per season in revenue loss. Jellyfish that managed to get into the cooling water circuits resulted in the plant shutting down, at a cost of ~ INR 5.5 million d^{-1} (~ US$ 100,000 d^{-1}) (Masilamoni et al. 2000).

In 2011, three power stations were temporarily shut down over the space of 10 days as a result of jellyfish ingress, which was widely reported in the media: Shimane nuclear power station, Japan (25 June); Torness nuclear power station, Scotland (30 June); and Orot Rabin coal-fired power station, Israel (5 July). Most likely these closures in quick succession were coincidental, resulting from regular summer blooms of jellyfish – *Aurelia aurita* in Scotland and Japan and the rhizostome *Rhopilema nomadica* in Israel. Nevertheless, these blooms can be substantial. The magnitude of jellyfish numbers involved in such incidents is illustrated in Fig. 6.2, with media reports indicating that 50 tonnes of *Rhopilema* jellyfish were removed from the Orot Rabin site.

6.2.4 Ship Operations

Similar to coastal power stations, many ships rely on seawater to cool their condensers, and jellyfish can thus impact shipping operations when they clog condensers. In 2006 some capabilities on the US$ 5 billion, 97,000-tonne aircraft carrier

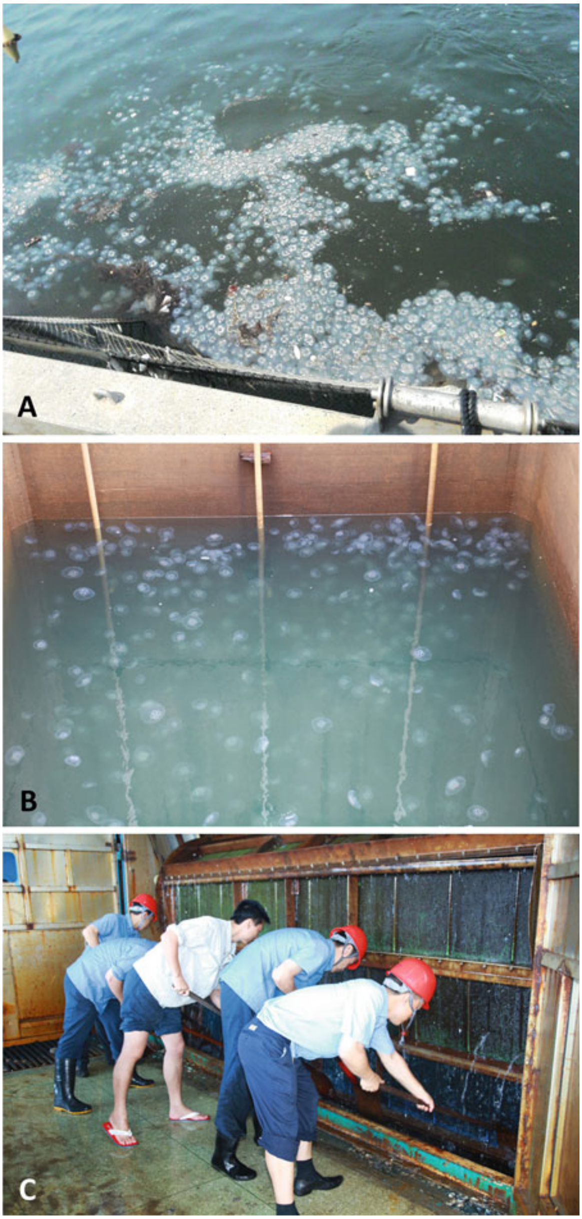

Fig. 6.2 **(a–c)** Blooms of *Aurelia aurita* impacting power stations. (**a**) *Aurelia* medusae near a screen protecting a cooling water intake in Japan; (**b**) Large numbers of *A. aurita* in cooling seawater filters in Qingdao in July, 2009; (**c**) Power station workers cleaning *A. aurita* away from the filter screens in Qingdao in July, 2009 (Photo A reproduced by permission of Shin-Ichi Uye; Photos B, C reproduced by permission of Zhijun Dong)

'USSR Ronald Regan' were disabled when a large number of the rhizostome *Catostylus mosaicus* were sucked into the cooling water condensers in the Port of Brisbane, Australia (Herald Sun, 27th January 2006). Moreover, jellyfish can also clog the bow thrusters of ships which can pose a serious threat when ships are undertaking delicate manoeuvring operations in port (R. Moreton, Port of Brisbane. pers. comm.).

6.2.5 Tourism

Probably the most high-profile example of the impact that jellyfish have on society is the detrimental effect on coastal tourism. Tourism is one of the world's largest economies, with coastal tourism being one of the most common types, and in tropical and subtropical regions, coastal tourism has huge economic importance. The economies of Spain, Portugal, Italy and Greece all depend heavily on tourism, with 130 million visitors, mainly from the wealthy countries of Germany and the UK. However, coastal tourism is very sensitive to public perception. How crowded are the beaches? Is the water clean and safe to swim in? Some of the most popular beach destinations in the world include the northern rim of the Mediterranean, the north and north-east coasts of Australia, the Indo-Pacific and the southern United States, in particular Florida. Several of these regions are adversely affected by the presence of jellyfish, some of which have nasty or even fatal stings (e.g. *Physalia physalis*, *Rhopilema nomadica*, *Cyanea lamarckii*, *Chironex fleckeri*, *Carukia barnesi*) (Purcell et al. 2007). Jellyfish may be present in the shallow waters where people swim and snorkel, or they may get washed up onto the beaches following strong onshore winds. How the public responds to these events depends on their prior knowledge and perception of the potential dangers posed by the species present, their cultural background and whether they feel that their activities and enjoyment will be compromised. For the most part, there is a great deal of negative reporting in the media, and this influences people's perceptions of jellyfish and their own safety and enjoyment.

The most extreme example of jellyfish impacting tourism involves the northern coast of Australia (mainly Queensland, QLD, and the Northern Territory, NT), Thailand, the Philippines and other Pacific nations where cubozoan jellyfish are found (Fenner and Williamson 1996; Fenner et al. 2010). Severe envenomation from the sting of the chirodropid 'box jellyfish' *Chironex fleckeri* causes cardiac and respiratory arrest which may prove to be fatal in only 2–3 min. More recently *Carukia barnesi* and several other unnamed carybdeids have been identified as the cause of Irukandji Syndrome, the symptoms of which include intense lower back and chest pain, abdominal cramps, nausea, vomiting, difficulty breathing, headache, anxiety and severe hypertension that may last for 1–2 days (Gershwin et al. 2010). Several medical studies have summarised reports of stings, hospitalisations, types of treatment and fatalities as a result of *C. fleckeri* and 'Irukandji jellyfish' around the northern coast of Australia between Broome (Western Australia, WA) and Fraser Island (QLD) (e.g. Fenner and Harrison 2000; Macrokanis et al. 2004; Currie and Jacups 2005; Nickson et al. 2009) and other parts of the Indo-West Pacific (Fenner et al. 2010). Based primarily on regional hospital data, the number of reported *Chironex* or Irukandji stings in Australia ranges between <10 and ~ 200 year^{-1} for each region or state, with the majority of casualties being tourists (Sando et al. 2010). Many people require either basic first aid (vinegar, picking off tentacles, cold packs) on site, although for Irukandji stings the majority of victims require transportation to hospital (Table 6.2) for pain management or care for 1–2 days. Fatalities in Australia are remarkably rare. Fenner and Harrison (2000) reported that *Chironex*

Table 6.2 Numbers of people diagnosed with Irukandji Syndrome in tropical Queensland 2001–2007, with methods used to get to hospital (Modified from Sando et al. 2010)

Year	Number of people	Locals %	Tourists %	Self	QAS land	EMQ chopper	RFDS
2001	44	52.3	47.7	23	18	3	0
2002	50	46.0	54.0	22	17	11	0
2003	18[a]	61.1	38.9	6	8	4	0
2004	16	43.8	56.3	3	8	5	0
2005	14	42.9	57.1	3	7	4	0
2006	19	26.3	73.7	3	4	11	1
2007	24	29.2	70.8	4	13	7	0
Total	185	44.1	55.9	64	75	45	1

Self travel to hospital using private transport, *QAS land* Queensland ambulance service land ambulance, *EMQ chopper* emergency management Queensland helicopter, *RFDS* royal flying doctor service

[a] In the original Table 3, Sando et al. 2010, there is one person of unknown origin in 2003, which has been removed from this table

had caused 67 deaths in Australia between 1884 and 1996, while the first reported death from Irukandji Syndrome occurred in 2002 (Fenner and Hadock 2002). Jellyfish-related fatalities are far more common in countries such as Malaysia and the Philippines, where between 20 and 50 people die each year as a result of jellyfish stings (Fenner et al. 2010).

While the potentially fatal box jellyfish may grab the headlines in Australia and the Indo-West Pacific, several other types of jellyfish with nasty stings are prevalent in the region. On the east coast of Australia, ~10,000 stings each summer are attributed to the Portuguese man o'war (known locally as 'blue bottles'), *Physalia physalis*, with *Cyanea* sp. and *Catostylus* sp. stings also reported (Fenner and Williamson 1996). *Nemopilema nomurai*, *Cyanea nozakii*, *P. physalis*, *Aurelia aurita*, *Rhopilema esculentum* and *Pelagia noctiluca* are the most common jellyfish responsible for stings in Chinese coastal waters, where there have been at least 13 known fatalities and several thousand hospitalisations between 1983 and 2007 (Dong et al. 2010: Table 2). In recent years, Mediterranean tourism has been affected by the increased frequency and abundance of the mauve stinger, *P. noctiluca*. While this jellyfish undoubtedly possesses a nasty sting that may require medical treatment (e.g. in July 2008, the French emergency services received >500 calls in one day along a 16-km stretch of coast from Nice to Cannes), it is very rarely life threatening, only proving fatal if the person affected has an underlying medical condition. Nevertheless, the public perception of this jellyfish is highly negative, which combined with the expectation of an uninterrupted beach holiday, results in public reaction that greatly outweighs the actual risk associated with this species. The impact of jellyfish to tourism may be minimal if the beach closures are for only a few hours, but if closures become more persistent year on year or a significant number of people require medical treatment, then the media reports that arise may persuade tourists to seek alternative destinations.

6.3 Management and Adaptation Strategies

6.3.1 Net-Based Fisheries and Aquaculture

At present, year-to-year bloom intensity of *Nemopilema nomurai* has become possible to forecast in early summer based on monitoring of juvenile medusae from ships of opportunity in Chinese waters, the seeding and nursery ground of this species and the transport and timing of appearance of medusae into Japanese waters using hydrodynamic modelling (Uye, unpublished). Thereby, Japanese fishermen can be made aware of impending jellyfish blooms and prepare some countermeasures before medusae outburst in their waters (see Chap. 8). However, a similar bloom forecasting system has not yet been established for *Aurelia aurita*, because the seeding place is often unclear and the seasonal life cycle and physical oceanography differ from one place (or bay) to another. One of the countermeasures used by Japanese fishermen is to slice *Nemopilema* and *Aurelia* with so-called jellyfish cutters using carbon steel wires at the cod-end of trawls to facilitate removal, but the operation is generally confined to small areas compared to the vast geographical range of jellyfish distribution, indicating that slicing is only useful for highly aggregated jellyfish patches. Any net-based fisheries are more or less damaged by entrapped jellyfish, and various types of jellyfish-excluding devices have been invented and deployed. JET (Jellyfish Excluder for Towed fishing gear), a device similar to the TED (Turtle Excluder Device) used in shrimp trawls (Watson et al. 1993; Mitchell et al. 1995), was designed to remove *Nemopilema* from towed fishing nets (Fig. 6.3, redrawn from Matshushita and Honda 2006) and has been used by Japanese fishermen during bloom years. To alleviate the damage by *Nemopilema* blooms, some modified set-nets have already been manufactured (see Chap. 8).

The aquaculture industry is also developing strategies to protect its stock. Options available to fish farmers can be classified as ‘site location’, ‘early warning systems’ and ‘mitigation methods and technologies’ (O’Callaghan et al. 2011). Although not really practicable for established farms, it is suggested that new salmon farms should not be situated in tidal fronts and eddies where jellyfish aggregations tend to develop (Graham et al. 2001) and instead placed in higher energy offshore sites where jellyfish densities are likely to be lower and flushing rates are higher, which improves oxygenation and reduces biofouling. However, technical issues that would need resolving before locating salmon farms further offshore include designing robust and submersible cage structures able to withstand the higher wave energy and managing the increased safety and financial costs associated with access requirements to the offshore site (O’Callaghan et al. 2011). Attempts to develop ‘early warning systems’ of impending blooms using water characteristics (but this requires long-term monitoring datasets), hydrodynamic models such as MIKE 3 (Elzeir et al. 2005), aerial surveys (Houghton et al. 2006; Nickell et al. 2010) and satellite (e.g. MODIS) data (Nickell et al. 2010) are also being undertaken. All have various limitations and investigations are ongoing. For established farms, there is now greater communication between agencies and fishermen; a watch-keeping

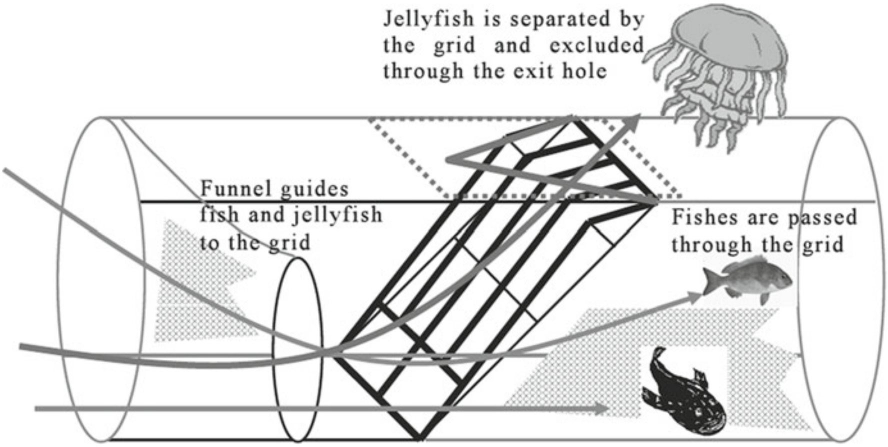

Fig. 6.3 Separation of jellyfish from target fish species by JET, Jellyfish Excluder for Towed fishing gear (Redrawn from Matshushita and Honda 2006)

system is utilised by the Scottish aquaculture industry to inform farmers of approaching blooms (Nickell et al. 2010).

Mitigation strategies that existing fish farms can use to defend their stock include deploying protective covers or booms and mesh or bubble screens to prevent jellyfish from entering the cages. Tank trials show that bubble screens, similar to those used to protect water intakes of power stations, create a horizontal current profile that repels those jellyfish in the upper water column away from the screen and pushes those jellyfish in the lower water column up towards the surface and then away to a collecting boom (Lo 1991, 1996). However, field trials at a Donegal (Ireland) salmon farm indicated that the number of *Muggiaea atlantica* was similar inside and outside the screen (O'Callaghan et al. 2011) and that this method is costly to implement, even for short periods. An alternative to barrier methods is to increase oxygen levels by aeration, which helps to keep the stock healthy (Rodger et al. 2011). Care must be taken to ensure that aeration bubbles do not in fact circulate the jellyfish within the cages. Aeration used in combination with finer meshes and tarpaulins around the cages prior to the arrival of the bloom is more successful in keeping jellyfish away from fish.

The polyp phase of scyphozoan life cycle can also be targeted. Polyps of ubiquitous jellyfish such as *Aurelia* have been found to inhabit man-made structures, including the undersides of marina pontoons, dock walls, marine debris and aquaculture cages (Duarte et al. 2013), and these represent a potential source of medusae recruits close to the target areas. Divers are employed to scrape off fouling epibiota, including hydroids and polyps from the salmon aquaculture cages deployed in Norwegian, Australian, Scottish and Irish waters. Japanese and Norwegian researchers (Guenther et al. 2009, 2010, Nogata et al. unpublished) have found that some antifouling chemicals (copper pyrithione, sea-nine 211) used in ship paints are lethal for hydroids and *Aurelia* polyps and that some chemical compounds isolated from the macroalga *Digenea simplex* inhibit *Aurelia* planula larvae from successful settlement and attachment on to the substrate. Silicone-based paints could also be used to delay or prevent biofouling hydroids and other epibiota (Hodson et al. 2000). If these compounds are painted on the surface of various marine constructions, they could contribute to the reduction of polyp colonisation and population size. However, many such substances (e.g. copper) are banned for use in the organic farms located in Scotland and Ireland. Alternatively, transplant of polyp predators such as nudibranchs (Hernroth and Gröndahl 1985; Hoover et al. 2012) to the polyp colony habitats may be an effective 'biological control' in decreasing polyp population numbers and thus reduce the recruitment success to the medusa population via strobilation (Lucas et al. 2012).

6.3.2 Energy Supplies

To protect water intakes of power stations and desalination plants, screens of various designs are put into place. Scientists working for consultancy companies advise government agencies and power plant operators about which screens, flow velocities and deterrents are most appropriate based on knowledge of fish swim speeds and behaviour. The vast majority of scientific and advisory reports focus on the impacts of fish ingress, with very little information specifically on jellyfish. Screens form either physical barriers (e.g. mesh or wire screens with diverters) or behavioural barriers (e.g. bubble, sound, electrical, acoustic, light, hydrodynamic screens) preventing ingress (Environment Agency 2005). The design, installation and operation of screens and barriers can add significantly to the capital and operating costs of the facilities, but good practice is essential. In addition to the impact of trapped organisms on the safe running of the power station itself, impingement is an important issue to consider from an environmental health perspective. Marine fauna may be removed from the ecosystem or may be returned to the source water body in a weakened condition, injured or dead, which may then represent a health and safety hazard. Alternative screen design (e.g. bubble screens and water jets, suitable mesh sizes, fish diverters) can both reduce the quantity of material captured and ensure maximum survival and subsequent return to the marine environment of organisms impinged (BEEMS, Scientific Advisory Report No 6. 2011). One of the very few reports considering how to mitigate the effects of jellyfish on cooling intakes, Verner (1984) reported on the use of bubble barriers to prevent blockage of cooling water supplies by jellyfish. The method of removal of the 2011 *Rhopilema nomadica* bloom from the Orot Rabin coal-fired station is illustrated in Fig. 6.2. The 50 tonnes of medusae were transferred from the screens into large containers, which were then taken away in trucks for disposal. Following the Torness jellyfish ingress in 2011, a quarterly site report indicated that 'arrangements are being put into place to monitor, and if necessary, to mitigate against any future increased risk of blockages that may be caused by the marine environment'.

6.3.3 Tourism, Including 'Citizen Science'

Cubozoan jellyfish sting incidents represent a major cost to northern Australian communities in terms of public health, leisure and tourism (Bailey et al. 2003; Gershwin et al. 2010). If a person becomes seriously ill following a sting, there are the costs associated with evacuation of the victim to hospital often by helicopter (Table 6.2), duration of stay in hospital (typically 1–2 d for Irukandji victims), lost work days and the development and production of antivenom for *Chironex* (note there is no antivenom for Irukandji as the identity of all the species that cause Irukandji Syndrome is still unknown). On average, northern Queensland records about 50 Irukandji hospitalisations per year, and approximately the same number per year is recorded in northern Western Australia (Macrokanis et al. 2004). It was estimated that the two Irukandji deaths in 2002 resulted in an AU$ 65 million (US$ 66 million) loss in tourist revenue in the region (see Gershwin et al. 2010). As a result, local and regional authorities and report managers in northern Australia and other jellyfish-affected regions of the world have developed a number of mitigating strategies based on medical and scientific advice, aimed at reducing or managing the detrimental effects that jellyfish can have on tourism focusing on (1) education, (2) information, (3) personal protection, (4) removal of jellyfish and (5) medical aid.

As a broad generalisation, the general public is not well informed about which species of jellyfish are dangerous or not, probably with the exception the Portuguese man o'war, *Physalia physalis*, and box jellyfish, *Chironex fleckeri*. For many decades, tourists (mainly the younger 'backpackers') visiting Queensland have known about the risks posed by *C. fleckeri*, and adaptation strategies to minimise the risk of contact are well established. This probably explains why there have been so relatively few deaths from this species in the region (Fenner and Harrison 2000). The situation with the carybdeid cubozoans such as *Carukia barnesi* is rather different. Following the first deaths of two international visitors to Queensland from Irukandji Syndrome in 2002, there was a considerable increase in public and scientific attention as it was clear that far less was known about this group of jellyfish than *Chironex* box jellyfish (Bailey et al. 2003). A survey of ferry passengers between Townsville and Magnetic Island, QLD, to assess local and visitor knowledge, perception and behaviour toward Irukandji Syndrome revealed that international tourists had little knowledge of Irukandji (34 % compared with 88 % locals and 70 % domestic tourists) and mistakenly assumed that it was safe to swim inside stinger nets (which are designed for the larger *C. fleckeri*: 25–30-cm bell diameter cf. 2-cm bell diameter for carybdeids) (Harrison et al. 2004). In addition, only 50 % of visitors had obtained travel health advice before coming to the region (Leggat et al. 2005).

In spite of the obvious dangers, northern Queensland has remained a popular tourist destination, and in fact deaths are remarkably rare given the potential severity of the jellyfish toxin. Education informs people of when it is safe to swim and how to administer basic first aid, while adaptation actions reduce encounters with jellyfish. In the Mediterranean, negative public reaction to the increased frequency of blooms of *Pelagia noctiluca* (Kogovšek et al. 2010) and other jellyfish species tends to outweigh the actual risk. In 2008, the Mediterranean Science Commission set up the CIESM JellyWatch programme to gather baseline data on the frequency and extent of jellyfish outbreaks throughout the jellyfish-affected Mediterranean Sea. The programme includes a citizen science-based system for reporting opportunistic observations, with posters providing information on whether species are ‘stingers’, ‘mild stingers’ or ‘harmless’ written in eight languages (www.ciesm.org/marine/programmes/jellywatch.htm). With the growth of various very successful ‘citizen science’ programmes around the globe (e.g. beach surveys for jellyfish such as Doyle et al. (2007) and Houghton et al. (2007); Mediterranean Science Commission/CIESM and Monterey Bay Aquarium Research Institute JellyWatch programmes; JelliesZone; UK Marine Conservation Society jellyfish survey), jellyfish now offer a potential looking glass through which to understand and appreciate the marine environment.

At the beaches themselves, several adaptation strategies are used to minimise contact with jellyfish. In Australia information signs warn bathers of the dangers of swimming during the ‘stinger season’ [Oct–Jun in the Northern Territory, NT], list the symptoms of envenomation by *Physalia*, *Chironex* and Irukandji jellyfish in particular and provide information on how to administer basic first aid or contact the emergency services (Gershwin et al. 2010: Fig. 4). Vinegar is placed in prominent places along the beach or held by lifeguards as the acetic acid inhibits firing of undischarged nematocysts. Stinger nets to protect swimmers are deployed during the box jellyfish season although these are not effective in preventing contact with the Irukandji jellyfish as these are small enough to pass through the 25 × 25-mm mesh (Harrison et al. 2004; Gershwin et al. 2010). Instead all-in-one Lycra stinger suits are more effective at protecting against Irukandji jellyfish. Stinger nets are also deployed in the Mediterranean to protect against *Pelagia noctiluca* blooms. Other mitigating strategies range from short-term beach closures while stranded jellyfish are cleared away to larger-scale removal and disposal of jellyfish from the water using fishing boats (Gili pers. comm., see Canepa et al. Chap. 11).

The Mediterranean coasts of France and Spain are among the most popular tourist destinations in Europe, which brings in significant revenue to the economies of these countries. Because these regions are being more regularly impacted by the increased frequency of *Pelagia noctiluca* outbreaks that have occurred in recent years (Gili and Pagès 2005; Molinero et al. 2005), scientists have turned their attention to developing jellyfish forecasting or ‘early warning’ systems. On 1 July 2012, the Jellywatch.fr website (http://lseet.univ-tln.fr/JELLYWATCH) was launched. This provides a ‘barometer of jellyfish’ based on forecasts of stranding and real-time observations for each resort in the region of Provence, Alpes and Cote d’Azur. The barometer provides a 5-point probability rating from 0 (no risk) to 5 (maximum jellyfish alert) based on modelling of particles (jellyfish) using current strength and wind direction and taking into account their diel vertical migration (Fig. 6.4). Other large-scale remote-sensing and modelling programmes that predict the distribution of jellyfish in Europe include EOJelly (= Star Jelly) (www.starlab.org) which also provides a 7-day advanced 5-point Jellyfish Prediction Index (JPI) for the NW Mediterranean coast and northern Irish Sea, and Aviso (www.aviso.oceanobs.com)

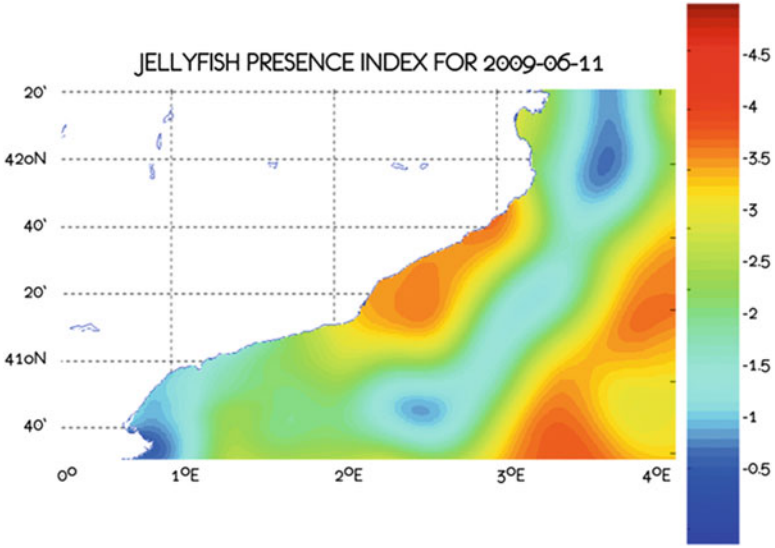

Fig. 6.4 Forecasting the appearance of jellyfish along the NW Mediterranean coast with the Jellyfish Presence Index, a 5-point probability rating from 0 (no risk) to 5 (maximum jellyfish alert) generated using models of particles (jellyfish) movement based on current strength and wind direction and taking into account jellyfish diel vertical migration (Reproduced by permission of EOJelly, www.starlab.es)

which uses Lagrangian analysis of 3D mesoscale dynamics from altimetry which describe ocean currents and coastal modelling to predict jellyfish distribution over the NW Mediterranean Sea. In Chesapeake Bay, USA, the likelihood of encountering sea nettles (*Chrysaora quinquecirrha*) is forecast by the National Ocean and Atmospheric Administration (NOAA). Forecasts are based on maps of surface salinity, and forecasts are validated by field observations made by scientists working in Chesapeake Bay and volunteer citizens (http://chesapeakebay.noaa.gov/forecasting-sea-nettles).

6.4 Concluding Remarks

While it is very true that some jellyfish blooms are economically detrimental to the livelihoods of local fishermen, tourist industries and power and water operations, much of people's perception of jellyfish is rather negative, which is partly driven by poor understanding of their diversity, biology and ecology. Understanding how the public engage with jellyfish in combination with education campaigns is a vitally important mechanism to rectify this. Scientists from the National Center for Ecological Analysis and Synthesis (NCEAS)-funded project '*Global expansion of jellyfish blooms*' participated in two public outreach events: the first at the

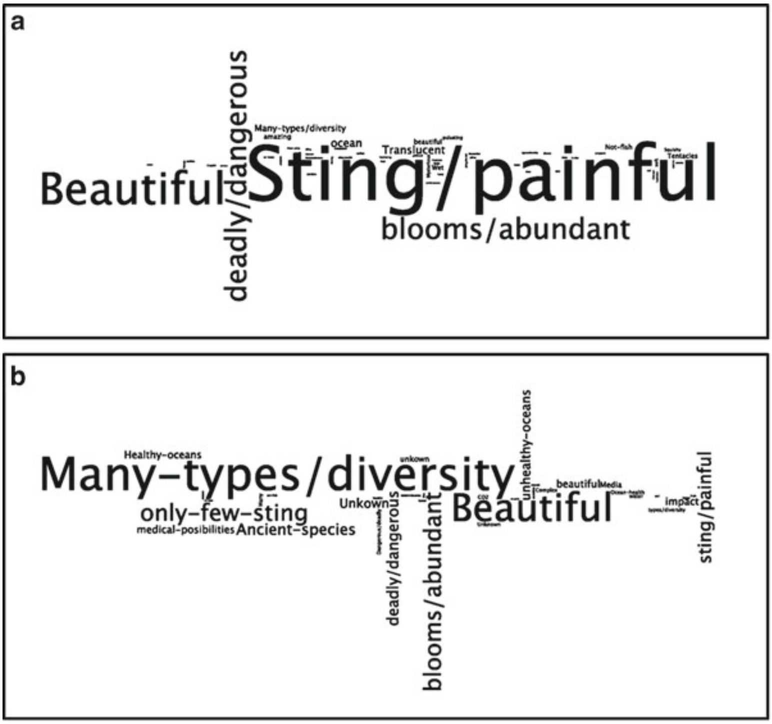

Fig. 6.5 (**a–b**) Tag clouds summarising the change in public perception of jellyfish, (**a**) before and (**b**) after a series of talks and videos presented by jellyfish scientists at a public outreach event held at the Santa Barbara Museum of Natural History in November 2010 (Data were collected using questionnaires)

Santa Barbara Museum of Natural History in November 2010 and the second, hosted and funded by the Fundación BBVA in Madrid in September 2011. At the Santa Barbara event, the audience was invited to fill out a questionnaire before and after a series of talks and videos, the results of which are illustrated in the form of 'tag clouds' (Fig. 6.5). The combination of scientific outreach events, aquarium displays of jellyfish, websites and citizen science-based programmes all help to educate and engage the public in jellyfish. On 1 August 2012, Jellywatch.org released Apps for iPhones and Android phones to enable the public to more easily submit sightings and photos to the global database.

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