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Harmful Algal Blooms in the Mediterranean Sea: Effects on Human Health

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Abstract

A harmful algal bloom (HABs) is defined as a bloom that has deleterious effects on plants, animals, or humans. Marine algal toxins are responsible for an array of human illnesses associated with consumption of seafood and exposure to aerosolized toxins. The impacts of algal toxins are generally observed as acute intoxications, whereas the environmental health effects of chronic exposure to low levels of algal toxins are only poorly documented and are an emerging issue. Consumption of seafood contaminated with algal toxins results in five seafood poisoning syndromes: paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, diarrhetic shellfish poisoning and ciguatera fish poisoning. Aim of this paper is to have an overview on related HABs issues in the Mediterranean Sea.

Keywords: Harmful algal bloom; Mediterranean sea; Amnesic shellfish poison; Ciguatera fish poisoning; Diarrhetic shellfish poisoning; Neurotoxic shellfish poisoning; Paralytic shellfish poisoning

Introduction

Algae are unicellular microscopic plants that are the foundation of life. An algal bloom develops in the marine or freshwater environment when there is an excess of growth of these organisms because of changes in that environment. A harmful algal bloom (HABs) is defined as a bloom that has deleterious effects on plants, animals, or humans [1,2]. Phytoplankton blooms, micro-algal blooms, toxic algae, red tides, or harmful algae, are all terms for these naturally occurring phenomena [3]. HABs can deplete the oxygen and block the sunlight that other organisms need to live, and some HABs release toxins that are dangerous to animals and humans. Marine algal toxins are responsible for an array of human illnesses associated with consumption of seafood and exposure to aerosolized toxins. On a worldwide basis, marine algal toxins are responsible for more than 60,000 intoxication incidents per year, with an overall mortality rate of 1.5%. In addition to their effects human health, algal toxins are responsible for extensive die-offs of fish and shellfish and have been implicated in the episodic mortalities of marine mammals, birds, and other animals dependent on the marine food web. The impacts of algal toxins are generally observed as acute intoxications, whereas the effects on health of chronic exposure to low levels of algal toxins are only poorly documented and are an emerging issue [4,5]. Algal toxin of dinoflagellates and diatoms has also on impact humans. Filter-feeding shellfish, zooplankton, and herbivorous fishes ingest these algae and act as vectors to humans either directly (e.g., shellfish) or through further food web transfer of sequestered toxin to higher trophic levels. Consumption of seafood contaminated with algal toxins results in five seafood poisoning syndromes: paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, diarrhetic shellfish poisoning, and ciguatera fish poisoning. Most of these toxins are neurotoxins and all are temperature stable, so cooking does not ameliorate toxicity in contaminated seafoods. In addition to foodborne poisonings, toxins from two dinoflagellate sources are aerosolized (brevetoxins) or volatilized (a putative Pfiesteria toxin) to impact human health through the respiratory route. Over the past three decades, the occurrence of harmful or toxic algal incidents has increased in many parts of the world, both in frequency and in geographic distribution [6-8]. The predicted changes in our oceans are likely to impact both directly and indirectly on interactions between humans and the oceans. Recent studies have reviewed general oceanic responses to future climate changes, while acknowledging the impacts that these changes will have on human societies [9-11]. Likewise, over the past decade, several studies have suggested possible relationships between climate and the magnitude, frequency, and duration of HABs [12].

Harmful algal blooms in the mediterranean sea and the black sea

Dense blooms of phytoplankton are a widespread phenomenon of the global oceanic coast. They develop in response to favourable conditions for cell growth and accumulation [13]. These blooms of autotrophic algae and some heterotrophic protists are increasingly frequent in coastal waters around the world. There is no doubt that HABs are occurring in more locations than ever before and that new sightings are reported regularly. Several researchers have argued that this trend is due to increasing eutrophication throughout the world [14] but, generally, phytoplankton bloom has regional, seasonal and species-specific aspects that must be considered [15,16]. 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 on the Mediterranean area, such as fish killed 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

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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 [17,18]. 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 [19]. 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 openocean 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 [20]. 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 mostly subjected to the influence of freshwater nutrient inputs. The input of nutrients and dissolved organic matter to the northwest shelf of the Black Sea by the Danube, the Dniepar and the Dniestar rivers increased about 10 times in the period 1950–1980. An increase in phytoplankton blooms frequency, involved species, duration, timing and area, is 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 [15]. Table 1 shows a series of events occurred HABS in the Mediterranean Sea and Black Sea [16].

Human health-related problems caused or associated with the bloomings

HABs are harmful in two fundamental ways: inhalation of airborne toxins and consumption of affected marine food resources. About inhalation several phytoplanktonic species can release toxins that become aerosolized after lysis or that become caught up in bubble-mediated transport [21]. 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

Year	Genus	Location	Source
Late 1960s	*Prorocentrum*	North Adriatic Sea	Fonda Umani [37]
1970s	*Noctiluca, Gonyaulax, Prorocentrum, Gyrodinium, Glenodinium*	North Adriatic Sea	Fonda Umani [37]
1980s	*Katodinium, Noctiluca, Glenodinium, Prorocentrum, Gyrodinium, Gonyaulax, Scrippsiella, Massarthia*	North Adriatic Sea	Fonda Umani [37]
1984	*Gonyaulax*	Spain	Shumway [38]
1986	*Prorocentrum*	Black Sea	Heil et al. [39]
1989	*Gymnodinium*	Mediterranean Sea	Shumway [38]
1993	*Dinoflagellates*	Black Sea	Bodeanu et al. [40]
1995-1996	*Pseudo-nitzschia, Nitzschia, Cheatoceros, Ditylum, Cylindrotheca, Rhizosolenia, Heterocapsa, Protoperidinium, Scripsiella, Emiliana, Gonyaulax, Prorocentrum*	Black Sea	Turkoglu et al. [41]
Since 1994	*Karenia*	Tunisia	Marrouchi et al.[42]
1994 and 1996- 1999	*Alexandrium*	Spain	Vila et al. [43]
1994 and 1997	*Prorocentrum, Noctiluca, Erythropsidinium*	Greece	Nikolaidis et al [44]
1998	*Alexandrium*	France	Masselin et al. [34] Lilly et al. [36]
1998	*Chattonella*	Greece	Nikolaidis et al [44] Nikolaidis et al [44]
1999	*Prorocentrum*	France	Heil et al. [39]
1998, 2000-2001	*Ostreopsis*	Tyrrhenian Sea	Sansoni [45]
2001	*Skeletonema, Cerataulina, Prorocentrum, Gymnodinium*	Black Sea	Taylor et al. [46]
2003	*Alexandrium, Gymnodinium*	Spain	Basterretxea et al. [13]
2000-2004	*Prorocentrum, Noctiluca, Gymnodinium, Alexandrium, Dinophysis, Pseudonitzschia*	Greece	Nikolaidis et al [44]
2005-2006	*Ostreopsis*	Ligurian Sea	Mangialajo [47]
2006	*Coolia*	Tunisia	Armi et al. [48]
2007	*Ostreopsis*	North Adriatic Sea	Totti et al. [49]
2010	*Ostreopsis*	Southern Italy	ARPA Sicilia [50]

Table 1: Table below summarizes only some of the many algal blooms events that occurred in the Mediterranean and Black Sea during the last 50 years [16].

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 [22]. 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. Regarding 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 when cooked; 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 [23]. Given the large blooms is important to describe the adverse effects on human health ascribed to the marine toxin palytoxin after different exposure routes. After five human syndromes are presently recognized as to be caused by HABs: Amnesic shellfish poison (ASP), Ciguatera fish poisoning (CFP), Diarrhetic shellfish poisoning (DSP), Neurotoxic shellfish poisoning (NSP) and Paralytic shellfish poisoning (PSP).

Human poisonings to palytoxins exposure

Palytoxin (PTX) was first isolated from the zoanthid Palythoa toxica. Due to co-occurrence with other seafood toxins, such as ciguatoxins, saxitoxins, and tetrodotoxin, it has been difficult to assess the true risk of PTX poisoning through seafood consumption in humans, but limited cases have been well documented, some involving human fatalities. Recent evidence also suggests that humans are negatively impacted through PTX exposure by inhalation and dermal routes (52) [24]. The symptoms commonly recorded during PLX intoxication are general malaise and weakness, associated with myalgia, respiratory effects, impairment of the neuromuscular apparatus and abnormalities in cardiac function. Systemic symptoms are often recorded together with local damages whose intensity varies according to the route and length of exposure. Gastrointestinal malaise or respiratory distress is common for oral and inhalational exposure, respectively. In addition, irritant properties of PLX probably account for the inflammatory reactions typical of cutaneous and inhalational contact. Unfortunately, the toxin identification and/or quantification are often incomplete or missing and cases of poisoning are indirectly ascribed to PLXs, according only to symptoms, anamnesis and environmental/epidemiological investigations (i.e. zoanthid handling or ingestion of particular seafood) (53) [25].

Amnesic shellfish poisoning

Amnesic shellfish poisoning is caused by consumption of shellfish that have accumulated domoic acid, a neurotoxin produced by some strains of phytoplankton. The neurotoxic properties of domoic acid result in neuronal degeneration and necrosis of specific regions of the hippocampus [26]. Human exposure to domoic acid occurs via the consumption of contaminated shellfish that have accumulated the toxin while filter feeding on toxigenic phytoplankton during blooms. The first reported human domoic acid poisoning event occurred in Canada in 1987 during which clinical signs of acute toxicity such as gastrointestinal distress, confusion, disorientation, memory loss, coma and death were observed, the illness was named amnesic shellfish poisoning (ASP). Due to effective seafood monitoring programs there have been no documented severe ASP cases since 1987. However, domoic acid poisoning has a significant effect on marine wildlife and multiple poisoning events have occurred in marine birds and mammals over the last few decades. Currently, domoic acid producing diatom blooms are thought to be increasing in frequency worldwide, posing an increasing threat to wildlife and human health. Of particular concern are the potential impacts of long-term low-level exposure in „„at risk‘ ‘ human populations. The impacts of repetitive low-level domoic acid exposure are currently unknown [27]. This syndrome 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 [28]. Mild human ASP intoxication is presently known in many parts of the world [23,29] and several episodes were reported from Spain, France, Greece and Italy, while so far, there are not reported occurrences from Black Sea [28].

Ciguatera fish poisoning

Ciguatera fish poisoning is a foodborne illness affecting humans worldwide. Humans develope this illness by eating reef fish containing the naturally occurring toxins, ciguatoxins. Multiple ciguatoxins have been identified, but in this paper ciguatoxins will be collectively referred to as "CTX." CTX is derived from benthic dinoflagellates of the genus Gambierdiscus, growing predominantly in association with macroalgae in coral reefs in tropical and subtropical climates. The toxin is transferred through the food web as the algae is consumed by herbivorous fish, which are consumed by carnivorous fish, which are in turn consumed by humans [29]. CFP produces gastrointestinal, neurological, and cardiovascular symptoms. Generally, gastrointestinal symptoms such as diarrhea, vomiting, and abdominal pain occur first, followed by neurological including temperature sensation dysfunction, 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 [30]. 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 shows 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

Diarrhetic shellfish poisoning, is a wide spread type of shellfish poisoning which produces gastrointestinal symptoms, usually beginning between 30 minutes and 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 [23,28]. 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 [28]. But the first cases of contamination have been detected in France in 1987. DSP contamination also occurred along the eastern coast of Corsica [31].

Neurotoxic shellfish poisoning

Neurotoxic shellfish poisoning is a disease caused by the consumption of molluscan shellfish contaminated with brevetoxins; these are a group of more than ten natural neurotoxins produced by the marine dinoflagellate, Karenia brevis (formerly known as Gymnodinium breve and Ptychodiscus brevis) [32]. 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 [33]. 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 [23]. This syndrome has been restricted to the US Atlantic coast, Gulf of Mexico and New Zealand [32].

Paralytic shellfish poisoning

Paralytic shellfish poisoning, is due toxins are naturally occurring potent neurotoxins synthesised by microscopic dinoflagellates from the genii Alexandrium, Gymnodinium and Pyrodinium in marine and freshwater environments [34]. Increased temperatures, sunlight and nutrient-rich waters are considered to cause the rapid reproduction of dinoflagellate species and thereby lead to potential „harmful algal blooms‘‘. Climate change, increased ocean eutrophication and commercial shipping are believed to contribute to the increasing frequency and occurrence of these blooms worldwide [35]. PSP 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 [36]. There is no known antidote to PSP. The known global distribution has increased markedly over the last few decades. Each year about 2000 cases of PSP are reported with 15% mortality [23]. Many PSP cases are reported from the Mediterranean Sea [37-39], but none from Black Sea.

Conclusions

This review of recent knowledge in HABs research in the Mediterranean Sea has focused on the potential exposures health effects. The problems and impacts of HABs are diverse, as are the causes and underlying mechanisms controlling the blooms. Pollution and other human activities in the coastal zone have increased the abundance of algae, including harmful and toxic forms. Should be made seasonal monitoring and data collection in the Mediterranean and Black Sea. Specifically, future research efforts should focus on developing the empirical, theoretical, and numerical simulation models to integrate observations, test and validate hypotheses, and make risk forecasts of HAB occurrences and their impacts on human health under the suite of 21st-century future climate change scenarios.

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