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GFCM

Workshop on

Algal and Jellyfish Blooms in the Mediterranean and Black Sea

(6th/8th October 2010, Istanbul, Turkey)

A brief review

Algal and Jellyfish Blooms in the Mediterranean and Black Sea

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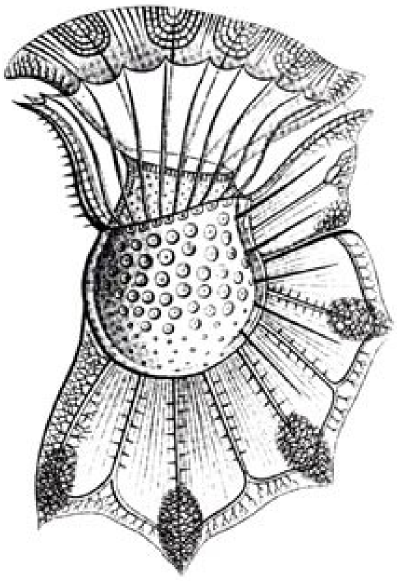
Introduction

Algae

Large accumulations of phytoplankton, macroalgae and, occasionally, colorless heterotrophic protists are increasingly reported throughout the coastal areas of all continents (Sellner et al. 2003) often causing visible water discoloration (Glibert 2007). Aggregations of these organisms can in fact, discolour the water giving rise to red, mahogany, brown, or green tides, and also can float on the surface in scum, cover beaches with biomass or exudates (foam) and deplete oxygen levels through excessive respiration or decomposition (Sellner et al. 2003, Glibert 2007). Phytoplankton blooms, micro-algal blooms, toxic algae, red tides, or harmful algae, are all terms for this naturally occurring phenomena (IOC HAB Programme 2010). About three hundred species of microalgae are reported at times to form mass occurrence, so called "blooms" and nearly one fourth of these species are known to produce toxins. The scientific community usually refers to these events with the term, 'Harmful Algal Bloom' (HAB) (IOC HAB Programme 2010). In fact, proliferations of microalgae in marine or brackish waters can cause massive fish kills, contaminate seafood with toxins and alter ecosystems in ways that humans perceive as harmful (IOC HAB Programme 2010).



Dinophysis sp. (SERC, online); a large genus with some 200 described species several of which are toxic and cause the Diarrhetic Shellfish Poisoning (see below).

A broad classification of HABs distinguishes two groups of organisms: the toxin producers – which can contaminate seafood or kill fish – and the high-biomass producers – which can cause anoxia and indiscriminate kills of marine life after reaching dense concentrations (Smayda 1997b, IOC HAB Programme 2010); this kind of bloom can also lead to fish starvation or cause harmful mechanical and physical damage and chemical effects attributable to physical-chemical reactions, phycotoxins, or other metabolites (Smayda 1997b) (see Effects of algal and jellyfish blooming on fisheries). Some HABs have characteristics of both (IOC HAB Programme 2010).

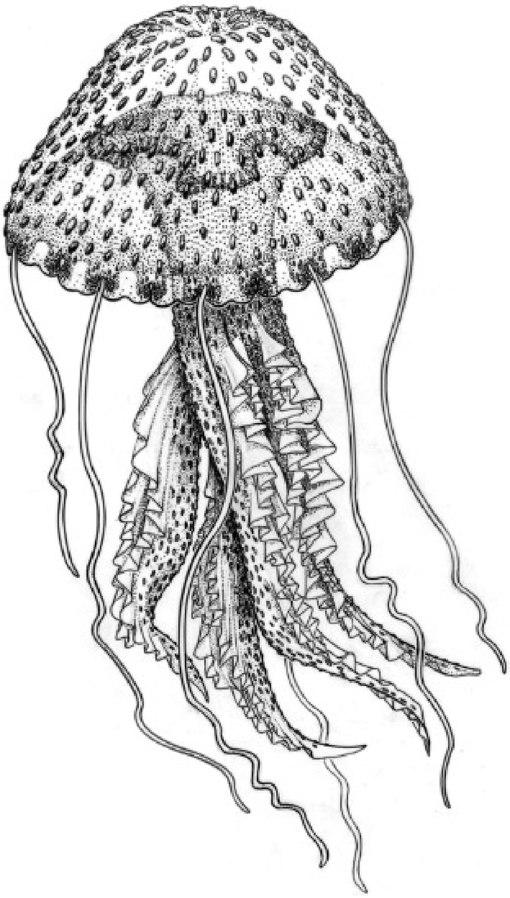
The toxin producers' species in harmful algal blooms exert their effects through the synthesis of toxins compounds that can alter cellular process of other organisms from plankton to humans. The most severe effects of HABs include fish, bird, and mammal (including human) mortalities, respiratory or digestive tract problems, memory loss, seizures, lesions and skin irritation, as well as losses of coastal resources such as submerged aquatic vegetation and benthic epi- and in-fauna (Sellner et al. 2003).

Reasons for the increasing interest in HABs include not only public safety concerns associated with protecting human health, but also adverse effects on living resources of many coastal systems, economic losses attributed to reduced tourism, recreation, or seafood related industries, and costs required to maintain public advisory services and monitoring programs for shellfish toxins, water quality, and plankton composition (Sellner et al. 2003). Many of the syndromes and other harmful effects pertain to occurrences of dinoflagellates. There is, however, an increasing number of species recognized as toxic in other algal classes and harmful species are now found in at least 5 groups of algae (IOC HAB Programme 2010):

- *Dinophyceae* (dinoflagellates)
- *Prymnesiophyceae* (*Haptophyceae*)
- *Raphidophyceae*
- *Bacillariophyceae* (diatoms)
- *Cyanophyceae* (blue-green algae)

Jellyfish

Usually the term 'jellyfish' is used in reference to medusae of the phylum Cnidaria (Scyphozoa, Cubozoa, Hydrozoa) and to planktonic members of the *phylum* Ctenophora (Mills 2001). Though not closely related, these organisms share many characteristics including their watery or 'gelatinous' nature, and a role as higher-order carnivores in plankton communities (Mills 2001). By the pulsed nature of their life cycles, gelatinous zooplankton come and go seasonally, giving rise in even the most undisturbed circumstances to blooms (Mills, 2001). Several species increase in number in the spring or summer when planktonic food is available in greater abundance (Mills 2001). Beyond that basic life cycle-driven seasonal change in numbers, several other kinds of events appear to be increasing the numbers of jellies present in some ecosystems (Mills 2001). Over recent decades, man's expanding influence on the oceans has begun to cause real change and there is reason to think that in some regions, new blooms of jellyfish are occurring in response to some of the cumulative effects of these impacts (Mills 2001, Purcell et al. 2007). Gelatinous zooplankton blooms exert tremendous pressure on marine planktonic food webs, including in regions of important commercial fisheries (Graham & Bayha 2007). Therefore reports of human problems with jellyfish have increased and have captured public attention (Purcell et al. 2007). Such problems come mainly from jellyfish stinging swimmers and interfering with fishing, aquaculture and power plant operations (Purcell et al. 2007).



Pelagia noctiluca (Cnidaria, Scyphozoa), one of the most common jellyfish of the Mediterranean and Black Sea (P. Stephens-Bourgeault, online).

Generally, only a relatively few coastal species of large jellyfish are responsible for those problems. These large species are conspicuous; however, they are only a portion of the diverse gelatinous fauna (Purcell et al. 2007).

The ability of gelatinous species to occur in large numbers (i.e. to bloom) is due to the cnidarians (Scyphozoa, Cubozoa, Hydrozoa) having both asexual and sexual reproduction and to the ctenophores. Most coastal jellyfish are asexually budded from an attached stage in the life cycle, a scyphistoma for scyphozoans, and a hydroid (often colonial) for hydromedusae. The benthic stages are usually referred to ‘polyps’; polyps bud more polyps, and many jellyfish can be budded from a single polyp; cubozoan polyps are an exception, transforming into individual jellyfish without budding. Swimming jellyfish reproduce sexually, often have great fecundity and may brood the larvae, which settle to become polyps. Temperate species typically have an annual cycle, with small jellyfish (1 to 2 mm ‘ephyrae’ for scyphozoans) being produced in fall or spring, and the jellyfish growing to sexual maturity over the summer. By contrast, siphonophores (Hydrozoa) and ctenophores lack an attached stage in the life cycle (i.e. holoplanktonic). The siphonophores also have asexual multiplication of reproductive individuals, followed by sexual reproduction. Most ctenophores are hermaphroditic, and have direct development and great fecundity. Therefore, siphonophores and ctenophores are not constrained to one generation per year, in contrast to many species in the other taxa (Purcell et al. 2007). Although this represents a general picture of the life cycles, cnidarians, especially the hydrozoans, are renowned for reproductive variety; many hydromedusae are holoplanktonic, while this is rare in scyphozoans, and some hydromedusan jellyfish reproduce asexually (Boero et al. 2002). Thus, the ability of pelagic cnidarians and ctenophores to bloom in good conditions is intrinsic

(Purcell et al. 2007, Boero et al. 2008). Some blooms appear to be long-term increases in native jellyfish populations. A different phenomenon is demonstrated by jellyfish whose populations regularly fluctuate, apparently with climate, causing periodic blooms. Perhaps the most damaging type of jellyfish increase in recent decades has been caused by populations of new, non-indigenous species gradually building-up to ‘bloom’ levels in some regions (Mills, 2001).

Cnidarians species that usually rise in blooms in the Mediterranean and Black Sea are *Pelagia noctiluca* (Scyphozoa), *Cotylorhiza tuberculata* (Scyphozoa), *Rhizostoma pulmo* (Scyphozoa), *Rhopilema nomadica* (Scyphozoa), *Aurelia aurita* (Scyphozoa); ctenophores species that usually rise in blooms in the Mediterranean and Black Sea species are *Mnemiopsis leidyi* (Lobata) and *Beroe ovata* (Beroida).

Reported cases of algal and jellyfish blooms in the Mediterranean and Black Sea: an updated review

Algae

Dense blooms of phytoplankton are a widespread phenomenon of the global coastal ocean. They develop in response to favourable conditions for cell growth and accumulation (Basterretxea et al 2007). These blooms of autotrophic algae and some heterotrophic protists are increasingly frequent in coastal waters around the world (Sellner et al. 2003). There is no doubt that HABs are occurring in more locations than ever before and new sightings are reported regularly (Sellner et al. 2003). Several researchers have argued that this trend is due to increasing eutrophication throughout the world (Sellner et al. 2003) but, generally, phytoplankton bloom has regional, seasonal and species-specific aspects that must be considered (Moncheva et al. 2001).

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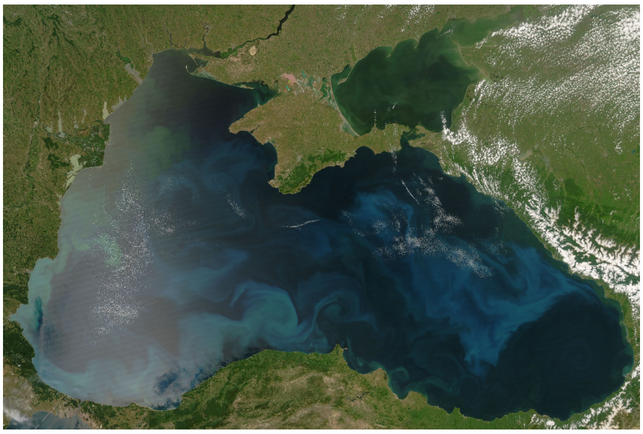
In contrast to large-scale blooms that are dominated by mesoscale circulation, Mediterranean HABs are a more localized phenomenon commonly related to areas of constrained dynamism, such as bays, lagoons, ports, beaches and estuaries. In these areas, enhanced growth of phytoplankton not only leads to a perceivable water discoloration along the shoreline but also to deterioration in water quality. Other unprecedented ecological effects in the Mediterranean, such as fish kills and risks to human health, have been attributed to toxic algal proliferations in recent years. Given that a bloom represents a deviation from the normal cycle of biomass and despite the fact that in some cases the proliferation of algae may have a natural origin, it is considered that coastal blooms are an emerging problem that could be related to nutrient enrichment of coastal waters. Intensive urbanization and recreational use of coastal watersheds has resulted in a remarkable increase in sources of nutrients along the Mediterranean coasts. This cultural eutrophication generates a contrast between coastal waters and the open ocean where, owing to summer stratification and nutrient depletion, oligotrophic conditions prevail in the upper layer. Nutrient-rich coastal environments of the Mediterranean Sea and, in particular, semi-enclosed areas with low turbulence levels constitute a new and unique environment for which several phytoplankton species with harmful effects may become dominant. Even though most of the factors involved in the Mediterranean near shore algal outbreaks are known, the mechanisms that underpin their occurrence are not yet well established (Basterretxea et al. 2007). Along the coasts of North Africa, the spatial distribution of chlorophylls and carotenoids is attributed to the human-altered patterns of the physical structure and the nutrient concentrations, but also to the Modified Atlantic Water (MAW). The physical forcing resulting from the MAW advection could confront distinct water masses and generate potential mixing of water from coastal and/or open-ocean origin. This water mixing may have an impact on the phytoplankton populations, which, in North Africa, experience large variations in their abundance, composition and size structure due to the dynamic nature of their environment (Bel Hassen et al. 2009). In the Black Sea, since the late 1970s, anthropogenic nutrient enrichment has been identified as a key ecological problem for this basin, especially its north-western and western part, which is subjected most to the influence of freshwater nutrient inputs. The input of nutrients and dissolved organic matter to the north-west shelf of the Black Sea by the Danube, the Dniepar and the Dniestar river flows for the period 950–1980 increased about 10 times. An increase in phytoplankton blooms frequency, species involved, duration, timing and area are well documented, provoking substantial perturbations of the entire food web structure and functioning. Changes in zooplankton communities structure and deterioration of benthic coenoses, culminating during the 1980s (period of intensive eutrophication in the Black Sea), were to a great extent associated with the dramatic alterations in phytoplankton communities and recurrent hypoxic conditions. Microalgal blooms were therefore identified as one of the key issues for the Black Sea's ecological health. Similar eutrophication problems have been recognized in the Eastern Mediterranean Sea in several Aegean and Ionian coastal areas, affected by urban and industrial wastewaters and/or nutrient inputs from rivers and agricultural activities; thus phytoplankton, as primary producer, became the first target of the anthropogenic induced stress, resulting in dramatic alterations in species composition, abundance and biomass, seasonal dynamics and succession in the two basins (Moncheva et al. 2001).

In February 2009, the southern coast of Italy is flanked by an algal bloom with distinctive swirls. The shoreline of the Apulia region (the peninsula above) is mostly clear of algae, while those of the Calabria (bottom) and Basilicata (centre) regions are completely surrounded. The tip of Sicily (bottom left) and Albania (top right) can also be seen. The Sicilian shoreline is relatively clear, whereas part of the Albanian one has an intense bloom (Earth Snapshot, Copyright © 2008-2010 Chelys srl).



The image shows a colourful bloom of phytoplankton in the Black Sea in June 2008, along the southern coast near the Turkish cities of Sinop and Samsun. Loops and swirls of blooming phytoplankton follow the coastline, while farther out in the open waters (upper right), the blooms become more spread out. The greenish plumes hugging the coast from Sinop westward to just beyond Samsun may be river plumes. River plumes can contain nutrients that stimulate phyto-plankton blooms. (NASA/GSFC, MODIS Rapid Response 2008).

Table below summarizes only some of the many algal blooms events
that occurred in the Mediterranean and Black Sea during the last 50 years
(only Genus of the species involved are reported).

Year	Genus	Location	Source
late 1960s	*Prorocentrum*	North Adriatic Sea	Fonda-Umani 1996
1970s	*Noctiluca, Gonyaulax, Prorocentrum, Gyrodinium, Glenodinium,*	North Adriatic Sea	Fonda-Umani 1996
1980s	*Katodinium, Noctiluca, Glenodinium, Prorocentrum, Gyrodinium, Gonyaulax, Scrippsiella, Massarthia*	North Adriatic Sea	Fonda-Umani 1996
1984	*Gonyaulax*	Spain	Shumway 1990
1986	*Prorocentrum*	Black Sea	Heil et al. 2005
1989	*Gymnodinium*	Mediterranean Sea	Shumway 1990
1993	Dinoflagellates*	Black Sea	Bodeanu et al. 1998
1995-1996	*Pseudo-nitzschia, Nitzschia, Cheatoceros, Ditylum, Cylindrotheca, Rhizosolenia, Heterocapsa, Protoperidinium, Scripsiella, Emiliana, Gonyaulax, Prorocentrum*	Black Sea	Turkoglu & Koray 2004
since 1994	*Karenia*	Tunisia	Marrouchi et al. 2009
1994 and 1996-1999	*Alexandrium*	Spain	Vila et al. 2001
1994 and 1997	*Prorocentrum, Noctiluca, Erythropsidinium*	Greece	Nikolaidis et al. 2005
1998	*Alexandrium*	France	Masselin et al. 2001; Lilly et al. 2002
1998	*Chattonella*	Greece	Nikolaidis et al. 2005
1999	*Prorocentrum*	France	Heil et al. 2005
1998, 2000-2001	*Ostreopsis*	Tyrrhenian Sea	Sansoni et al. 2003
2001	*Skeletonema, Cerataulina, Prorocentrum, Gymnodinium*	Black Sea	Taylor & Longo 2010
2003	*Alexandrium, Gymnodinium*	Spain	Basterretxea et al. 2007
2000-2004	*Prorocentrum, Noctiluca, Gymnodinium, Alexandrium, Dinophysis, Pseudo-nitzschia*	Greece	Nikolaidis et al. 2005
2005-2006	*Ostreopsis*	Ligurian Sea	Mangialajo et al. 2008
2006	*Coolia*	Tunisia	Armi et al. 2009
2007	*Ostreopsis*	North Adriatic Sea	Totti et al. 2010
2010	*Ostreopsis*	Southern Italy	ARPA Puglia 2010; ARPA Sicilia 2010

* Group

Jellyfish

Jellyfish populations have bloomed in coastal lagoons along the Mediterranean coasts since the 1970s and a several-year bloom in the early 1980s stimulated two 'Jellyfish Blooms' meetings in Athens in 1984 and 1991 (UNEP 1984, 1991) (Purcell et al. 2007). High abundances of gelatinous species in the Mediterranean Sea have been associated to alterations in the trophic structure of marine ecosystems owing to overfishing and to hydroclimatic effects (Licandro et al. 2010); outbreaks are also attributed to variations in water mass and high salinity as well as warm temperature (Purcell et al. 2007), since sea temperature can influence jellyfish life cycles and reproductive output (Purcell et al. 2007, Boero et al. 2008, Licandro et al. 2010).

High abundances of gelatinous species in the Mediterranean Sea have been associated to alterations in the trophic structure of marine ecosystems owing to overfishing and to hydroclimatic effects.

In the Adriatic Sea, in the last twenty years, a series of massive disruptions had greatly impaired local economies and ecosystem functions. The main cause of all this originates in eutrophication, caused by agricultural, industrial and urban activities leading to enormous nutrient overloads, mainly discharged by the Po River. The years were characterised by jellyfish outbreaks, red tides, bottom anoxia leading to benthic mass mortalities and mucilage (Boero 2001). Mean time, pollution, eutrophication and many anthropogenic alterations of the natural environment have vastly altered the Black Sea in the past 50 years. This highly productive ecosystem has converted from supporting a number of valuable commercial fisheries to having few fishes and high numbers of 'jellyfishes' – medusae and ctenophores. By the 1960s, largely due to the effects of pollution combined with over fishing, many of the native fishes in the Black Sea had become uncommon, including the jellyfish-eating mackerel *Scomber* *scombrus*. Perhaps directly related to the loss of this and other fishes, and to increasing eutrophication, the Black Sea has experienced severe outbreaks of three different species of 'jellyfish' in the past 3 decades (Mills 2001).

Table below summarizes jellyfish blooms events in
the Mediterranean and Black Sea reported from 1970s to date.

Year	Species	Location	Source
late 1960s - early 1970s	*Rhizostoma pulmo*	NW Black Sea	Zaitsev 1997
1971 - 1980	*Cotylorhiza tuberculata*	Adriatic	Malej 2001
1971 - 1990	*Pelagia noctiluca*	Adriatic	Malej 2001; Mills 2001
early 1980s	*Aurelia aurita*	Black Sea	Zaitsev 1997
after 1980	*Rhopilema nomadica*	Eastern Mediterranean	Mills 2001; Purcell et al. 2007
1984 - 1987	*Pelagia noctiluca*	France, Monaco	Purcell et al. 2007
late 1980s - early 1990s	*Mnemiopsis leidyi*	Black Sea	Mills 2001
1991 - 2000	*Aurelia aurita*	Adriatic	Malej 2001
1991 - 2000	Ctenophora*	Adriatic	Malej 2001
annual, after 1993	*Cotylorhiza tuberculata*	Spain	Pagès 2001
annual, after 1993	*Rhizostoma pulmo*	Spain	Pagès 2001
1995	*Cotylorhiza tuberculata*	Adriatic	Benovic & Lucic 2001
1995	*Mnemiopsis leidyi*	Black Sea	Graham & Bayha 2007
1996-1997	*Pelagia noctiluca*	Adriatic	Benovic & Lucic 2001
1998	*Cotylorhiza tuberculata*	Adriatic	Benovic & Lucic 2001
1999	*Beroe ovata*	Black Sea	Ivanov et al. 2000
2001	*Rhizostoma pulmo*	Adriatic	Benovic & Lucic 2001
2000	*Velella velella*	Western Mediterranean	CIESM 2001
2000	*Aurelia aurita*	Adriatic	Benovic & Lucic 2001
2001	*Mnemiopsis leidyi*	Black Sea	Finenko et al. 2003
2004	*Pelagia noctiluca*	France, Monaco	Purcell et al. 2007
2006	*Pelagia noctiluca*	Spain	Purcell et al. 2007
2006	*Aurelia aurita*	France	Purcell et al. 2007
2006	*Rhizostoma pulmo*	France	Purcell et al. 2007
2006	*Mnemiopsis leidyi*	France	Purcell et al. 2007
2007-2008	*Pelagia noctiluca*	Western Mediterranean	Licandro et al. 2010
2010	*Rhopilema nomadica*	Eastern Mediterranean	Galil 2010

* Group

Mitigating measures/approaches taken in relation to algal and jellyfish bloomings

Algae

Several decades ago, relatively few countries were affected by HABs, but now most coastal countries are threatened, in many cases over large geographic areas and by more than one harmful or toxic species. The causes behind this expansion are debated, with possible explanations such as (Anderson 2005):

- natural mechanisms of species dispersal;
- human-related phenomena such as pollution-related nutrient enrichment;
- climatic shifts;
- transport of algal species via ship ballast water.

Several studies (e.g. Moncheva et al. 2001, Anderson et al. 2002, Sellner et al. 2003, Imai et al. 2006, Glibert 2007) indicate that a positive relationship between anthropogenic eutrophication and phytoplankton blooms does exist. Whatever the reasons, coastal regions throughout the world are now subject to an unprecedented variety and frequency of HAB events. Many countries are faced with a bewildering array of toxic or harmful species and impacts, as well as disturbing trends of increasing bloom incidence, larger areas affected, more fisheries resources impacted, and higher economic losses. This diversity in blooms and their impacts presents a significant challenge to those responsible for the management of coastal resources threatened by algal blooms (Anderson 2005). The strategies needed to

A positive relationship between anthropogenic eutrophication and phytoplankton blooms does exist.

protect fisheries, minimize economic and ecosystem losses, and protect public health vary considerably among locations and among HAB types (Anderson 2005). Anderson (2005) provides a brief summary of some of these strategies, emphasizing the distinctions between management actions that fall into the defined categories of *mitigation, prevention*, and *control.*

- *Mitigation*

Many of the management actions taken to respond to HABs can be termed mitigation – i.e., dealing with an existing or ongoing bloom, and taking whatever steps are necessary or possible to reduce negative impacts (Anderson 2005). Thus an early alert means that specific contingency plans can be put in action to avoid health problems and limit economic losses (Zingone et al. 2000). Examples of mitigation actions are routing monitoring programme for toxins in shellfish to detect possible bloom events, towing of fish net pens away from the sites of intense HABs (Zingone et al. 2000, Anderson 2005), harvesting mussels before they become toxic (Zingone et al. 2000) or removal of scallop viscera and marketing only the adductor muscle of shellfish which generally contains no HAB toxins (Anderson 2005).

- *Prevention*

Prevention refers to actions taken to keep HABs from happening or from directly impacting a particular resource. Nevertheless, scientists do not have all of the knowledge needed about why HABs form in many areas, so it is obviously difficult to regulate or control those factors; thus substantial and sustained research on all aspects (ecology, physiology and oceanography) of HABs, is needed. In some other cases it is known that certain environmental factors are influencing the population dynamics of a specific HAB organism, but there are limitations on what can be done to feasibly modify or control those factors. We might know that a particular HAB is strongly influenced by the outflow of a river system, but local administrators are unlikely to be able to justify the alteration of that river flow solely on the basis of HAB prevention. The rapid increase in the input of plant nutrients, particularly nitrogen compounds, into coastal waters throughout the world reflects the growing disposal of sewage from expanding populations, increased use of chemical fertilizers in agriculture, and increased fossil fuel combustion. To prevent bloom events the legislative or policy changes implemented in some countries all over the world (e.g. Japan) demonstrate that control of sewage or waste discharges has the potential to prevent certain types of HABs. Many countries, implementing sewage reduction strategies, are making good strides towards: more efficient fertilizer application methods or instituting other controls that help to capture the nitrogen and phosphorus before they enter rivers and streams; this trend should be encouraged (Anderson 2005).

- *Control*

This concept refers to actions taken to suppress or destroy HABs – to directly intervene in the bloom process but so far we have rudimentary knowledge and slow moving research. Indeed, as the HAB problem continues to worsen in certain areas of the world, the pressure for, and the acceptance of bloom control or suppression strategies is likely to increase. Nowadays, there are four general strategies that can be used to combat or suppress an invasive or harmful species, these include: mechanical, biological, chemical and genetic control. One form of mechanical control is the removal of HAB cells from the water by dispersing clay over the water surface. The clay particles aggregate with each other and with HAB cells, removing those cells through sedimentation. The balance cost/benefit of this kind of control, with respect to the ability to obtain permits, environmental clearances and funds to employ this strategy, is not easily assessable. Chemical control was attempted in 1957 against the Florida red tide organism using copper sulphate delivered with crop dusting airplanes but so far chemical control has not been actively pursued by the HAB community, because of the general feeling that it will be difficult and perhaps impossible to find an environmentally acceptable chemical that would target a particular HAB species but not cause widespread mortality of other organisms. Biological and genetic control are all strategies that are commonly used to contrast the invasion of terrestrial harmful species (e.g. the release of sterile males or the use of pheromones to control insect pests), but the issues surrounding these type of control strategy during HAB events concern the possible negative impacts of introducing in the ocean one organism to control another or a non-indigenous organism (Anderson 2005).

Jellyfish

Recent concerns that jellyfish populations are increasing have stimulated theories about possible causes including climate change, eutrophication, over fishing and invasions. Historical plankton records of several long-term (8 to 100 yr) trends in jellyfish populations demonstrate that their abundances vary with climate and persistent increases of jellyfish unrelated to climate variation have not yet been demonstrated (Purcell et al. 2007, Boero et al. 2008); nevertheless the best indications that jellyfish blooms have increased are from the reports of problems caused by jellyfish (Purcell et al. 2007). Commercial fishing efforts continue to remove top-predator fishes throughout the world oceans and it seems reasonable to watch concomitant trends in jellyfish populations, as jellyfish typically feed on the same kinds of prey as do many

The best indications that jellyfish blooms have increased are from the reports of problems caused by jellyfish.

either adult or larval fishes. Increases in jellyfish have also been the result of recent introductions followed by population explosions of non-indigenous species into coastal ecosystems. Although environmental degradation typically leads to species loss, eutrophication can apparently also sometimes lead to increases of jellyfish in local environments; such cases typically involve only single species and may sometimes in fact be non-native species (Mills, 2001). Decreasing levels of oxygen (hypoxia) in some bodies of water, often associated with eutrophication, may also favour increases in jellyfish populations (Mills 2001); for example the great success of the introduced ctenophore, *Mnemiopsis leidyi*, in the Black Sea was probably due to many factors, including previous ecosystem damage, overfishing, climate variations and the initial absence of a controlling predator (Purcell et al. 2007). Subsequently, the *M. leidyi* population was controlled by the invasion of an other predator, the ctenophore *Beroe ovata* (Purcell et al. 2007).

Even if it is early to determinate whether recent jellyfish increases will be sustained or the populations will fluctuate with climate, if environmental deterioration, including ocean warming, is responsible for the blooms, high jellyfish populations may persist. Therefore it is necessary to consider how climate change, eutrophication, fishing, aquaculture, construction, species invasions and the co-occurrence of many of these factors may enhance populations of gelatinous species (Purcell et al. 2007) and subsequently to detect where and how efforts aimed at limiting and mitigating this phenomena must be directed.

- *Environmental variables and climate change*

Several studies (e.g. Goy et al. 1989, Purcell et al. 1999b, Mills 2001, Oguz 2005b) indicate that fluctuations of pelagic cnidarian and ctenophore abundance are correlated with environmental variables. The majority of moderate-temperature species studied have been reported to increase in warm temperatures. Environmental factors such as temperature and salinity may directly affect the size and timing of jellyfish populations, increasing and accelerating the reproduction rate. Some blooms of pelagic cnidarians often are associated with changes in current patterns, which may cause incursions or retention of pelagic cnidarians. High abundances of gelatinous species in the Mediterranean Sea also have been associated with variations in water mass and high salinity as well as warm temperature. Changes in temperature and salinity also can affect pelagic cnidarian and ctenophore populations by changes in ocean productivity, but the results of such changes are difficult to predict since they must translate up through the food web and will differ by location. Various authors have suggested that increased stratification related to warming and the resulting recycled production might favourably affect jellyfish populations. One major repercussion of increasing CO_2 concentrations in the atmosphere is decreasing pH of ocean waters, which has been reported widely. Ocean pH is predicted to decrease by 0,3 during the 21st century (IPCC 2007) and sea acidification could have serious consequences for organisms that build skeletons or shells of calcium carbonate ($CaCO_3$) such as pteropods. Many jellyfish have microscopic calcium statoliths that serve in orientation; however, the effects of decreasing pH on statoliths secretion by jellyfish are unknown. Long-term changes in climate have been documented, such as increased temperatures and decreased ice in the Arctic, changes in precipitation, ocean salinity, wind patterns and extreme weather frequency and intensity; it is considered ‘virtually certain’ that these changes will continue in the 21st century (IPCC 2007). Global warming is predicted to cause a temperature increase of 0.1 to 0.2°C per decade and ocean surface temperatures will rise nearly everywhere (IPCC 2007). There is a high degree of uncertainty in predicting specific changes in many important factors (e.g. precipitation, salinity, currents, cloudiness, production, pH) and the consequences for organisms, because of hydrographic and seasonal variation, and of interactions and feedbacks among the multiple factors, as well as many direct human effects. For example, the food available to pelagic cnidarians and ctenophores would depend on their competitors and predators (e.g. fish) as well as production. Nonetheless, changes in temperature, salinity, currents and light are very likely to cause changes in the population sizes, distributions and timing of gelatinous species (Purcell et al. 2007).

To understand how climate variables affect the various species, predictive equations and models using environmental data and climate indices need to be developed. Combinations of field and laboratory studies also are necessary. It is important to remember that environmental changes will affect both the benthic and pelagic stages of the cnidarians. Even less is known about the benthic stages than the pelagic jellyfish. Basic information, such as polyp habitat, is unknown for most species. To understand the factors affecting jellyfish blooms, it is essential to learn more about the ecology of the benthic stages (Purcell et al. 2007). This means that research on plankton must include the study of environments where “classical” plankters are not supposed to thrive, i.e. the sea bottom (Marcus & Boero 1998).

- *Eutrophication*

Eutrophication is considered to be one of the major global pollution problems. This phenomenon is associated with increased nutrients, altered nutrient ratios and increased turbidity where humans develop coastal areas. Increased nutrients often lead to greater biomass at all trophic levels. More food for polyps and jellyfish increases asexual production of jellyfish and sexual reproduction. Even if has not been yet possible to positively identify the cause of jellyfish blooms to be nutrient increases, outbreak of jellyfish populations have been attributed to excessive nutrient additions from human sources in additional areas (e.g. agriculture and development increased nitrate levels in the Mar Menor, Spain, associated with annual blooms of 2 jellyfish species since 1993). This suggests that high nitrogen ratios may favour jellyfish blooms. Eutrophication also causes complex changes in the food web because high N:P ratios means the bloom of the flagellate based food-path that ends with consumers such as jellyfish; sea eutrophication shifts the phytoplankton community away from diatoms towards flagellates and jellyfish. Eutrophication often is associated with low dissolved oxygen levels (hypoxia), especially in the bottom waters. Fish avoid or die, in waters of ≤ 2–3 mg O_2 l^{-1}, but many jellyfish species are tolerant of ≤ 1 mg O_2 l^{-1}; jellyfish polyps are also tolerant of low oxygen and may find additional habitat where other epifauna is reduced in hypoxic waters. Some species of jellyfish (and planktonic ctenophores) lack a polyp stage, and those species may persist where hypoxic bottom waters prevent others with vulnerable benthic stages. Eutrophication and development reduce water clarity and light penetration, which may alter the feeding environment to benefit gelatinous predators over fish. Epipelagic fish are visual feeders, while jellyfish are non-visual; turbid water could reduce feeding by fish, but not affect jellyfish (Purcell et al. 2007).

Increased fertilizer use may cause dissolved inorganic nitrogen exports to the coastal oceans to more than double by 2050 and studies on the effects of eutrophication and hypoxia on jellyfish and ctenophores are needed (Purcell et al. 2007).

- *Fishing and aquaculture*

Fishing may positively affect pelagic cnidarian and ctenophore populations by removing predators of the gelatinous species. Gelatinous species are eaten by many species of fish, some of which are commercially important. Also, populations of other predators such as turtles, believed to eat primarily gelatinous prey, decreased dramatically in the seas of the entire world. Moreover fishing for zooplanktivorous forage fish species (e.g. anchovies, sardines and menhaden) removes potential competitors of gelatinous predators. Diets of forage fishes and gelatinous species overlap; therefore, reduction of forage fish can provide additional food for gelatinous predators (Purcell et al. 2007). Reduction of zooplanktivorous fish populations was implicated when ctenophores and jellyfish replaced fish in the Black Sea (Shiganova 1998). Overfishing is considered to be a severe problem of one resource after another and, in combination with other ecosystem damage, it may lead to greater jellyfish and ctenophore populations. Also aquaculture may unintentionally benefit jellyfish populations in several ways. First, if additional feed is provided, eutrophication of the waters can result (Purcell et al. 2007) in those consequences previously discussed. Second, the culture structures provide additional substrate on which the benthic stages may live and produce more jellyfish. Another unintended benefit for gelatinous predators is that forage fish (e.g. anchovies, sardines and menhaden) are harvested for fish meal for aquaculture feed and removal of zooplanktivorous fish may provide opportunities for their gelatinous competitors' population growth (Purcell et al. 2007), as already discussed.

Global fish production is projected to double between 1997 and 2020, with especially large increases occurring in developing nations and in aquaculture. Much of the extremely valuable long-term data on jellyfish populations are from fisheries. Quantification of jellyfish live catch volume and numbers should become standard protocol in fisheries surveys. Contrary to nearly all past research in which jellyfish and fish are studied separately, future work should consider them together. A larger human population brings increased coastal development, aquaculture and commerce, with enhanced opportunities for polyp settlement and alien species introduction. Global bivalve (mussels, oysters, scallops) and marine fish aquaculture have increased dramatically in recent decades and can provide favourable habitat for jellyfish polyps. Research to determine materials that reduce polyp recruitment should be conducted (Purcell et al. 2007).

- *Construction*

The term 'construction' is used for a variety of human disturbances to aquatic habitats that have either added structures to or altered the characteristics of coastal waters. In addition to aquaculture, humans add many other structures to coastal waters including docks, marinas, breakwaters, oil platforms and artificial reefs, all of which provide surfaces for polyps, but the importance of this is unknown (Purcell et al. 2007). Most reported jellyfish blooms have occurred in heavily populated areas surrounding semi-enclosed water bodies (Pagès 2001, Purcell et al. 2007). Such areas often have extensive construction in addition to eutrophication and fishing, and the effects are impossible to separate (Purcell et al. 2007).

- *Alien invasions*

Several species of jellyfish have been accidentally introduced in many locations around the world and some have caused tremendous ecosystem disruptions and economic losses. The transport between locations has mostly been via ballast water, and sometimes from the aquarium trade. Newly introduced species often display large initial blooms that become less intense; however, the stage is set for subsequent large blooms when fortuitous conditions prevail, and for expansion of the population into new areas (Purcell et al. 2007). *Rhopilema nomadica* first appeared in the Mediterranean in the mid-1970s and now is found along all coastlines of the eastern Mediterranean Sea (Mills 2001, Purcell et al. 2007). In the early 1980s, the notorious ctenophore, *Mnemiopsis leidyi,* first invaded the Black Sea, where it spreads to the Sea of Azov and the Mediterranean and Caspian seas (Zaitsev 1997, Mills 2001, Purcell et al. 2007). The invasion by *Mnemiopsis leidyi* was followed in 1997 by that of another ctenophore, *Beroe ovata*, hat feeds almost exclusively on other ctenophores, especially *Mnemiopsis* (Graham & Bayha 2007).

The invasive cnidarian *Rhopilema nomadica* (top), and the ctenophores *Mnemiopsis leidyi* (middle) and *Beroe ovata* (bottom).

Moreover, last June, the first sighting of the Atlantic jellyfish *Catostylus tagi* in the Mediterranean Sea has been recorded: the presence of this jellyfish has been documented by diving operators in the Sicily Channel (Boero *pers. comm.*). Thus, blooms may take place in areas where the species did not previously occur (Purcell et al. 2007) and effects on the entire ecosystem are unpredictable.

Greater care should be taken to prevent transport of gelatinous species to different environments. Transport of pelagic stages (e.g. Mnemiopsis leidyi) and polyp stages is possible (e.g. Cassiopea spp.). Many species may easily survive transport because the benthic stages enter a dormant stage (cyst or stolon) in response to stressful conditions in which they can survive extended periods (Purcell et al. 2007).

Table below summarizes species of jellyfish and ctenophores known to have been inadvertently introduced to non-native habitats (from Graham & Bayha 2007).

Invading species	Areas of invasion	Year
Rhopilema nomadica	Eastern Mediterranean Sea	after 1980
Phylloriza punctata	Mediterranean Sea	1965
Cassiopea andromeda	Mediterranean Sea	after 1886
Mnemiopsis leidyi	Black and Mediterranean Sea	late 1980s
Beroe ovata	Black Sea	1997

Effects of algal and jellyfish bloomings on fisheries

Algae

Some microalgae may have devastating effects on fish and other marine life, both in wild and aquacultures (Anderson 2005, IOC HAB Programme 2010). HABs cause mortalities of wild fish, seabirds, whales, dolphins, and other marine animals, typically as a result of the transfer of toxins through the food web (Anderson 2005). This historically has resulted in extensive fish kills with major economic losses. Sometimes additional losses may be inferred from public discredit of seafood products due to misunderstandings and misinformation about harmful algal events (IOC HAB Programme 2010).

Algal blooms may have devastating effects on fish and other marine life, both in wild and aquacultures.

Several species of microalgae belonging to different taxonomic groups (see Introduction) can produce toxins which damage fish gills by hemolytic effects (IOC HAB Programme 2010). Adult fish can be killed by the millions in a single outbreak, with long and short-term ecosystem impacts. Likewise, larval or juvenile stages of fish or other commercially important species can experience mortalities from algal toxins. Impacts of this type are more difficult to detect than the acute poisonings of humans or higher predators, since exposures and mortalities are subtle and often unnoticed. Impacts might not be apparent until a year class of commercial fish reaches harvesting age but is in low abundance. Chronic toxin exposure may therefore have long-term consequences that are critical with respect to the sustainability or recovery of natural populations at higher trophic levels (Anderson 2005).

Also fish and shrimp mortalities caused by HABs have increased considerably at aquaculture sites in recent years (Anderson 2005). In 1997 and in 2002, has been estimated that algal blooms have been the second cause of aquaculture industry losses and the third in 2007 (Rutter 2010). With the increasing problems of overfishing, aquaculture may become an increasingly important alternative for the supply of seafood. To minimize the risk of sea-food poisonings and the risk of major economic losses due to fish kills, it is important to establish adequate surveillance programmes and quality control of the seafood products which will often require expert assistance from countries which have longstanding experience in this matter (Anderson 2005, IOC HAB Programme 2010).

Typically, aquatic animals are exposed to toxic or harmful concentrations of algae when planktonic or epibenthic species bloom and dominate the food web, but there are also less obvious means of exposure. The chances of an organism being exposed to a toxic or harmful species depends on the basic ecology of the HAB species, the environmental conditions that are conducive to bloom formation, and the likelihood that a susceptible organism will come into contact with the HAB. Whether HAB species are benthic or planktonic, predatory or photosynthetic, or in a resting cyst phase will influence which communities of marine organisms might be affected by exposure to that HAB species. The degree of harm incurred may, in turn, depend on whether the organisms can detect blooms or toxins and then avoid them (Landsberg 2002). In some cases, there may be no obvious mechanism by which some organisms could detect toxins, and so they may inadvertently consume toxic HAB species or prey. In these cases, chronic or sub-lethal effects may occur.

Exposure to harmful microalgae and characterized toxins can affect fish, shellfish and all the marine fauna through many ways either direct or indirect (Landsberg 2002):

- *Exposure to intracellular toxins* (direct)

Organisms are directly exposed to microalgal cells and their toxins either by drinking them or ingesting them via various feeding modes (e.g., filter feeding, predation). Zooplankton, sponges, and shellfish that filter feed can take up toxic cells directly from the water column; many of these organisms retain toxins in the viscera. Planktivorous fish that actively prey on toxic microalgae can also absorb toxins. Because filter feeders and predators are not necessarily discriminatory, they can be exposed to most of the known major microalgal toxins (Landsberg 2002).

- *Exposure to exotoxins or exudates* (direct)

During active growth, many microalgae release exudates such as extracellular toxins (exotoxins) into the surrounding water, and organisms can be affected by such products even in the apparent absence of cells. Release of exotoxins by microalgae and the long-term persistence of toxins in water are determined by basic physicochemical properties that influence their stability; release of toxins into a watery milieu may not always pose a threat to organisms if large volumes of water dilute the toxins (Landsberg 2002).

- *Cell surface contact* (direct)

Many organisms can be affected by direct cell-to-cell contact with microalgae, either through exposure to microalgal toxins present on the cell surface or through the mechanical damage caused when microalgal anatomical structures penetrate the gills or skin of the exposed organism (Landsberg 2002).

- *Lysed cell contact* (indirect)

Many species that normally produce intracellular toxins release little into the environment under normal conditions. Under stressful environmental conditions (e.g., salinity change, wind action or currents, or during senescence and collapse of a bloom), HABs release toxins as the cells lyse. For this reason, treating blooms with chemicals or by manipulating the environment can cause toxins to be released into the environment and ultimately may cause damage to aquatic organisms (Landsberg 2002).

- *Trophic toxin transfer, bioaccumulation, biomagnification* (indirect)

Biotoxins are transferred trophically when organisms consume other organisms that have been exposed directly to toxic microalgae and have bioaccumulated, bioconverted, or biomagnified the toxins. In many cases, the organism that was consumed has modified the toxins from the form that was originally produced by the microalgae. Filter-feeding zooplankton consume and retain toxic microalgae that are then passed one step up the food chain to zooplanktivores. Filter-feeding shellfish also consume toxic microalgae and accumulate the toxins, which in turn become available to both animal and human consumers. This transfer of toxins up the food chain is one of the most common ways in which higher trophic levels, including humans, are affected by microalgal toxins (see below) (Landsberg 2002).

Jellyfish

Enormous medusae numbers may have negative impacts on fisheries mainly damaging gears and nets of fisheries, interfering with aquaculture activities and avidly predating on fish food and fish eggs and larvae.

- *Fishing operations*

Interference with fishing operations is the most frequently reported problem occurring with great abundances of jellyfish (Lucas 2001; Purcell et al. 2007; Mariottini & Pane 2010). Large catches of jellyfish can split the fishing nets and ruin the quality of the catch (Purcell et al. 2007). The weight of jellyfish biomass causes direct damage to fishing because in several cases it is impossible to separate the medusae from fishes, the yield of nets is impaired and the mechanical structures and engines are subjected to notable efforts; in some spring months the weight of jellyfish is even higher than that of catch fish (Mariottini & Pane 2010). Fishermen may collect enormous quantities of gelatinous organisms in short time and their equipment will be often significantly damaged; in addition, usual fishing grounds will become unsuitable for exploitation until the outbreak is over. The economic damage is easily quantifiable in terms of lost days of activity, damaged gears and reduction of catches (CIESM 2001). Such problems apparently are more widespread than reported in the literature, as suggested by the many jellyfish-exclusion devices used with fishing gear (Purcell et al. 2007).

- *Aquaculture activities*

Jellyfish also kill fish in aquaculture pens and small jellyfish and tentacles of large species enter the fish pens and irritate the fish gills resulting in haemorrhage and subsequent suffocation. Decapods culture also has been reported to be affected adversely by jellyfish blooms (Purcell et al. 2007). In 2002, has been estimated that jellyfish blooms have been the fourth cause of aquaculture industry losses (Rutter 2010).

Medusae damage gears and nets interfere with aquaculture activities and predate on fish food and fish eggs and larvae.

- *Predation on fish food, eggs and larvae*

Moreover, jellyfish eat zooplankton and can reduce and change zooplankton populations; in fact they can reduce the food available to fish (Purcell et al. 2007). The vast numbers of gelatinous predators will draw much energy from food webs, impairing the flux of matter and energy from either phytoplankton or crustacean grazers to the higher levels of the food web (CIESM 2001) that ends with 'low energy' consumers (e.g. jellyfish) (Purcell et al. 2007). In doing so, jellyfish reduce the availability of food for exploited species, but the economic damage due to this impact is not easily quantifiable (CIESM 2001). In fact jellyfish are so strong competitors for fish food that may thus impede the recovery of fish stocks even after a cessation of fishing (Lynam et al. 2006). They also eat ichthyoplankton (eggs and larvae of fish) as well as juvenile fish, and, thus, directly reduce fish populations (Purcell et al. 2007). This direct impact on fish populations has been demonstrated in several cases and may well be the main impact of gelatinous massive events (CIESM 2001). The relationship between jellyfish and fisheries can be exemplified by the ctenophore *Mnemiopsis leidyi* invasion into the Black Sea and Sea of Azov. The arrival of this ctenophore into the Black Sea in the early 1980s resulted in heavy predation on the eggs and larvae of anchovies, as well as on a shared zooplankton prey resource of anchovies, and likely contributed to the collapse of the regionally important anchovy fishery (Graham & Bayha 2007). The economic damage of such impacts is easily quantified when the effects are so catastrophic – as was the case of *M. leidyi* – but is less tractable in other cases or when mixed causes of larval mortality come into play (CIESM 2001).

Human health-related problems caused or associated with the bloomings

Algae

Proliferations of algae (i.e. harmful algal blooms or HABs), that cause fish kills, disruptions to the normal flow of energy and material through microbial ecosystems and contaminate seafood with toxins, are a growing concern around the world (Sellner et al. 2003, Glibert 2007). HABs are harmful in two fundamental ways: through the production of toxins which may kill fish and shellfish and then harm human consumers (see Effects of algal and jellyfish blooming on fisheries) and through the high biomass accumulation which may lead to environmental damage, including hypoxia, anoxia and shading of submerged vegetation, each of which in turn can lead to a multitude of negative environmental consequences. Virtually all HABs cause some disruption to ecosystem function and to the pathways by which food chains are normally maintained (Glibert 2007). The range of toxins produced by HABs is quite extensive (Glibert 2007) and for certain toxin producing species, significant impacts occur at population densities of only several hundred cells per litre (Sellner et al. 2003). For example, *Dinophysis* need only to be present at 100s of cells l^{-1} to induce diarrhetic symptoms, as they are concentrated by shellfish and then ingested by human consumers. *Pfiesteria piscicida* and *P. shumwayiae* are associated with fish death and lesions, skin and eye irritation, and short-term neurocognitive disorders, and need only to reach levels of 250 zoospores l^{-1} to be of concern (Sellner et al. 2003).

HABs cause disruption to ecosystem function and to the pathways by which food chains are normally maintained.

Toxin-producing species are found in other groups besides the dinoflagellates, including raphidophytes, diatoms, cyanobacteria, and several other groups with fewer toxic representatives (e.g. Prymnesiophytes) (Sellner et al. 2003). Thus, human health can be affected by algal blooms directly and/or indirectly by several species of phytoplankton that rise in blooms. Hereby is summarized how humans can be affected by HABs:

- *Toxin air-breathing* and *cell surface contact*

Several phytoplanktonic species can release toxins that become aerosolized after lysis or that become caught up in bubble-mediated transport. Bubble-mediated transport has been shown to concentrate toxins at the sea surface, where concentrated toxins are subsequently released as an aerosol. Terrestrial organisms such as air-breathing mammals and reptiles can be adversely affected by these aerosolized toxins. Also, blooms of some marine phytoplankton species (cyanobacterium included) cause a type of contact dermatitis (swimmer's itch) in humans swimming or bathing in affected waters. Symptoms include itching, rash, burning, blisters and deep skin erosions that can be very painful (Landsberg 2002). In Liguria (Italy), during 2005, more then 200 tourists and swimmers were hospitalized due to fever, cough, headache, nausea, conjunctivitis and dermatitis caused by coastal *Ostreopsis ovata* (Dinophyceae) blooms.

- *Consumption of affected marine food resources*

The impact of harmful microalgae is particularly evident when marine food resources, e.g. aquacultures, are affected. Shellfish and in some cases finfish are often not visibly affected by the algae, but accumulate the toxins in their organs. The toxins may subsequently be transmitted to humans and through consumption of contaminated seafood become a serious health threat. Although the chemical nature of the toxins is very different, they do not generally change or reduce significantly in amount upon cooking; neither do they generally influence the taste of the meat. Unfortunately, detection of contaminated seafood is not straight forward, and neither fishermen nor consumers can usually determine whether seafood products are safe for consumption. To reduce the risk of serious seafood poisoning intensive monitoring of the species composition of the phytoplankton is required in the harvesting areas in connection with bioassays and/or chemical analyses of the seafood products (IOC HAB Programme 2010).

Five human syndromes are presently recognized to be caused by consumption of contaminated seafood (Sellner et al. 2003, Glibert 2007, IOC HAB Programme 2010) and often more species of cyanobacteries are found to produce toxic effects on humans (Sellner et al. 2003).

Amnesic shellfish poisoning (ASP)

Causative organisms: *Pseudo-nitzschia* spp.
Toxin produced: Domoic acid

This syndrome can be life-threatening. Domoic acid accumulates in shellfish, but the disease can apparently also be fish borne, since fish and crab viscera can also contain domoic acid, so the risk to humans may be more serious than previously believed. It is characterized by gastrointestinal and neurological disorders including loss of memory. Gastroenteritis usually develops within 24 hours of the consumption of toxic shellfish; symptoms include nausea, vomiting, abdominal cramps, and diarrhea. In severe cases, neurological symptoms also appear, usually within 48 hours of toxic shellfish consumption. These symptoms include dizziness, headache, seizures, disorientation, short-term memory loss, respiratory difficulty, and coma (Anderson 2008, IOC HAB Programme 2010). Human ASP intoxication is presently known in many parts of the world (Anderson 2008, IOC

HAB Programme 2010) and several episodes were reported from Spain, France, Greece and Italy, while so far, there are not reported occurrences from Black Sea (Anderson 2008).

Ciguatera fish poisoning (CFP)

Causative organisms: *Gambierdiscus toxicus*, *Prorocentrum* spp., *Ostreopsis* spp., *Coolia monotis*, *Thecadinium* spp., *Amphidinium carterae*
Toxins produced: Ciguatoxin/Maitotoxin

Ciguatera Fish Poisoning (CFP), transmitted by several tropical reef fish, produces gastrointestinal, neurological, and cardiovascular symptoms. Generally, gastrointestinal symptoms such as diarrhea, vomiting, and abdominal pain occur first, followed by neurological dysfunction including reversal of temperature sensation, muscular aches, dizziness, anxiety, sweating, and numbness and tingling of the mouth and digits. Paralysis and death have been documented, but symptoms are usually less severe although debilitating. Rapid treatment (within 24 hours) with mannitol is reported to relieve some symptoms. As there is no antidote, supportive therapy is the rule, and survivors recover. However, the recovery time is variable among individuals and may take weeks, months, or even years. Absolute prevention of intoxication depends upon complete abstinence from eating any tropical reef fish, since there is at present no method to routinely measure the toxins (ciguatoxin and maitotoxin) that cause ciguatera fish poisoning in any seafood product prior to consumption (Anderson 2008, IOC HAB Programme 2010). CFP is widely distributed in the tropics; thus in the period 1960-1984, there were a total of 24.000 cases of ciguatera in French Polynesia alone. Evidence is accumulating that disturbance of coral reefs by hurricanes, tourist activity etc. increase the risk of ciguatera by providing more suitable habitats for the benthic dinoflagellates such as *Gamberidiscus toxicus*. Because of the tropic distribution of the causative species, so far CFP has never been documented in Mediterranean and Black Sea.

Diarrhetic shellfish poisoning (DSP)

Causative organisms: *Dinophysis* spp., *Prorocentrum* spp.
Toxin produced: Okadaic Acid

This is a wide spread type of shellfish poisoning which produces gastrointestinal symptoms, usually beginning within 30 minutes to a few hours after consumption of toxic shellfish with diarrhea, vomiting and abdominal cramps. It is not fatal and the patients usually recover within a few days (Anderson, 2008, IOC HAB Programme 2010). There are thousands of reported incidents from developed countries, e.g. 5000 in Spain in 1981 alone, but with the pathological picture of DSP, many incidents may be regarded as an ordinary stomach disorder, and therefore remain unreported. Chronic exposure to DSP is suspected to promote tumour formation in the digestive system (IOC HAB Programme 2010).

Neurotoxin shellfish poisoning (NSP)

Causative organism: *Karenia brevis*
Toxins produced: Brevetoxins

NSP produces an intoxication syndrome nearly identical to that of ciguatera in which gastrointestinal and neurological symptoms predominate. In addition, formation of toxic aerosols by wave action can produce respiratory asthma-like symptoms. No deaths have been reported and the syndrome is less severe than ciguatera, but nevertheless debilitating. Unlike ciguatera, recovery is generally complete in a few days. Monitoring programs (based on *K. brevis* cell counts) generally suffice for preventing human intoxication, except when officials are caught off-guard in previously unaffected areas (Anderson 2008). This syndrome has been restricted to the US Atlantic coast, Gulf of Mexico and New Zealand (Anderson, 2008 IOC HAB Programme 2010).

Paralytic shellfish poisoning (PSP)

Causative organisms: *Alexandrium spp., Gymnodinium catenatum, Pyrodinium bahamense*
Toxins produced: Saxitoxins

PSP, like ASP, is a life threatening syndrome. Symptoms are purely neurological and their onset is rapid. Duration of effects is a few days in non-lethal cases. Symptoms include tingling, numbness, and burning of the perioral region, ataxia, giddiness, drowsiness, fever, rash, and staggering. The most severe cases result in respiratory arrest within 24 hours of consumption of the toxic shellfish (Anderson, 2008). There is no known antidote to PSP (Anderson 2008, IOC HAB Programme 2010). The known global distribution has increased markedly over the last few decades. Each year about 2000 cases of PSP are reported with 15% mortality (IOC HAB Programme 2010). Many PSP cases are reported from the Mediterranean Sea (e.g. Masselin et al. 2001, Taleb et al. 2001, Lilly et al. 2002), but none from Black Sea.

Cyanobacteria toxin poisoning

Also cyanobacteries have negative effects on humans and sea animals as they are the cause of the cyanobacteria toxin poisoning; represented in this diverse group are neurotoxins, carcinogens and a number of other compounds, chemistries (e.g., free radical formation), and symptomologies that affect living resources or humans exposed to the causative organisms or to their toxins following concentration by filter-feeding bivalves or planktivorous fish (Sellner et al. 2003).

Jellyfish

The toxicity of Cnidaria is a subject of concern due to its influence on humans; it is well known that jellyfish stings can induce both local and general symptoms and sometimes can be lethal (Mariottini et al. 2008). As human populations and recreational activities continue to increase along the coasts, the presence of jellyfish is projected to become an increasing public health problem because of the toxic effects of contact with them (Purcell et al. 2007, De Donno et al. 2009). When pelagic cnidarians occur in great abundance, stinging can occur at epidemic levels (Purcell et al. 2007). For example, in 2007, only in the southern coasts of Apulia Region (Italy), up to 446 bathers sought medical assistance after contact with jellyfish (De Donno et al. 2009). Beaches infested with jellyfish undoubtedly are detrimental to tourist appeal and not only swimmers, but also fisherman and aquaculturists, as they pull fishing gear on board and handle nets with gelatinous matter trapped in, can suffer stings (CIESM 2001, Purcell et al. 2007). Stinging structures of Cnidaria (nematocysts) produce remarkable effects on human skin, such as erythema, swelling, burning and vesicles, and at times further severe dermonecrotic, cardio- and neurotoxic effects, which are particularly dangerous in sensitive subjects. After envenomation, some neuromuscular manifestations such as localised neuropathy and mononeuritis multiplex as well as neurological manifestations such as delirium, stupor, central respiratory failure and muscular weakness have been reported. Guillain-Barré syndrome was also described, presumably a consequence of an aberrant immune response (Mariottini et al. 2008). In general, though, jellyfish stings usually cause a mild local dermatitis and so serious or fatal systemic reactions are uncommon (Mariottini et al. 2008); fortunately deadly jellyfish, like the

Stings from pelagic cnidarians cause discomfort and sometimes medical emergencies for swimmers and fishermen.

cubozoan *Chironex,* are not present in the Mediterranean and Black Sea (CIESM 2001).

To date toxicological research on Cnidarian venoms in the Mediterranean region is not well developed due to the weak poisonousness of venoms of jellyfish living in this area. In spite of this, during last decades several problems were caused in the Mediterranean by stinging consequent to blooms mainly caused by *Pelagia noctiluca* which is known to be the most venomous Mediterranean jellyfish. *Pelagia noctiluca* stings are usually limited to the skin surface and cause only erythematous, edematous, and vesicular topical lesions, with local pain which persists for 1-2 weeks, while systemic complications or cutaneous infections are infrequent (Mariottini et al. 2008).

Last August, the first deadly event due to jellyfish stinging was recorded in the Mediterranean Sea. A 69 year old woman, swimming in waters off the southern coast of Sardinia (Italy), was killed by an allergic reaction after she was stung on the leg, probably by a specimen of Portuguese Man of War, *Physalia physalia* (Siphonophores). This type of jellyfish has always been present in the Mediterranean Sea but now they are increasing in number due to global warming and they can grow tentacles up to 20 metres long, so often it is impossible to catch sight of the animal even if we are being hurt by its tentacles. A sting from one these medusae is like an electric shock and the mark it leaves is intense and painful, but if treated quickly does not usually prove fatal.

Methodologies and data collection programmes developed in relation to bloomings

Algae

As is the case with any natural or anthropogenic-driven phenomenon that represents a potential hazard to the health of humans, wildlife, or ecosystems, effective management and mitigation strategies are essential for reducing the hazards associated with HAB events. While no single approach can address all possible impacts, timely detection of harmful algal species and the toxins they produce represents a critical component of most HAB management plans. Such information, if made available early in the process of HAB initiation/development, can provide coastal resource managers, fishermen, aquaculture operators, and public health officials with the data needed to recommend or take actions for minimizing the effects of HABs. Moreover, organism and toxin detection capabilities are also critical tools for researchers studying HAB population and toxin dynamics, and developing models needed to forecast and predict these events (Sellner et al. 2003).

Effective management and mitigation strategies are essential for reducing the hazards associated with HAB events.

Algal bloom detection techniques

The in-water sampling historically completed by field oceanographers is now replaced by large area sensor detection, managed by electronics engineers and equipment maintenance specialists, with oceanographers receiving telemetric data for rapid assimilation and interpretation. Further, aerial and satellite sampling with appropriate sensor packages for salinity, temperature, wave heights, and some pigments ensures rapid data accumulation over much greater spatial scales than previously possible; the repeated over flight schedules eases some temporal limitations and increases sample number, providing greater sample density than otherwise attainable (Sellner et al. 2003).

- *Optical Detection*

Remote sensing for the detection of surface pigment, reflectance, or temperature signatures has been utilized for HAB detection for the last 30 years. The large spatial scale and high frequency of observations provided by remote sensing makes it appealing as a means of detecting and assessing HAB features (Sellner et al. 2003). The utility of a satellite has been demonstrated for detecting HABs through the use of imagery from the coastal zone colour scanner (**CZCS**) (e.g. Steidinger & Haddad 1981, Muller-Karger et al. 1991) and the interaction of some hydrographic features and algal blooms can be synoptically assessed for near-surface waters using ocean colour sensors. The advanced very high resolution radiometer (**AVHRR**) has been used to find blooms of phytoplankton that scatter light or that occur in highly turbid water (e.g. Capone et al. 1998). The sea-viewing, wide field-of-view sensor (**SeaWiFS**) currently collects global chlorophyll concentration data on nearly a daily basis (e.g. Barale et al. 2008); The United States NOAA CoastWatch program now acquires and processes SeaWiFS imagery for HAB monitoring utilizing patterns of chlorophyll anomalies (Sellner et al. 2003). Also utilizing **spectral reflectance** (ocean colour) and an ocean colour inversion model, the phytoplankton community composition associated with HAB events has been estimated (Sellner et al. 2003). Additionally, the model is sensitive to optical variations within algal groups related to cell-specific pigment variations, making it possible to assess algal physiology at the same time (Sellner et al. 2003).

- *Platforms and arrays*

Sampling the marine environment is difficult due to large spatial and temporal variations in chemistry, biology, and physics. Classically, off-pier or shipboard sampling has yielded single point determinations in time and space and, therefore, limited harmful alga-specific sampling except for the rarer, obvious HAB event. With development of the suite of identification methods for species and toxins (see Sellner et al. 2003) there has been an increasing commitment to transforming these techniques to in-water capabilities that could be packaged with a suite of platforms and sampling systems permitting simultaneous detection of environment, species, and impact. Moorings of numerous instrument types, suspended from fixed structures, floats, or buoys, are now routine in oceanography and limnology. These arrays often include autonomous technologies for measuring currents (**ADCPs**), temperature, conductivity, and depth sensors (**CTD systems**), fluorescence (pigments and coloured dissolved organic matter), optical properties, seston/turbidity and several nutrient species (nitrate, ammonium, phosphate, iron) with data stored internally or transmitted to shore through wireless communications. Towed sensor packages generally include CTD, fluorescence, and occasionally taxa-specific sampling capacities like sippers for small seston and dissolved samples, nets for zooplankton, and recording devices (Sellner et al. 2003).

International Research Programs

Research and management of HABs is a responsibility of individual nations, but the global nature of the problem has led to the formulation of many international programs, both bi- and multi-lateral. An example of the former is the EU-US Scientific Initiative on Harmful Algal Blooms. For decades, HABs have been studied in relative isolation on both sides of the Atlantic. National and regional programs such as ECOHAB in the US and EUROHAB in Europe have funded research on HABs, but these efforts did not include significant international collaboration until the European Union and the U.S. National Science Foundation pooled resources for a joint program (Anderson 2008).

- *European Harmful Algal Bloom Programme (EUROHAB)*

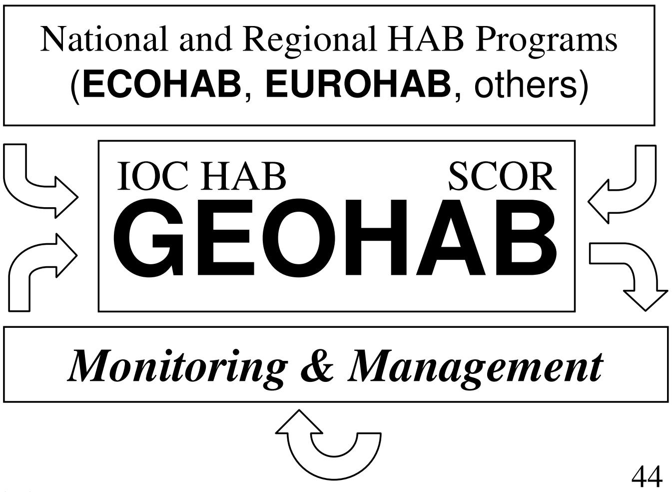
The European Commission (EC) has, over the past decade or more, funded numerous individual projects related to harmful algae and there are many efforts devoted to monitoring and research on a local scale in several European countries (Anderson 2008). These integrated, multidisciplinary, across-boundaries initiatives will lead to a better understanding of the factors that regulate the dynamics of HABs in the context of physical and chemical forcing, ecosystem dynamics, and human infuences. This in turn will result in more effective management and mitigation of the effects of HABs, thus safeguarding the intrinsic and commercial value of coastal marine ecosystems (Zingone et al. 2000).

- *Intergovernmental Oceanographic Commission – Harmful Algal Bloom Programme (IOC HAB Programme)*

A significant factor in the globalization of HAB research, management, and education has been the IOC Harmful Algal Bloom Programme (www.ioc.unesco.org/hab). The overall goal of this programme is "*to foster the effective management of, and scientific research on, HABs in order to understand their causes, predict their occurrences, and mitigate their effects*." In addition to sponsoring, hosting, and coordinating scientific workshops and conferences of various types throughout the world, the IOC programme offers numerous training courses on toxin detection, taxonomy, and other skills that scientists and managers worldwide need in order to effectively manage HABs. Another important aspect of the IOC education and outreach programme are its publication of conference proceedings and workshop reports and the newsletter Harmful Algae News that is distributed to more than 2000 subscribers throughout the world (Anderson 2008).

- *Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB)*

GEOHAB (http://www.geohab.info) is an initiative sponsored by UNESCO's Intergovernmental Oceanographic Commission (IOC) and SCOR (the Scientific Committee on Oceanic Research). GEOHAB is an international, multidisciplinary programme designed to foster cooperative research on HABs in ecosystem types sharing common features. GEOHAB is not a funding programme – it coordinates and builds on related national, regional and international efforts in HAB research. It encourages investigators from different disciplines and countries to exchange technologies, concepts, and findings to address issues related to the global ecology and oceanography of HABs. Through such efforts, the emergence of a global synthesis of scientific results is facilitated. The emphasis is on comparative studies that include observational and modeling components (Anderson 2008).



The relationships between national and international scientific initiatives concerning harmful algal blooms: GEOHAB and its two mother organizations (IOC HAB and SCOR); the linkage of national HAB research to the GEOHAB Programme (adapted from Zingone et al. 2000).

Jellyfish

If gelatinous plankton constitutes an old, largely unresolved "black box" for planktonologists, it is largely due to dismal sampling yields (CIESM 2001) and so far, ecological studies involving large jellyfish have been limited by the inability of oceanographers to measure the abundance and distribution patterns of these highly aggregated animals at local scales (Brierley et al. 2005). For example, traditional plankton nets are impaired within a few minutes when operating in a gelatinous outbreak and the collected samples will fast become an unrecognisable blob of little use to plankton studies. Sampling periodicity, furthermore, is often inadequate to intercept events that last a short time, as many gelatinous outbreaks do (CIESM 2001). Another crucial issue is the geographic coverage (CIESM 2001). In consideration of negative impact of jellyfish outbreaks on human coastal activities and of the fact that jellyfish abundance could be indicative of climate-induced changes and/or regime shifts in pelagic ecosystems there is the urgent requirement to be able to estimate jellyfish abundance robustly and to map jellyfish distribution at sea (Brierley et al. 2005).

There is the urgent requirement to be able to estimate jellyfish abundance robustly and to map jellyfish distribution at sea.

So far jellyfish abundance over the years has been estimated by researchers in different ways; acoustically (e.g. Brierley et al. 2001, 2005, Purcell et al. 2000), visually (aerial, ship and coastal surveys) (e.g. Purcell et al. 2000, Sparks et al. 2001), with trawls and nets (e.g. Pogodin 1998, Graham 2001, Suchman & Brodeur 2005), trough videos and ROVs (e.g. Bergstrom et al 1992, Graham et al. 2003) and trough the Continuous Plankton Recorder (CPR) (e.g. Attrill et al. 2007, Licandro et al. 2010).

Jellyfish detection techniques

Hereby are briefly described gelatinous zooplankton sampling and observational techniques (see Gorsky 2001) nowadays available to the researchers.

- *Net sampling*

Standard WPII nets with mesh size larger than 200 µm are used for meso-zooplankton sampling. **Large collector** nets are used for sampling large gelatinous organisms; their use is limited due to handling difficulties and when encountering dense populations of medusae, trawl nets are more appropriate. **Multiple nets** are poorly adapted for sampling gelatinous zooplankton due to their destructive nature.

- *Optical methods*

The **Video Plankton Recorder** visualizes and quantifies small-size zooplankton while the **Underwater Video Profiler** allows the visualization of the macrozooplankton from the surface to a depth of 1000 m. With the rapid progress of imaging technologies, the quality of the data collected by both instruments is constantly improving. However, although the quantitative data are of good quality, the images are not satisfactory yet for the taxonomists. They may be used for a rapid determination of dominant populations, but not for the identification of rare or new species. **Submersibles** are well suited for the qualitative *in situ* study of large gelatinous organisms. They allow good quality imaging and sampling of the animals. **ROVs** also fulfil this task but less easily due to the narrow field of vision, slow reaction and laborious manipulation. **Aircraft observations** allow spotting large superficial outbreaks of gelatinous organisms such as medusae and their extent and evolution in space and time can be measured.

- *Acoustics*

Acoustic techniques are often used to detect gelatinous zooplankton aggregation. Nevertheless acoustics in not well adapted to the study of these organisms because some of them are permeable to sound and do not produce a well-defined backscatter. Some pattern of echo amplitudes may be specific to a faunistic group but the variability is still high.

International Research Programs

At local level, in 2007 the Agència Catalana de l'Aigua (ACA) started the "Medusa Project", constituted by a network of organizations. The aim of this plan is to monitor the presence of jellyfish along the entire Catalan coast. The ACA underwrites the project, records the presence of jellyfish daily along more than 300 beaches covering the 69 Municipalities of Catalonia as part of their routine monitoring program. Inspectors record presence of jellyfish at fixed locations on beaches, in near-shore water, and at a distance of 200 m offshore beyond the swimming zone. The project also involves Emergency Services from 26 of the 69 Municipalities, and the Fisherman Associations of Catalonia report as well the presence of jellyfish daily. As part of the project data on water temperature and salinity are recorded. All the information are summarized on the ACA web page and are available to the public (Fuentes et al. 2009).

On a larger scale, in 2008, the Mediterranean Science Commission (CIESM) set up "The CIESM JellyWatch Programme". The purpose of this project is to gather for the first time baseline data on the frequency and extent of jellyfish and pelagic tunicates outbreaks across the Mediterranean Sea (CIESM JellyWatch Programme, online). A common, standardized protocol has been adopted for both coastal and open sea sightings of jellyfish swarms in the whole Basin: a poster has been published in five different languages (English, French, Greek, Italian and Turkish) and distributed (with joint support of local organization), to draw the attention of coastal users (fishermen, divers, tourists, ferry passengers) asking for their report of sightings of jellyfish swarms. The poster presents true-to-life drawings that illustrate the most common species of jellyfish and tunicates found in the Mediterranean, along with a list of basic questions (formulated for the non-specialist observer) on the location, type and extension of the observed swarm. As reported by CIESM, the poster had a great success and records were sent by email to key scientists who acted as focal points in different regions. The massive presence of jellyfish during 2009 enhanced the value of the initiative, and hundreds of records, documented by photographs, have been received by CIESM. In Italy, this year, "citizen scientists" could send their photos by-email either to Boero (the leader of the scientist of CIESM who leads the JellyWatch Programme) or to the website of the popular Italian science magazine "Focus". CIESM remarks that thanks to this program medusa blooms have been documented as no other jellyfish outbreak has ever been documented worldwide and that after accurate screening and validation of the photographic records, data collected will be centralized and integrated in the CIESM database so as to better predict and manage future events (CIESM JellyWatch Programme, online).

This summer (June 2010), Malta has started its own jellyfish monitoring programme: "Spot the Jellyfish". This project is run by the International Ocean Institute (IOI) and the University of Malta, in partnership with the Malta Tourism

Authority, among others. As for the CIESM JellyWatch Programme, the "scientists" and the "observers" are the citizens who report jellyfish that swim close to shore identifying them through the online interactive form (www.ioikids.net/jellyfish). Alan Deidun, the biologist responsible for the project, remarks the great success of the initiative and the importance of increasing the public's awareness about the types of jellyfish around Malta. More than 350 reports, most backed by photos, were received during the reporting period and it is planned to continue with the initiative over the coming winter and the next summer. Moreover, thanks to the project, the presence of previously unrecorded (for Maltese waters) jellyfish species, such as *Porpita porpita* and *Aequorea* sp. has been reported (Deidun, *pers. comm.*).

Literature cited

Anderson DM (2005) The Ecology and Oceanography of Harmful Algal Blooms: Multidisciplinary Approaches to Research and Management by Donald M. Anderson. IOC Technical Series 74, UNESCO 2007. IOC/2007/TS/74

Anderson DM (2008) The Harmful Algae Page. Woods Hole Oceanographic Institution. Copyright WHOI 2007 www.whoi.edu/redtide

Armi Z Turki S Trabelsi E Ben Maiz N (2009) First recorded proliferation of *Coolia monotis* (Meunier, 1919) in the North Lake of Tunis (Tunisia) correlation with environmental factors. Environ Monit Assess DOI 10.1007/s10661-009-0903-z

ARPA Puglia (2010) Riepilogo delle osservazioni di *Ostreopsis ovata* nelle acque marine siciliane. Comunicati stampa. http://www.arpa.sicilia.it/

ARPA Sicilia (2010) Ostreopsis 2010. Arpa news. http://www.arpa.puglia.it

Attrill MJ Wright J Edwards M (2007) Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea. Limnol Oceanogr 52:480-485

Barale V Jaquet JM Ndiaye M (2008) Algal blooming patterns and anomalies in the Mediterranean Sea as derived from the SeaWiFS data set (1998–2003). Remote Sens Env 112:3300-3313

Basterretxea G Garcés E Jordi A Angles S Masó M (2007) Modulation of nearshore harmful algal blooms by in situ growth rate and water renewal. Mar Ecol Prog Ser 352:53-65

Bel Hassen M Drira Z Hamza A Ayadi H Akrout F Messaoudi S Issaoui H Aleya L Bouaïn A (2009) Phytoplankton dynamics related to water mass properties in the Gulf of Gabes: Ecological implications. Journal of Marine Systems 75 216-226

Benovic A Lucic D (2001) Jellyfish outbreaks: natural cycle or stress response effect? In: CIESM Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series, n°14, 112 pages, Monaco pp 59-62

Bergstrom BI Gustavsson A Stromberg JO (1992) Determination of abundance of gelatinous plankton with a Remotely Operated Vehicle (ROV). Arch Hydrobiol Beih Ergeb Limnol 36:59-65

Bodeanu N Moncheva S Ruta G Popa L (1998) Long-term evolution of the algal blooms in Romanian and Bulgarian Black Sea waters. Cercet Mar Rech Mar 31:37-55

Boero F (2001) Adriatic ecological history: a link between jellyfish outbreaks, red tides, mass mortalities, overfishing, mucilages, and thaliacean plankton? In: CIESM Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series, n°14, 112 pages, Monaco pp 55-57

Boero F Bouillon J Piraino S Schmid V (2002) Asexual reproduction in the Hydrozoa (Cnidaria). In: Hughes RN (ed) Reproductive biology of invertebrates XI: progress in asexual reproduction. Oxford and IBH Publishing, New Delhi p 141-158

Boero F Bouillon J Gravili C Miglietta MP Parsone T Piraino S (2008) Gelatinous plankton: irregularities rule the world (sometimes). Mar. Ecol. Prog. Ser. 356, 299-310

Brierley AS Axelsen BE Buecher E Sparks CAJ Boyer H Gibbons MJ (2001) Acoustic observations of jellyfish in the Namibian Benguela. Marine Ecology Progress Series 210:55-66

Brierley AS Boyer C Axelsen BE Lynam CP Sparks CAJ Boyer HJ Gibbson MJ (2005) Towards the acoustic estimation of jellyfish abundance. Marine Ecology Progress Series 295:105-111

Capone DG Subramaniam A Montoya JP Voss M, Humborg C Johansen AM Siefert RL Carpenter EJ (1998) An extensive bloom of the N2-fixing cyanobacterium Trichodesmium erythraeum in the central Arabian Sea. Mar Ecol Prog Ser 172:281-292

CIESM (2001) Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series, n°14, 112 pages, Monaco www.ciesm.org/publications/Naples01.pdf

CIESM JellyWatch Programme (online). http://www.ciesm.org/marine/programs/jellywatch.htm

De Donno A Idolo A Bagordo F (2009) Epidemiology of jellyfish stings reported to summer health centres in the Salento peninsula (Italy). Contact Dermatitis 60: 330-335

Earth Snapshot (2008-2010) Chelys srl http://www.eosnap.com/?m=20090209

Finenko GA Romanova A Abolmasova GI Anninsky BE Svetlichny LS Hubareva ES Bat L Kideys AE (2003) Ingestion, growth and reproduction rates of the alien Beroe ovata and its impacts on the plankton community in the Black Sea. J. Plankton Res. 25:539-549

Fonda Umani S (1996) Pelagic production and biomass in the Adriatic Sea, Sci. Mar. 60:65-77.

Fuentes V Atienza D Gili JM Purcell JE (2009) First records of *Mnemiopsis leidyi* A. Agassiz 1865 off the NW Mediterranean coast of Spain. Aquatic Invasions 4 (4): 671-674

Galil B (2010) In: Marshall A. Stinging Season: Can we learn to love the jellyfish? TIME online. http://www.time.com/time/printout/0,8816,2012178,00.html

Glibert PM (2007) Eutrophication and Harmful Algal Blooms: A Complex Global Issue, Examples from the Arabian Seas including Kuwait Bay, and an Introduction to the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Programme. International Journal of Oceans and Oceanography ISSN 0973-2667. 2(1):157-169

Graham WM (2001) Numerical increases and distributional shifts of Chrysaora quinquecirrha (Desor) and Aurelia aurita (Linné) (Cnidaria: Scyphozoa) in the northern Gulf of Mexico. Hydrobiologia 451:97-111

Graham WM Martin DL Martin JC (2003) In situ quantificiation and analysis of large jellyfish using a novel video profiler. Marine Ecology Progress Series 254:129-140.

Graham WM Bayha KM (2007) 14 Biological invasions by marine jellyfish. In: Nentwig W (ed) Ecological studies, Vol 193, biological invasions. Springer-Verlag, Berlin, p 240-255

Heil CA Glibert PM Fan C (2005) Prorocentrum minimum (Pavillard) Schiller. A review of a harmful algal bloom species of growing worldwide importance. Harmful Algae 4:449-470.

Imai I Yamaguchi M Hori Y (2006) Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. Plankton Benthos Res 1(2): 71-84

IOC HAB Programme (2010) What are Harmful Algae? http://www.ioc-unesco.org/hab/

IPCC (2007) Summary for policymakers. In: Solomon S Qin D Manning M Chen Z Marquis M Averyt KB Tignor M Miller HL (eds) Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Ivanov VP Kamakin AM Ushivtzev VB Shiganova T Zhukova1 O Aladin N Wilson SI Harbison GR Dumont HJ (2000) Invasion of the Caspian Sea by the comb jellyfish Mnemiopsis leidyi (Ctenophora). Biological Invasions 2:255-258

Landsberg JH (2002) The Effects of Harmful Algal Blooms on Aquatic Organisms. Reviews in Fisheries Science. 10: 2, 113-390, First published on: 24 June 2010 (iFirst)

Licandro P Conway DVP Daly Yahia MN Fernandez de Puelles ML Gasparini S Hecq JH Tranter P Kirby RR (2010) A blooming jellyfish in the northeast Atlantic and Mediterranean. Biology letters. Online.

Lilly EL Kulis DM Gentien P Anderson DM (2002) Paralytic shellfish poisoning toxins in France linked to a human-introduced strain of Alexandrium catenella from the western Pacific: evidence from DNA and toxin analysis. J Plankton Res 24:443–52.

Lucas CH (2001) Reproduction and life history strategies of the common jellyfish, Aurelia aurita, in relation to its ambient environment. Hydrobiologia 451:229-246

Malej A (2001) Are irregular plankton phenomena getting more frequent in the northern Adriatic Sea? In: CIESM Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series, n°14, 112 pages, Monaco pp 67-68

Mangialajo L Bertolotto R Cattaneo-Vietti R Chiantore M Grillo C Lemee R Melchiorre N Moretto P Povero P Ruggieri N (2008) The toxic benthic dinoflagellate Ostreopsis ovata: Quantification of proliferation along the coastline of Genoa, Italy. Mar Poll Bull 56:1209-1214

Marcus NH Boero F (1998) Minireview: The importance of benthic-pelagic coupling and the forgotten role of life cycles in coastal aquatic systems. Limnol. Oceanogr., 43(5):763-768

Mariottini GL Giacco E Pane L (2008) The Mauve Stinger *Pelagia noctiluca* (Forsskål, 1775). Distribution, Ecology, Toxicity and Epidemiology of Stings. A Review. Mar. Drugs, 6:496-513

Mariottini GL Pane L (2010) Mediterranean Jellyfish Venoms: A Review on Scyphomedusae

Marrouchi R Dziri F Belayouni N Hamza A Benoit E Molgó J Kharrat R (2009) Quantitative Determination of Gymnodimine-A by High Performance Liquid Chromatography in Contaminated Clams from Tunisia Coastline. Mar Biotechnol DOI 10.1007/s10126-009-9245-7

Masselin P Amzil Z Abadie E Carreras A Chiantella C Le Becm C Nézan E Truquet P (2001) Paralytic shellfish poisoning on French Mediterranean coast in the autumn of 1998: Alexandrium tamarense as the causative agent. In: Hallegraeff GM Blackburn SI Bolch CJ Lewis RJ (eds.), Harmful Algal Blooms 2000. IOC-UNESCO Publ. pp. 26-29

Mills CE (2001) Jellyfish blooms: Are populations increasing globally in response to changing ocean conditions? Hydrobiologia 451:55-68

Moncheva S Gotsis-Skretas O Pagou K Krastev A (2001) Phytoplankton blooms in Black Sea and Mediterranean coastal ecosystems subjected to anthropogenic eutrophication: similarities and differences. Estuar Coast Shelf Sci 53:281-295

NASA/GSFC Modis Rapid Response (2008) http://earthobservatory.nasa.gov/IOTD/view.php?id=8817

Nikolaidis G Koukaras K Aligizaki K Herakleous A Kalopesa E Moschandreou K Tsolaki E Mantoudis A (2005) Harmful microalgal episodes in Greek coastal waters. Journal of biological research-Thessaloniki 3: 77-85

Pagès F (2001) Past and present anthropogenic factors promoting the invasion, colonization and dominance by jellyfish of a Spanish coastal lagoon. In: CIESM Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series, n°14, 112 pages, Monaco pp 69-74

Pogodin AG (1998) Aurelia limbata — a new component of the scyphomedusan fauna of the Sea of Japan. Russ J Mar Biol 24(4):264-265

Purcell JE Brown ED Stokesbury KDE Haldorson LJ Shirley TC (2000) Aggregations of the jellyfish Aurelia labiata: abundance, distribution, association with age-0 walleye pollock, and behaviors promoting aggregation in Prince William Sound, Alaska, U.S.A. Marine Ecology Progress Series 195:145-158

Purcell JE Uye SI Lo T (2007) Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Marine Ecology Progress Series 350:153-174

Rutter T (2010) Managing Risk and Uncertainty. Workshop on Advancing the Aquaculture Agenda. Paris 15th/16th April 2010. http://www.oecd.org/dataoecd/11/3/45400772.pdf

Sansoni G Borghini B Camici G Casotti M Righini P Rustighi C (2003) Fioriture algali di Ostreopsis Ovata (Gonyaulacales: Dinophyceae): Un problema emergente. Biol Ambientale.17:17–23

Sellner KG Doucette GJ Kirkpatrick GJ (2003) Harmful algal blooms: Causes, impacts and detection. J Ind Microbiol Biotechnol 30: 383-406

SERC. Smithsonian Environmental Research Center (2010) http://www.serc.si.edu/labs/phytoplankton/guide/Haeckel/Haeckel-Dinophysis-1.jpg

Shiganova TA (1998) Invasion of the Black Sea by the ctenophore Mnemiopsis leidyi and recent changes in pelagic community structure. Fish. Oceanogr. 7:3/4 305-310

Shumway SE (1990) A review of the effects of algal blooms on shellfish and aquaculture. Journal of the World Aquacultural Society 21, 65-104

Smayda TJ (1997) What is a bloom? A commentary. Limnol Oceanogr 42, 1132–1136

Sparks C Buecher E Brierley AS Axelsen BE Boyer H Gibbons MJ (2001) Observations on the distribution and relative abundance of the scyphomedusan Chrysaora hysoscella (Linneus, 1766) and the hydrozoan Aequorea aequorea (Forskal, 1775) in the northern Benguela ecosystem. Hydrobiologia 451:275-286

Steidinger KA Haddad KD (1981) Biologic and hydrographicb aspects of red tides. Bioscience 31:814-819

Suchman CL Brodeur RD (2005) Abundance and distribution of large medusae in surface waters of the northern California. Current Deep-Sea Res II 52:51-72

Taleb H Vale P Jaime E Blaghen M (2001) Study of paralytic shellfish poisoning toxin profile in shellfish from the Mediterranean shore of Morocco. Toxicon 39:1855-1861

Taylor T Longo A (2010) Valuing algal bloom in the Black Sea Coast of Bulgaria: A choice experiments approach. Journal of Environmental Management 91 1963-1971

Totti C Accoroni S Cerino F Cucchiari E Romagnoli T (2010) Ostreopsis ovata bloom along the Conero Riviera (northern Adriatic Sea): Relationships with environmental conditions and substrata. Harmful Algae 9 (2010) 233-239

Turkoglu M Koray T (2004) Algal blooms in surface waters of the Sinop Bay in the Black Sea, Turkey. Pakistan Journal of Biological Sciences 7:1577-1585

Vila M Garcés E Masó M Camp J (2001) Is the distribution of the toxic dinoflagellate Alexandrium catenella expanding along the NW Mediterranean coast? Mar Ecol Prog Ser 222:73-83

Zaitsev YP (1997) The Black Sea: Status and Challenges. In Hobson S, Mee DL (eds): Symposium II: THE BLACK SEA IN CRISIS. World Scientific Publishing Co. Pte. Ltd. p 72-77

Zingone A Enevoldsenb HO (2000) The diversity of harmful algal blooms: a challenge for science and management. Ocean & Coastal Management 43 725-748