36 Seafood Safety and Human Health Implications

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Abstract

Current projections for the twenty-first century show that global warming will accelerate, with stronger storms, extreme precipitation, dry spells and rising sea levels as the primary symptoms. Such changes will have implications in seafood production, security, and safety, as well as in human health, due to the increase in the frequency of harmful algal blooms, levels and bioaccumulation of several chemical contaminants, prevalence and virulence of common foodborne pathogenic microorganisms. The Mediterranean will be particularly affected by climate change due to water scarcity in the region. Assuring seafood safety in such scenario requires the active involvement of all stakeholders to elaborate and implement adaptation and mitigation plans. In this context, the current chapter aims to provide an overview of the potential effects of climate change in the Mediterranean seafood safety and human health, taking into account chemical and biological contaminants, and to discuss potential adaptation and mitigation measures.

Keywords:

Climate change • Seafood safety • Benefit and risk assessment • Adaptation • Mitigation

Introduction

Seafood is a balanced, nutritious, readily digestible and healthy food for human consumption, able to prevent coronary heart diseases, hypertension, diabetes and cancer, since contains low cholesterol levels, high quality proteins with all essential amino acids, polyunsaturated n-3 fatty acids, liposoluble vitamins and essential elements like calcium, iodine and selenium (Simopolpoulos 1997). Compared with land animals, seafood has a far higher percentage of edible flesh and little waste, with few exceptions like shellfish. Nonetheless, some seafood is affected by the accumulation of microbiological and chemical contaminants, particularly toxic elements (e.g. Hg, Cd, Pb and As), toxins from harmful algal blooms (HABs) and pathogenic microorganisms, which can be extremely dangerous for human health.

The Mediterranean is an oligothrophic, semi-enclosed and water deficitary sea with 2.5 million km^2 surface, incorporating water from the Atlantic Ocean and Black Sea, and contributing with 0.8 % to the total world marine surface and 0.3 % volume (Lleonart and Maynou 2003). The Mediterranean Sea is located in the temperate zone of the Northern hemisphere with a marked seasonal cycle, i.e. absence of precipitation and stratified water masses in summer with constant temperature 13 °C below 400 m and surface temperatures ranging between 14 and 26 °C (Lleonart and Maynou 2003; EEA 2006). Its salinity is high (mean around 39 g L^{-1}), higher in the Eastern basin and lower in the western. Oxygen levels are almost saturated in the surface

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layer (6 mg L^{-1} in winter and 4.8 mg L^{-1} in summer), and slightly lower in deep waters (4.5 mg L^{-1} in the western and 4.2 mg L^{-1} in the eastern) (EEA 2006). The Mediterranean counts 22 border countries, only possess territorial waters within 12 nautical miles, and the continental shelf is mostly a narrow coastal fringe (Ronzitti 1999). Consequently, the international management structures have not been enforced sufficiently and regular assessment by international working groups have only recently started (Lleonart and Maynou 2003). From fisheries and aquaculture point of view, the Mediterranean has a rich marine fauna and flora, representing 8–9 % of world seas species richness (4–18 % according to the group of species considered e.g. mollusc, echinoderms, crustaceans, etc.), including 18 % of the flora, of which 28 % are endemic (Caddy 1998; EEA 2006). Mediterranean seafood production in 2009 accounted 3.5 % of the world production (Eurostat 2011).

The Mediterranean has long been identified as a "hot spot" for substantial impact of climate change in the future because of water scarcity in the region, a rapidly increasing population. Mediterranean climate modelling project increased risk of changes in temperature, precipitation, moisture, extreme events (droughts and floods) and sea level rise (EEA 1999).

Importance of Seafood in Mediterranean Countries

Seafood is widely consumed in the Mediterranean (average 16.5 kg/capita/year in the 22 countries, ranging from 5.2 in Algeria and 40.0 in Spain; data from 2007; FAO 2011a), being the consumption of several seafood species strongly linked to religious traditions and social (e.g. cod in Christmas). Interestingly, Mediterranean fisheries provide only 7.2 kg of the total consumption, with the rest being imported. The growth of seafood demand in the Mediterranean is expected to increase in the future, especially in southern countries (Cochrane and de Young 2007).

One fourth of the Mediterranean seafood supply comes from aquaculture activities, whereas the remaining is from fisheries. Aquaculture production in the Mediterranean reached 1.3 million tonnes in 2009, representing approximately 1.8 % of the world aquaculture production (72 million tonnes) (FAO 2011a). Although Mediterranean aquaculture was mostly focused on mollusc production in the past (62 % in 1992), the share of fish production is constantly increasing (from 37 % in 1992 to 84 % in 2009) (FAO 2011a). Fish aquaculture production is mainly represented by tilapia (*Oreochromis niloticus*), carp (*Cyprinus carpio*), trout (*Oncorhynchus mykiss*), seabream (*Sparus aurata*), seabass (*Dicentrarchus labrax*), mullet (*Mugil cephalus*), European eel (*Anguilla anguilla*) and turbot (*Psetta maxima*) (Basurco and Lovatelli 2003). In contrast, molluscan shellfish aquaculture production is mainly represented by mussels (*Mytilus edulis* and *Mytilus galloprovincialis*), oysters (*Crassostrea gigas*) and clams (*Ruditapes philippinarum*) (Basurco and Lovatelli 2003).

Fisheries production in the Mediterranean region attained four million tonnes in 2009, approximately 4.5 % of the world fisheries production (90 million tonnes) (FAO 2011a). Mediterranean fisheries are mostly dependent on small scale artisanal fisheries (80 % vessels are lower than 12 m length) with bottom otter trawls, purse seines and coastal gears (e.g. gillnets, trammel nets, long-lines, hand-lines with hooks, traps and pots) that mostly capture fish (89 %), molluscs (8 %) and crustaceans (3 %) (data from 2009, FAO 2011a). The most important species captured in Mediterranean are European anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), sardinellas (*Sardinella* sp.), horse mackerel (*Trachurus* spp.), sprat (*Sprattus sprattus*), bonito (*Sarda* sp.), bogue (*Boops boops*), hake (*Merluccius* sp.), bluefin tuna (*Thunnus thynnus*), blue whiting (*Micromesistius poutassou*), swordfish (*Xiphias gladius*), octopus (*Octopus* sp.) and striped venus clam (*Chamelea gallina*) (Eurostat 2008). Currently, several Mediterranean seafood stocks are overexploited: (a) demersal fish are almost fully exploited, if not over-exploited, with a general trend towards smaller individual sizes; (b) small pelagic fish stocks are highly variable in abundance (depending on environmental conditions) and not fully exploited, except for anchovy; (c) large pelagic fish (tuna and swordfish) are overexploited, especially red tuna for which the Mediterranean is an important spawning area; and (d) habitats of high biological significance, such as the *Posidonia oceanica* meadows, are frequently destroyed by trawl-nets operating close to the shore (EEA 1999).

Current Problems Affecting the Mediterranean Sea

Socio-economical

The concentration of resident and non-resident populations and human activities around the Mediterranean Sea represent considerable threats to coastal ecosystems and seafood resources that are expected to increase in the future. The resident population of the Mediterranean was 246 million in 1960, is currently 450 million, and is expected to rise to 520–570 million in 2030 and 600 million in 2050 (EEA 1999). Population density is greater in coastal regions, especially near big cities. Additionally, the Mediterranean is the world's leading tourist destination, accounting 30 % of international tourism. Coastal tourism is strongly seasonal and has been steadily increasing annually (135 million in 1990 and is expected to reach 350 million in 2025, EEA 1999).

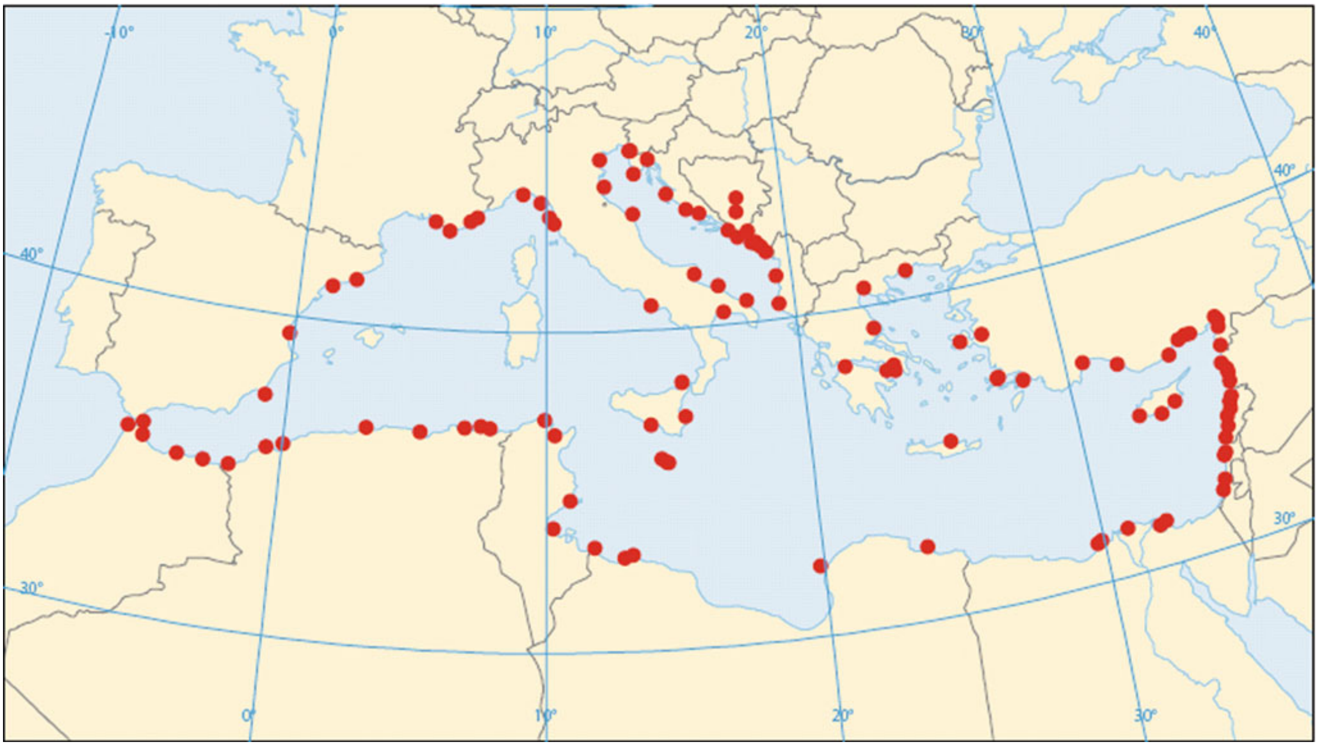

Fig. 36.1 Pollution hot spots (*red dots*) along the Mediterranean coast (Adapted from EEA 2006)

The specific morphology of the Mediterranean basin allows intense agricultural activity in the limited coastal plains. The main pressures from agriculture are soil erosion and nutrient surplus when excessive fertilisers are applied (EEA 1999).

There is a wide range of industrial activities scattered around the Mediterranean basin, with 161 identified hot-spots of heavy industrial complexes (e.g. chemical/petro-chemical and metallurgy) and big commercial harbours concentrated mainly in the north-west (EEA 1999, 2006). Other industrial sectors include treatment of wastes and solvent regeneration, surface treatment of metals, production of paper, paints and plastics, and tanneries (EEA 1999).

Concerning maritime traffic, the Mediterranean is one of the most important routes in the world. It is estimated that about 220,000 vessels of more than 100 tonnes cross the Mediterranean each year, representing 30 % of the total merchant shipping in the world and 20 % of oil shipping (EEA 1999). This represents a huge concern with the introduction of exotic species and pollution.

Chemical Contaminants in Seafood

Mediterranean health authorities and consumers are deeply concerned with the exposure to toxic chemical contaminants in seafood. In recent years, the contamination of the marine environment by chemical contaminants has risen due to the global increase of population and industrial development (e.g. non controlled discharges from chemical industries, sewage and agriculture, EEA 1999, see pollution hot-spots in Fig. 36.1). In order to ensure seafood stakeholders confidence, EU authorities have established Maximum Permissible Levels (MPLs) for the presence of several contaminants in seafood (e.g. Commission regulation 1881/2006 and later amendments for Hg, Cd and Pb).

Toxic elements like Hg, Cd, As and Pb are the chemical contaminants of major concern in aquatic environments. These contaminants bioaccumulate along the food chain, though only part is used for metabolic purposes, while the remaining is excreted (through faeces, eggs or moulting) or detoxified (binding to proteins, such as metallothioneins, or to insoluble metaliferous granules) (Rainbow 2002). Bioaccumulation is a serious problem due to the toxicity for fish and humans when reaching a substantially high level (Islam and Tanaka 2004; Francesconi 2007).

The main toxicity mechanisms of these contaminants are related to the osmotic disturbances and alterations of enzyme synthesis and activity (Jezierska et al. 2009). Additionally, toxic metals in seafood can affect various physiological processes, including tissue damages, inability to regenerate damaged tissues, growth inhibition, damages to genetic material and changes in breeding and development (Jezierska et al. 2009). The embryonic development, soon after fertilization, and the hatching period are the most sensitive periods to toxic elements intoxication, resulting in disturbances of developmental processes and causing embryonic and larval malformation and mortality (Jezierska et al. 2009). Such physiological changes in marine organisms can be amplified by changes in environmental conditions (Jezierska et al. 2009). Concerning Hg, particularly fish species, like tuna, black scabbardfish, anglerfish and elasmobranchs, typically accumulate high levels in muscle tissues (e.g. Afonso et al. 2007). Additionally, Hg values in Mediterranean seafood species are generally higher than those found in the Atlantic Ocean, mainly due to the fact that Mediterranean is located in the Himalayan mercuriferous belt (EEA 1999; Bernhard 1988). Part of the Mediterranean fishing communities is above the United States Benchmark Hg Dose Limit of ten times the Hg Reference Dose, i.e. the level with clear neurological effects (EC 2005). As far as Cd is concerned, most seafood has low levels, with the exception of shellfish like lobsters, crabs, oysters, gastropods and bivalves, where Cd binds with proteins (FDA 1993). Crabs and lobsters hepatopancreas have particularly high Cd concentration (up to 40 mg kg^{-1}), being systematically above the MPLs set by the EU for crustacean's muscle (no limits were set for hepatopancreas despite being widely consumed; Barrento et al. 2008, 2009; Marques et al. 2010a). The release of Cd from sediments has been reported in several Mediterranean regions, including the Gulf of Trieste, in the northern Adriatic Sea off the mouth of the river Po (Zago et al. 2000). Arsenic and lead are commonly found in seafood, particularly Pb in shrimps and bivalves, and As in algae, fish and crustaceans (e.g. Anacleto et al. 2009).

Persistent organic pollutants (POPs) are also of concern in Mediterranean seafood, since they have the ability to accumulate in the biota, being mostly released from anthropogenic sources (Islam and Tanaka 2004). These pollutants include certain prohibited pesticides and industrial chemicals like polycyclic aromatic hydrocarbons (PAHs), dicloro-difenil-tricloroetano (DDT), aldrin, dieldrin, endrin, chlordane, hexachlorocyclohexanes (HCHs, like lindane), heptachlor, hexachlorobenzene, mirex, toxaphene, polychlorinated biphenyls (PCBs), dioxins and furans. Recently, particular attention is being paid to the presence of emerging contaminants in seafood like pharmaceutical and personal care products, new endocrine disruptors, perfluorinated compounds (PFCs), brominated flame retardants (BFRs) and marine litter released into the environment. The use of organochlorine pesticides (OCPs), like DDT and PCBs, was banned more than 30 years ago in Mediterranean countries, being reflected in the low values registered in Mediterranean seafood (average PCBs below 30 and 20 ng g^{-1} for DDT, EEA 1999). Nonetheless, marine mammals, sardines and swordfish are still affected by high levels of OCPs that tend to accumulate in seafood body fat. In contrast, PFCs tend to accumulate in blood proteins and liver, being recently found in dolphins, swordfish and tuna, despite data is still scarce (Alessi et al. 2006). BFRs, such as polybrominated diphenylethers, are ubiquitous compounds that were recently found in Mediterranean dolphins (Alessi et al. 2006). Yet, BFRs data is still limited as far as other Mediterranean seafood is concerned. Concerning PAHs compounds, the carcinogenic benzo(a)pyrene accumulate in marine organisms, such as bivalve molluscs and demersal fish (Moon et al. 2010). Recently, accumulation of total PAHs was detected in Mediterranean mussels, being higher in native specimens compared to farmed ones (e.g. Galgani et al. 2011).

Biological Contaminants in Seafood

Seafood biological contaminants include micro-organisms and parasites.

Pathogenic microorganisms enter the Mediterranean marine coastal environment mainly through municipal wastewater discharges and rivers, principally bacteria, viruses and fungi. Yet, other microorganisms naturally occurring in the marine environment have the capability to become pathogenic to humans, particularly members of the *Vibrio* genus. These microorganisms are accumulated by seafood, particularly filter-feeding organisms like bivalves. *Vibrio cholerae* is still the leading cause of Vibrio-associated illnesses worldwide, being usually transmitted to humans through contaminated water and not generally considered to be a threat to human health through seafood consumption (Faruque et al. 1998). Yet, *V. vulnificus* and *V. parahaemolyticus* also cause a significant number of clinical infections, usually through the ingestion of raw or incompletely cooked fish or shellfish (Bonner et al. 1983).

Apart from pathogenic microorganisms discharged into the marine environment, another group of naturally occurring marine microorganisms can pose a similar threat to human health when present in large numbers, i.e. marine algae that produce toxins, also known as Harmful Algal Blooms (HABs), mainly composed by dinoflagellates (Table 36.1), to which man is exposed mainly through the consumption of contaminated shellfish. HABs usually occur in areas with excessive organic material, i.e. eutrophication areas (Fig. 36.2), being responsible for the consumption or even depletion of oxygen, and causing a series of secondary problems, including mortality of marine organisms, formation of corrosive and other undesirable substances (e.g. CH_4, H_2S, and NH_3), taste and odour-producing substances, organic acids, mucilage and toxins (EEA 1999, 2006). Marine toxins originating from HABs are generally tasteless and odorless, and heat- and acid-stable, and can cause gastrointestinal, cardiological and neurological problems or induce mortalities after the consumption of contaminated seafood (EEA 2006). Therefore, legislation is available in the EU to protect consumers from ASP (Amnesic Shellfish Poisoning), PSP

Table 36.1 Pathogenic bacteria, viruses and microalgae responsible for algal blooms and toxin production, reported in the Mediterranean Sea

Microalgae		Bacteria	Virus
Diatoms	*Gonyaulax* sp. (PSP/DSP)	*Salmonella* spp.	Enteroviruses
Cerataulina bergonii	*Gymnodinium* sp. (PSP/NSP)	*Shigella* spp.	Poliovirus
Chaetoceros sp.	*Katodinium rotundatum*	*Vibrio cholerae*	Echovirus
Cyclotella sp.	*Peridinium* sp.	*V. algynolyticus*	Coxsackie virus A/B
Leptocylindrus spp.	*Prorocentrum* sp. (DSP)	*V. parahaemolyticus*	Hepatitis A virus
Nitzschia closterium	*Ptrotogonyaulax tamarensis*	*Staphylococcus aureus*	Other viruses
Pseudo-Nitzschia sp. (ASP)	*Scrippsiella trochoidea*	*Pseudomonas aeruginosa*	Adenovirus
Rhizosolenia sp.	Coccolithophores	*Clostridium perfringens*	Rotavirus
Skeletonema costatum	*Coccolithus pelagicus*	*Campylobacter* spp.	
Thalassiosira sp.	*Emiliania huxleyi*	*Aeromonas hydrophila*	
Dinoflagellates	Other flagellates		
Alexandrium sp. (PSP)	*Chlamydomonadaceae*		
Amphidinium curvatum	*Cryptomonas* sp.		
Cachonina sp.	*Cyanobacteria*		
Chattonella subsalsa	*Microflagellates*		
Dinophysis spp. (DSP)	*Noctiluca* sp.		
Gambierdiscus sp. (CFP)	*Pyramimonas* sp.		
Glenodinium sp.	*Spirulina jenneri*		

Adapted from EEA (1999, 2006), Spatharis et al. (2007), Caillaud et al. (2010)
Abbreviations: *ASP* amnesic shellfish poisoning, *DSP* diarrheic shellfish poisoning, *PSP* paralytic shellfish poisoning, *NSP* neurotoxic shellfish poisoning, *CFP* ciguatera fish poisoning

(Paralytic Shellfish Poisoning), and some lipophilic toxins, including okadaic acid, dinophysistoxins, pectenotoxins and azaspiracids. Yet, many other natural toxins produced by HAB organisms can affect human health due to the ingestion of contaminated seafood (primarily shellfish), such as diarrheic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP) and ciguatera fish poisoning. Recent detection of the tropical genus *Gambierdiscus* responsible for the production of ciguatera fish poisoning (CFP) ciguatoxins occurred in the Mediterranean Sea, as well as in north-eastern Atlantic Ocean, Canary Islands and Madeira (Caillaud et al. 2010). CFP is responsible for severe human disorders due to the consumption contaminated fish. Palytoxin is one of the most potent toxins known in nature, reported in Mediterranean seafood, including sardines, but was also reported to occur in other fish, molluscs, crustaceans and equinoderms (Yasumoto and Satake 1998; Onuma et al. 1999). Gymnodimine toxin (GYM) was also recently identified in the digestive gland of clams *Ruditapes decussatus* from Tunisia, as well as in greenshell mussel, blue mussel, scallop, cockle, surf clam, oyster and abalone (Stirling 2001; Biré et al. 2002; MacKenzie et al. 2002). Despite the GYM chronic toxicity remains unclear, its role in the development of neurodegenerative illnesses like Alzheimer or Parkinson's diseases has been debated (Alonso et al. 2011).

About 35 parasitic diseases have been reported in the Mediterranean Sea (Athanassopoulous et al. 2009). The main parasitic diseases in freshwater seafood are trichodiniasis, costiasis, white spot diseases, *Dactylogyrus* and gyrodactilosis. In contrast, the main parasitic diseases in marine seafood are trichodiniasis, costiasis, *Enteromyxum leei*, *Ceratomyxa*, amyloodiniosis, mycrocotylosis and sea lice disease. There is an increasing concern of parasitic diseases in seafood from the Mediterranean area, particularly farmed seafood, since some parasites triggers mortality episodes, such as *Amyloodinium* (Dinoflagellates), Scuticociliatida (Ciliates), *Enteromyxum* spp. (Myxosporea) or Mycrocotylidae (Monogenea). The geographical spread of parasites (and their hosts) to areas where previously they were inhibited by lower temperature is a reality despite being moderated by several ecological and environmental factors (Harvell et al. 1999, 2002).

Climate Change in the Mediterranean and Seafood Safety

Projected Environmental Fluctuations

Several reports from the Intergovernmental Panel on Climate Change (IPCC) indicate that variations in world climate will be reflected in the Mediterranean region, with a discernible trend of increased salinity and warmer temperature in key water masses registered over the last 50 years (IPCC 2007). According to IPCC, potential impacts in the Mediterranean associated to climate change include drought, decline of water quality, floods, changes in soil erosion and desertification, storms, coastal erosion, changes in seawater temperature, salinity and pH, sea level rise and biodiversity reduction

Fig. 36.2 Mediterranean areas where eutrophication phenomena (**a**), harmful algal blooms (HAB); and (**b**) seafood toxin blooms (STB) were reported (Adapted from EEA 1999, 2006)

(EEA 1999). Sea level rise, potentially accelerated by anthropogenic activities, is one of the most important impacts of climate change in coastal zones. New models project an increase in sea level of 3–61 cm until 2100 due to thermal warming, melting glaciers/ice sheets, and aerosol concentrations (Marcos and Tsimplis 2008). The IPCC (2007) estimates that global mean seawater surface temperature will increase 1.1–6.4 °C until 2100. Recent studies indicate that a global temperature rise of 2 °C is likely to lead to a corresponding warming of 1–3 °C in the Mediterranean region (Tin et al. 2005). A general warming trend has been observed in deep waters of the western Mediterranean, where temperatures have increased by 0.12 °C in the past 30 years as a possible result of global warming (Bethoux et al. 1990). Climate change is also expected to trigger seawater pH decrease by 0.14–0.35 units (IPCC 2007). Concerning salinity, the Mediterranean is expected to experience different increasing rates until 2100: (a) the global, Eastern, Western, and Levantine basins, with an average increase of 0.23 g L^{-1}; and (b) the Aegean and Adriatic Seas, with 0.61 and 0.70 g L^{-1} increases, respectively (Sevault et al. 2004). The Earth has not experienced variations of this magnitude in such short timescale and the consequences to future generations are largely unknown (IPCC 2007).

Direct and Indirect Impacts on Seafood

Climate change is expected to have economic effects on fisheries and aquaculture worldwide, such as losses in revenues

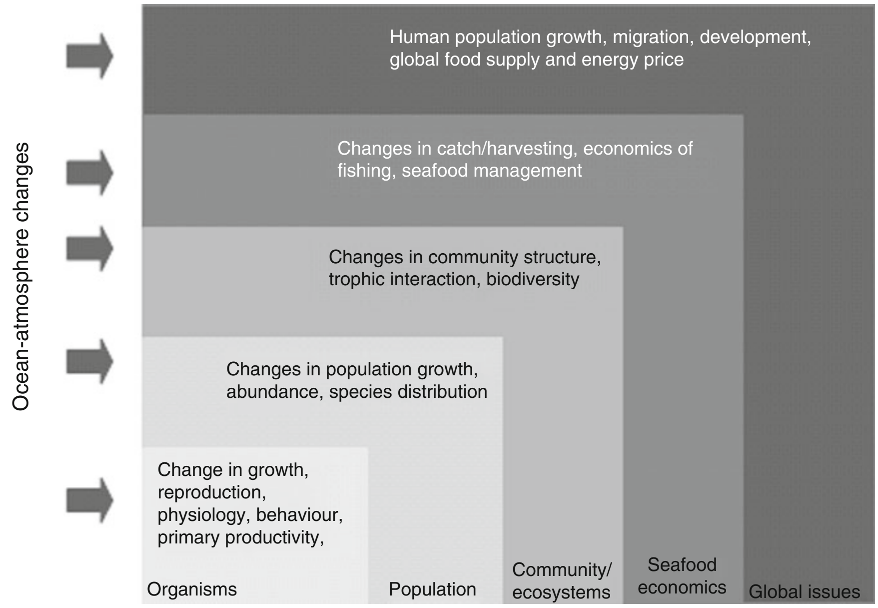

Fig. 36.3 Schematic diagram indicating the biophysical and socio-economic impacts of climate change at different levels of organizations, from seafood specimens to the society (Adapted from Sumaila et al. 2011)

and reduced availability of seafood to consumers, among other impacts (Fig. 36.3). Although the evolution of climate change is uncertain, high diversity coastal ecosystems like the Mediterranean Sea are more vulnerable to environmental perturbations than low diversity places (May 1973). Consequently, a reduction of biodiversity of marine species is expected in Mediterranean with climate change. Among the first species to disappear under heavy stress conditions are benthic organisms with large body size (EEA 1999). Climate change may lead to large-scale redistribution of catch potential, with an average of 5–15 % drop in the Mediterranean region (Cheung et al. 2010).

Climate fluctuations play a predominant role in marine ecosystems and seafood by: (a) directly affecting the organisms through changes in survival, reproductive success and dispersal pattern; (b) promoting modifications in biotic interactions; and (c) affecting ocean currents indirectly (EEA 1999; Gambaiani et al. 2009).

As seawater temperatures warm at a large spatial and temporal scale, the timing of ecological events or phenology may also change (Nye 2010). Many organisms time their migrations and spawning to changes in temperature and photoperiod. As temperature, salinity, and hydrography changes, organisms will likely shift the timing of spawning and migration. If species do not change in unison, the reproductive success for many organisms may be dramatically reduced. In the last decades, the northward expansion of the geographical range of warm-water marine species has been observed in Mediterranean areas due to increase in seawater temperature (e.g. Ligurian and Adriatic Seas, Astraldi et al. 1995; Bello et al. 2004). New species can have an impact on indigenous species through inter-specific competition, predation, and possible genetic degradation of indigenous stock (EEA 1999). In addition to northward migration, bathymetric displacements may occur among populations of invasive and endemic species (Galil and Zenetos 2002). This is the case of indigenous red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*) and spottail mantis shrimp (*Squilla mantis*) that were reported to move into deeper and cooler waters to avoid warm-water competitors (Oren 1957; Galil and Zenetos 2002). In contrast, cold-water species tend to disappear or move to more favourable habitats. Recently, anomalous increase of summer temperatures (2–3 °C) and the deepening of the thermocline in western Mediterranean coastal areas have resulted in massive mortalities of the benthic fauna (e.g. sponges and gorgonians) inhabiting hard substrates (Romano et al. 2000). Mortality was equally attributed to the surface water warming and stability of high sea temperatures over long periods (i.e. several months). Additionally, small temperature shift (0.05–0.10 °C) in Eastern Mediterranean deep sea is sufficient to considerable change species biodiversity (Danovaro et al. 2004).

The tropicalization of the Mediterranean has been recently confirmed in the Adriatic Sea, where among other the jellyfish *Pelagia noctiluca* and three toxic dinoflagellate tropical species occurred in the last years (*Ostreopsis lenticularis, Coolia monotis* and *Prorocentrum mexicanum*) (Bello et al. 2004; Licandro et al. 2010). The expansion of toxic microorganisms combined with the expected higher Mediterranean coastal eutrophication due to the increase of temperature and incidence of extreme events (e.g. floods), is likely to promote the frequency of HABs. HABs and microbial pollution in euthrophized areas generate the depletion of oxygen in the water, with detrimental impacts on productivity, nursery grounds, biodiversity, habitat and human health risks related to the ingestion of contaminated seafood (EEA 2006).

Recently, a sudden input of high nutrient water in Easter Mediterranean lead to an increase in phytoplankton biomass, with the dominance of the toxic HAB *Pseudo-nitzschia calliantha* (Spatharis et al. 2007). Climate change has the potential of increasing the incidence and spread of several foodborne pathogens and parasites, either through the emergence of new ones or through the selection of existing pathogenic strains that differ in survival, persistence, habitat range and ability to be transmitted or infect humans (Gamble 2008). Evidence of the impact of climate change on the transmission of seafood and waterborne diseases comes from a number of sources, e.g. the seasonality of foodborne and diarrhoeal diseases, changes in disease patterns due to temperature (e.g. *Vibrio*), and associations between the incidence of seafood and waterborne illness and severe weather events (Cook et al. 2002; De Paola et al. 2003; FAO 2008a). Changes in other environmental factors, such as salinity and pH, may also result in changes in the distribution and virulence of pathogens (Elena and Lenski 2003; Sokurenko et al. 2006). In aquaculture, the expected change in the incidence of diseases in seafood due to climate change may exacerbate the use of veterinary drugs, leading to higher and unacceptable levels of such drugs in seafood (FAO 2008b).

Ocean acidification (pH decrease) is expected to threat particularly marine organisms with calcified shells, since they may not be able to make the hard calcified shells and their growth is affected (Nye 2010). Some species like the blue crab and American lobster may respond favourably to ocean acidification, whereas most organisms will respond unfavourably (e.g. bivalve species that constitute important commercial fisheries) (Green et al. 2009).

The expected extreme weather events induced by climate change can result in escapes of farmed seafood stock and contribute to reductions in genetic diversity of wild stocks, thus affecting biodiversity (FAO 2008b).

The availability and toxicity of chemical contaminants is expected to vary due to the effect of climate change (Marques et al. 2010b). In regions where intense rainfall is expected to increase, pesticides, fertilisers, organic matter, heavy metals, among other, will be increasingly washed from soils to water bodies (FAO 2008b). Concerning salinity, metals like Cd, Cr, Cu, Hg, Ni and Zn are taken up more slowly by phytoplankton/fungi, annelids, bacteria, molluscs and crustaceans at higher salinities despite their toxicity increases (Hall and Anderson 1995; Modassir 2000). In contrast, no consistent trend has been detected for the toxicity of most POPs with salinity, except organophosphate insecticides (e.g., parathion, mevinphos, terbufos, trichlorfon) that increase at higher salinities (Hall and Anderson 1995). As far as temperature is concerned, high temperatures promote the uptake, bioaccumulation and toxicity of toxic elements (e.g. Cu, Zn, Cd, Pb) and POPs in several marine organisms, including crustaceans, echinoderms and molluscs (Sullivan 1977; Hutchins et al. 1996; Wang et al. 2005; Khan et al. 2006). Warmer seawater temperatures facilitate Hg methylation, and the subsequent uptake of methyl Hg by fish and mammals by 3–5 % for each °C rise in seawater temperature (Booth and Zeller 2005). Mubiana and Blust (2007) revealed a positive correlation between temperature and Cd and Pb accumulation in mussels (*Mytilus edulis* maintained between 6 and 26 °C), while Co and Cu were independent and inversely related to temperature. Temperature increase can promote the inhibitory effects of toxic elements on respiration of several other marine organisms that utilize the Cu-based hemocyanins as respiratory pigments, such as the zebra mussels *Dreissena polymorpha* (Rao and Khan 2000). Monserrat and Bianchini (1995) detected tenfold increase in acute lethality of crabs (*Chasmagnathus granulata*) to methyl parathion with temperature (12–30 °C).

Human Health Implications

The main risks to human health induced by climate change in the Mediterranean Sea arise from intake of pathogenic microorganisms or toxins from infected sea water and beach sand (e.g. faecal streptococci and coliform bacteria), and consumption of seafood contaminated by pathogens (e.g. *Salmonella*, *Shigella*, hepatitis A, *Candida albicans*), toxins from HABs or chemical pollutants (EEA 1999). The extent of damage to the Mediterranean population health still has to be determined. If climate change projections are correct for the Mediterranean Sea, and the expected increase in the occurrence of contaminants indeed occurs, the health risks for human populations will be amplified when eating seafood items like bivalves and predator fish species. In contrast, in Mediterranean areas where contaminant load diminishes, the expected seafood consumption risks will decrease, prevailing the nutritional benefits of eating seafood.

Health Risks from Microbiologically and Toxins Contamination

Pathogenic microorganisms and toxins produced by HABs present in seawater, sediments, beaches and shellfish can be broadly divided into two categories: those that affect the gastrointestinal tract, and those that affect other parts of the body (EEA 1999). As far as the former category is concerned, diseases spread by the faecal/toxins-oral route can occur, including: (a) bacterial diseases such as salmonellosis (including typhoid and paratyphoid fevers), shigellosis (bacillary dysentery), cholera and gastro-enteritis caused by enteropathogenic *Escherichia coli* and *Yersinia enterocolitica*; (b) viral diseases (e.g. hepatitis A and E), illnesses caused by enteric viruses (polioviruses, coxsackie viruses A and B, echoviruses, reoviruses and adenoviruses) and gastroenteritis caused by human rotavirus (Norwalk virus, Adenovirus serotype, calicivirus, parvo-like viruses); (c) diseases caused by a variety of protozoan and metazoan parasites, such as amoebic dysentery, giardiasis, and ascariasis; and (d) diseases from HABs toxins (WHO 1992, 1996; Marques et al. 2010b).

There is ample evidence that the major source of illness in areas where the sea is polluted, resulted from consumption of sewage contaminated shellfish and/or bathing near sewage contaminated beaches, as well as with toxins or microorganisms that affect the gastrointestinal tract (EEA 1999). This is particularly relevant for farmed shellfish, due to the animal density in mariculture systems and site location, usually in coastal urbanised areas subjected to intense sewage contamination. Diseases affecting the human gastrointestinal tract are usually caused by the consumption of raw or partially cooked seafood. Salmonellosis is one of the most important food-borne diseases in Europe, currently accounting 70 % of all laboratory-confirmed outbreaks of (WHO 2001; Kovats et al. 2004; Britton et al. 2010). The outbreaks caused by this food-borne pathogen is directly affected by temperature, as it has been reported an increase of 5–10 % in the number of cases for each °C increase in weekly temperatures has been estimated above a threshold of approximately 5 °C with inappropriate food preparation and adequate storage preceding consumption being important determining factors (Kovats et al. 2004). Recently, Vibrionaceae bacteria have been responsible for several disease outbreaks due to the ingestion of contaminated shellfish. As example, an unprecedented outbreak of *V. parahaemolyticus* gastroenteritis occurred in Alaska with more than 400 confirmed cases, when cruise ship passengers ate raw oysters harvested from Prince William Sound (McLaughlin et al. 2005). Increased water temperature was considered to be a major factor in the emergence of *V. parahaemolyticus* in Alaska, as the summer of 2004 was exceptionally warm with water temperature remaining above 15 °C over a 2 month period. The number of epidemics and outbreaks of various diseases attributed to the consumption of contaminated shellfish is also increasing in the Mediterranean, with reports in new regions where such outbreaks were previously absent (EEA 1999; Marques et al. 2010b).

Apart from diseases affecting the gastrointestinal tract, disorders affecting eyes, ears, skin, upper respiratory tract and other parts of the body have been associated with bathing in contaminated seawater. This particular category of infective conditions is caused by microorganisms like *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Clostridium welchii*, *Candida albicans* and adenoviruses (EEA 1999). These microorganisms cause infection after entering into skin, ear or nose wounds, including those resulting from diving or bathing.

While such records provide evidence of occurrence and indications of magnitude, they are still scarce and the extent of damage caused to local and tourist Mediterranean population health by the expected higher occurrence of pathogenic microorganisms and toxins from HABs in seafood due to climate change still has to be determined.

Health Risks from Chemical Contamination

The most relevant chemicals found in Mediterranean seafood and marine environment likely to create health risks are from the presence of toxic or heavy metals, POPs and illicit dumping of contaminated waste. Following entry into the marine environment, these chemicals accumulate in algae and animals and bioaccumulate along the trophic chain, reaching their highest levels in filter-feeders (e.g. bivalve molluscs) and large predatory fish (e.g. tuna and swordfish). Effects on human health are mainly caused by the consumption of chemically contaminated seafood and are essentially long-term, depending on the chemicals themselves, and the rate and amount of intake (reviewed by Marques et al. 2010b). In general, the principal risk is restricted to those individuals consuming seafood more than two times a week, although the risk varies with the type of seafood, the concentration of pollutants and the circumstances of the consumer (EEA 1999).

The European Rapid Alert System for Food and Feed (RASFF) has been created to provide food and feed control authorities with an effective tool to exchange information about measures taken against serious risks detected in relation to food or feed. According to 2009 data, among all food items, the highest number of alerts in Europe occurred with seafood (716 alerts; Fig. 36.4) representing almost 25 % of all food and feed alerts in 2009 (3,272 alerts) (RASFF 2010). Environmental contaminants represented more than 25 % of all European alerts in 2009, but the proportion of biotoxins and priority contaminants was much lower. Food products imported from Asia or produced in Europe had the highest amounts of alerts compared to food imported from other continents. However, the number of people contaminated with chemicals following seafood ingestion is still limited. In many cases mild effects are not noticed, or have not been correctly associated with contaminated seafood because the symptoms affecting the nervous system are not specific, and the condition can easily be attributed to other causes (e.g. Hg, WHO 1995).

Benefit and Risk Assessment Tools

The risks associated with fish products are toxic metals, PCBs and other organic pollutants, toxins, pathogenic microorganisms and parasites. Assessing potential risks from chemical and biological contaminants in seafood is

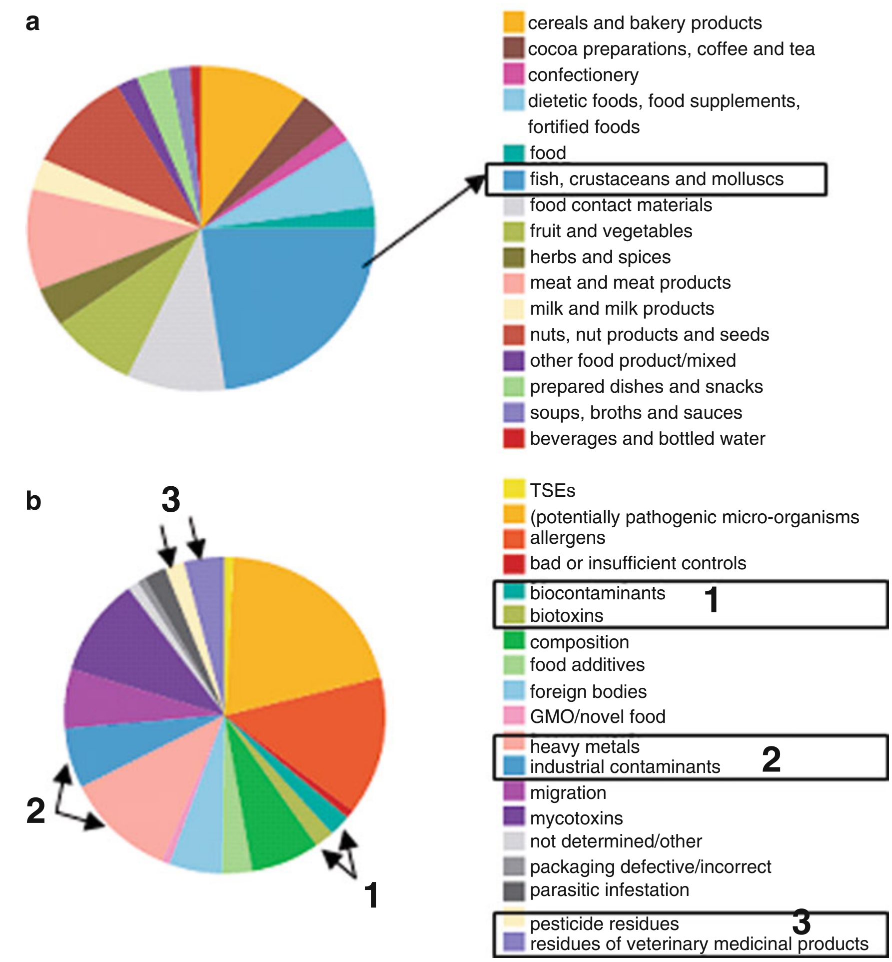

Fig. 36.4 (**a**) RASFF alert notification by hazard category in 2009 (seafood is *highlighted*); (**b**) RASFF alert notification by product category in 2009 (environmental chemical contaminants are *highlighted*) (Adapted from RASFF 2010)

difficult, since the amount of seafood ingested is only a fraction of the total food intake (WHO 1992). In addition, seafood consumption patterns are greatly influenced by food preference, price and availability. Presently, there is a lack of seafood consumption studies carried out in Mediterranean countries. In general, seafood is more available in coastal areas and to specific population sectors (e.g. fishermen, fish vendors and their families, and people on diet).

Concerning chemical contaminants, many studies have been conducted on risk-benefit assessment of seafood consumption in Europe (e.g. Domingo et al. 2007; Sioen et al. 2008; Cardoso et al. 2010; FAO 2011b). This body of evidence shows the pertinence and global interest in this theme. An accurate estimation of risk requires accounting for all the variability of the data, i.e. a full probabilistic approach, taking into account uncertainties in analytical data and interindividual differences in consumers' consumption pattern (e.g. neuroprobabilistic hazard index; Nadal et al. 2008) (Sioen et al. 2008). This procedure ensures the estimation of the probability that the individual exposure to a specific component of seafood surpasses a threshold or a reference value for that component. In a large population, an accurate estimation of this quantity is crucial since even a difference of 1 % involves many individuals. However, the estimation of this probability depends on the tail behaviour of the distribution, since reference values are usually higher than most individual intakes.

The application of some statistical estimators has led to inaccurate estimation of risks. Recently, promising statistical techniques have been developed, such as the extreme value theory (EVT) coupled with recent statistical innovations like bias correction techniques for the Hill estimator (Cardoso et al. 2010). However, further research and monitoring is still needed in this area, since the marine environment is continuously exposed to chemicals present in the environment for a long time, but also to emergent and priority chemicals. Such information is crucial to help health authorities to accurately measure the risks associated to seafood consumption in a changing environment in order to set rigorous adaptation and mitigation strategies.

Microbiological risk assessment and predictive microbiology are emerging tools for the evaluation of the safety of seafood supplies, which involve quantitative exposure

Table 36.2 Adaptation and mitigation measures for the effect of climate change in seafood safety from fisheries

Impact of climate change	Adaptation mitigation measures
Catch reduction	Increase fishing effort
	Shift targeted species
	Protect fishing stocks
	Shift to farmed seafood
Increase in catch variability	Promote catch and consumption of new species
	Shift targeted species
Change in distribution of fisheries	Shift fishing effort and strategies
	Shift target species
Less seafood available	Promote farmed seafood consumption
	Shift to farmed seafood
Increase virulence and expansion of contaminants and diseases	Increase biosecurity measures
	More monitoring and early warning systems
	Implement genetic improvements for higher resistance
	Adopt solutions to reduce contaminant load, e.g. processing seafood, cooking, phycoremediation, etc.
	Develop guidelines and predictive modelling tools for stakeholders
Calcareous shell formation/deposition	Adapt production and handling techniques
	Move to other production zones

assessment in a series of stages (tiered approach). A rough estimate is first made of the order of magnitude that individual factors or parameters may contribute to exposure or risk. This could be considered as analogous to preparing a risk profile. For those that contribute most significantly, a more detailed assessment is performed, or more data are gathered and combined in, for instance, a deterministic approach. Where relevant, an even higher level of detail can be achieved using, for instance, a stochastic approach (see more details in FAO 2008b). Several mathematical modelling approaches can be used (e.g., Event trees, Fault trees, Dynamic Flow Trees, PRM, MPRM, etc.) according to the step of the trade chain (e.g. primary production, processing and post processing). Several variables are crucial in the assessment, such as temperature, product formulation, time, cross-contamination and consumption data.

Adaptation and Mitigation Strategies

Adaptation is a mechanism for management and prevention of climate change impacts in seafood safety, whereas mitigation consists of limiting the process of climate change in seafood safety. A wide range of adaptations and mitigations can be implemented to minimize the effect of climate change in seafood safety, from products originated from the fisheries sector (Table 36.2). A comprehensive analysis for the aquaculture sector is given in Rosa et al., in this volume. These measures must be carefully selected, as excessive protective measures can have negative social and economic impacts. As far as Mediterranean seafood safety is concerned, it is necessary to establish strengthened communication and cooperation among professionals of the seafood sector, including public health, veterinary health, environmental health, and food safety services. Such cooperation must be combined with the thorough understanding of the fate of contaminants in the environment and of the links between seafood, contaminants and environment. Additionally, it is implement accurate monitoring programmes and predictive modelling tools for more effective risk management and prediction of seafood safety for consumers. The implementation of adaptive holistic, integrated and participatory approaches to fisheries and aquaculture management and practices is required in an ecosystem-based perspective. Such approaches should be the best and most immediate forms of adaptation, providing a sound basis for seafood production able to accommodate climate change impacts.

The expected catch reduction and increased species variability may promote a shift to aquaculture from fisheries coastal communities. Integrating aquaculture with agro/multitrophic aquaculture and culture-based fisheries, offers the possibility to recycle nutrients and efficiently use energy and water (FAO 2008c).

The application of waste water treatment with cost-effective and environmental-friendly techniques can also limit the impact of climate change in seafood safety. Short-cycle aquaculture may also be valuable, using new species/strains and new technologies/management practices to fit into seasonal opportunities (FAO 2008c). Aquaculture can be a useful adaptation option for other activity sectors, such as coastal agriculture under salinization threats and biofuel production (e.g. algal biomass or discards and by-products of fish processing), though the current aquaculture technologies will need to be improved to cope climate change impacts. For feed-based aquaculture, the dependence on fish meal and oil from fisheries, and growing competition for terrestrial raw materials is of concern as climate change can limit seafood meal supply. Feeding materials and formulation strategies will be particularly important in maintaining and expanding aquaculture production, while containing costs and energy inputs, and improving resilience to climate change (FAO 2008c). Adaptations also include changing to less carnivorous species, genetic improvements, feed source diversification, better formulation, quality control and management. Genetic knowledge and management in aquaculture are still insufficient, and will be a major challenge and opportunity in the future. Examples include genetic improvement for more efficient feeding and diet specificity, and for species resistance to higher temperature, lower oxygen and pathogens/contaminants (FAO 2008c). Since aquatic pathogen risks may be exacerbated with climate change, biosecurity and prevention measures may need to change accordingly, including early identification and detection mechanisms, suitable treatment strategies and developed products. The creation of certification systems, including sustainability, organic, fair-trade and other criteria will need to be addressed more carefully in the context of climate change (FAO 2008c).

The primary mitigation route for the seafood safety lies in fisheries and aquaculture energy consumption, through fuel, raw material use and production. The knowledge of contaminant levels in seafood feeds and possibilities to mitigate contaminants in those feeds e.g. physical adsorption on activated carbon is used during refining fish oil to remove organic contaminants such as dioxins/furans and dioxin-like PCBs (Maes et al. 2005; Oterhals et al. 2007). The use of vegetable ingredients in seafood feed may also reduce contaminant levels, though the proportion of vegetable constituents needs to be limited to avoid reducing the beneficial constituents in seafood, mainly omega-3 fatty acids (Berntssen et al. 2010). Phycoremediation, i.e. the use of micro or macroalgae to sequester contaminants in aquatic environments has been extensively reported to be extremely useful with toxic elements (Rajamani et al. 2007). Their ability to adsorb and metabolize trace metals is associated with their large surface-volume ratios (up to 10 % of their biomass), the presence of high-affinity, metal-binding groups on their cell surfaces, and efficient metal uptake and storage systems. Other mitigation strategies may involve the elaboration of stakeholders modelling tools and guidelines/recommendations with information for stakeholders like the type, size, season and origin of seafood that should be avoided, pre-treatment/culinary procedures that decreases contaminants levels (e.g. discard water from seafood boiled with water soluble biotoxins), etc. The careful selection of sites where aquaculture sites could be located, with precise definition of their environmental carrying capacity, will contribute to minimise nutrient load to ecosystems. At last, new technologies should be developed involving nanosciences and nanotechnologies able to remove chemical and microbiological contaminants from water in a simple and inexpensive way. Such tools can greatly facilitate improvements in food hygiene and safety management.

Conclusions

Assuring seafood safety is a complex task. Climate change-induced seafood safety hazards can arise at any stage of the trade chain from primary production to consumption. A better understanding of changes that might arise is an essential step to implement mitigation measures by stakeholders. Seafood from fisheries and aquaculture and its safety can be affected by climate change in several ways: (a) the spatial distribution of seafood stocks may change due to migration from one region to another in search of suitable conditions; (b) surface winds can alter the delivery of nutrient into the photic zone and the strength and distribution of ocean currents; (c) high CO_2 levels will alter ocean acidity and affect calcified marine organisms; (d) changes in sea levels and salinity will affect marine organisms; (e) productivity of aquaculture systems will be affected; (f) increase vulnerability of cultured fish to diseases and contaminants; (g) extreme weather events can result in escape of farmed stock and contribute to the reduction of wild stock genetic diversity; (h) eutrophication due to nutrient loading will cause phytoplankton growth and increased frequencies of HABs, including toxin-producing species; and (i) increase in water temperatures will promote the growth of pathogenic and foodborne microorganisms and facilitate methylation of Hg, availability and bioaccumulation of chemical contaminants in seafood. It is therefore necessary for governments and international authorities to be prepared for those changes. The complexity of seafood safety requires interdisciplinary approaches due to the inter-relationships between environment, seafood and contaminants. The current principles of good hygiene, aquaculture and fishery practices need to be adapted to address climate change challenges. Integrated monitoring and surveillance of environment and seafood is critical for the early identification of emerging problems. Accurate predictive modelling and risk assessment will depend on the quality and quantity of available data. Enhanced early warning systems and stakeholders' education are essential elements to reduce the exposure to contaminants in seafood due to climate change. At last, the creation of new technological tools able to remove contaminants from environment and seafood is also of utmost importance to ensure safe seafood for Mediterranean consumers.

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References

Afonso C, Lourenço HM, Dias A, Nunes ML, Castro M (2007) Contaminant metals in black scabbard fish (*Aphanopus carbo*) caught off Madeira and the Azores. Food Chem 101:120–125

Alessi E, Tognon G, Sinesi M, Guerranti C, Perra G, Focardi S (2006) Chemical contamination in the Mediterranean: the case of swordfish. World Wide Fund for Nature. http://wwf.fi/mediabank/1092.pdf. Accessed 22 Dec 2011

Alonso E, Vale C, Vieytes MR, Laferla FM, Giménez-Llort L, Botana LM (2011) The cholinergic antagonist Gymnodimine improves Aβ and Tau neuropathology in an *in vitro* model of Alzheimer disease. Cell Physiol Biochem 27:783–794

Anacleto P, Lourenço HM, Ferraria V, Afonso C, Carvalho ML, Martins MF, Nunes ML (2009) Total arsenic content in seafood consumed in Portugal. J Aquat Food Prod Technol 18:1–14

Astraldi MF, Bianchi CN, Gasparini GP, Morri C (1995) Climatic fluctuations, current variability and marine species distribution: a case study in the Ligurian Sea (north-western Mediterranean). Oceanol Acta 18:139–149

Athanassopoulous F, Pappas IS, Bitchava K (2009) An overview of the treatments of parasitic disease in Mediterranean aquaculture. Option Méditerranéennes A 86:65–83

Barrento S, Marques M, Teixeira B, Vaz-Pires P, Carvalho ML, Nunes ML (2008) Composition of essential elements and contaminants in edible tissues of European and American lobsters. Food Chem 111:862–867

Barrento S, Marques A, Teixeira B, Carvalho ML, Vaz-Pires P, Nunes ML (2009) Contaminants in two populations of edible crab Cancer pagurus: environmental and human health implications. Food Chem Toxicol 47:150–156

Basurco B, Lovatelli A (2003) The aquaculture situation in the Mediterranean sea predictions for the future. Ocean docs. http://hdl.handle.net/1834/543. Accessed in 22 Dec 2011

Bello G, Casavola N, Rizzi E (2004) Aliens and visitors in the Southern Adriatic Sea: effects of tropicalisation. Rapport du 37ème Congrès de la Commission Internationale pour l' Exploration Scientifique de la Mer Méditerranée. CIESM congress proceedings, Mónaco

Bernhard M (1988) Mercury in the Mediterranean. Regional seas reports and studies no. 98. UNEP. http://www.unep.org/regionalseas/publications/reports/RSRS/pdfs/rsrs098.pdf. Accessed 22 Dec 2011

Berntssen MHG, Olsvik PA, Torstensen BE, Julshamn K, Midtun T, Goksøyr A, Johansen J, Sigholt T, Joerum N, Jakobsen JV, Lundebye AK, Lock EJ (2010) Reducing persistent organic pollutants while maintaining long chain omega-3 fatty acid in farmed Atlantic salmon using decontaminated fish oils for an entire production cycle. Chemosphere 81:242–252

Bethoux JP, Gentili B, Raunet J, Tailliez D (1990) Warming trend in the Western Mediterranean deep water. Nature 347:660–662

Biré R, Krys S, Frémy JM, Dragacci S, Stirling D, Kharrat R (2002) First evidence on occurrence of gymnodimine in clams from Tunisia. J Nat Toxins 11:269–275

Bonner JR, Coker AS, Berryman CR, Pollock HM (1983) Spectrum of *Vibrio* infections in a Gulf Coast community. Ann Intern Med 99:464

Booth S, Zeller D (2005) Mercury, food webs, and marine mammals: implications of diet and climate change for human health. Environ Health Perspect 113:521–526

Britton E, Hales S, Venugopal K, Baker MG (2010) Positive association between ambient temperature and salmonellosis notifications in New Zealand, 1965–2006. Aust N Z J Public Health 34:126

Caddy JF (1998) GFCM and its future relationship to marine science. Workshop on gaps in fishery science. CIESM workshop series 5, Dubrovnik, pp 7–10

Caillaud A, de la Iglesia P, Darius HT, Pauillac S, Aligizaki K, Fraga S, Chinain M, Diogène J (2010) Update on methodologies available for ciguatoxin determination: perspectives to confront the onset of ciguatera fish poisoning in Europe. Mar Drugs 8:1838–1907

Cardoso C, Bandarra N, Lourenço H, Afonso C, Nunes M (2010) Methylmercury risks and EPA + DHA benefits associated with seafood consumption in Europe. Risk Anal 30:827–840

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Zeller D, Pauly D (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Glob Change Biol 16:24–35

Cochrane K, de Young C (2007) Ecosystem approach to fisheries management in the Mediterranean. Cah Option Mediterraneenes B 62:71–85

Cook DW, Bowers JD, DePaola A (2002) Density of total and pathogenic (tdh+) *Vibrio parahaemolyticus* in Atlantic and Gulf Coast molluscan shellfish at harvest. J Food Prot 65:1873–1880

Danovaro R, Dell'Anno A, DePaola AP (2004) Biodiversity response to climate change in a warm deep sea. Ecol Lett 7:821–828

De Paola A, Nordstrom JL, Bowers JC, Wells JG, Cook DW (2003) Seasonal abundance of total and pathogenic *Vibrio parahaemolyticus* in Alabama oysters. Appl Environ Microbiol 69:1521–1526

Domingo JL, Bocio A, Falcó G, Llobet JM (2007) Benefits and risks of fish consumption: part I. A quantitative analysis of the intake of omega-3 fatty acids and chemical contaminants. Toxicology 230:219–226

EC (2005) Commission staff working paper. Annex to the communication from the commission to the council and the European Parliament on Community Strategy Concerning Mercury. Extended Impact Assessment European Commisision. COM(2005)20 final. http://europa.eu.int/comm/environment/chem-icals/mercury/pdf/extended_impact_assessment.pdf. Accessed 22 Dec 2011

EEA (1999) State and pressures of the marine and coastal Mediterranean environment. European Environmental Agency, Copenhagen. http://www.eea.europa.eu/publications/medsea/at_download/file. Accessed 22 Dec 2011

EEA (2006) Priority issues in the Mediterranean environment. Report European Environmental Agency, Copenhagen. http://www.eea.europa.eu/publications/eea_report_2006_4/at_download/file. Accessed 22 Dec 2011

Elena SF, Lenski RE (2003) Evolution experiments with microorganisms: the dynamics and genetic bases of adaptation. Nat Rev Genet 4:457–469

Eurostat (2008) Half of Mediterranean fish catches are by Mediterranean Partner Countries. Agriculture and fisheries Statistics in focus. EUROSTAT 88/2008, 7p

Eurostat (2011) Fisheries statistics. European Commission, Brussels. http://epp.eurostat.ec.europa.eu/portal/page/portal/fisheries/introduction. Accessed 22 Dec 2011

FAO (2008a) Climate change for fisheries and aquaculture. Technical background document from the expert consultation held on 7–9 April 2008. Food and Agriculture Organization of the United Nations, Rome. ftp://ftp.fao.org/docrep/fao/meeting/013/ai787e.pdf. Accessed 22 Dec 2011

FAO (2008b) Exposure assessment of microbiological hazards in food – guidelines. World Health Organization. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/010/a0251e/a0251e00.htm. Accessed 22 Dec 2011

FAO (2008c) Climate change: implications for food safety. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/010/i0195e/i0195e00.htm. Accessed 22 Dec 2011

FAO (2011a) Fisheries stat. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/fishery/statistics/global-consumption/en. Accessed 22 Dec 2011

FAO (2011b) Report of the joint FAO/WHO expert consultation on the risks and benefits of seafood consumption. Food and Agriculture Organization of the United Nations, Rome. World Health Organization, Geneva. http://www.fao.org/docrep/014/ba0136e/ba0136e00.pdf. Accessed 22 Dec 2011

Faruque SM, Albert MJ, Mekalanos JJ (1998) Epidemiology, genetics, and ecology of toxigenic *Vibrio cholerae*. Microbiol Mol Biol Rev 62:1301–1314

FDA (1993) Guidance document for cadmium in shellfish. Food and Drug Administration, Washington, DC. http://dino.wiz.uni-kassel.de/dain/ddb/x270.html. Accessed 22 Dec 2011

Francesconi KA (2007) Toxic metal species and food regulations-making a healthy choice. Analyst 132:17–20

Galgani F, Martínez-Gómez C, Giovanardi F, Romanelli G, Caixach J, Cento A, Scarpato A, BenBrahim S, Messaoudi S, Deudero S, Boulahdid M, Benedicto J, Andral B (2011) Assessment of polycyclic aromatic hydrocarbon concentrations in mussels (*Mytilus galloprovincialis*) from the Western basin of the Mediterranean Sea. Environ Monit Assess 172:301–317

Galil BS, Zenetos A (2002) A sea change—exotics in the eastern Mediterranean. In: Leppakoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe. Distribution, impacts and management. Kluwer Academic Publishers, Dordrecht

Gambaiani DD, Mayol P, Isaac SJ, Simmonds MP (2009) Potential impacts of climate change and greenhouse gas emissions on Mediterranean marine ecosystems and cetaceans. J Mar Biol Assoc UK 89:179–201

Gamble JL (2008) Analyses of the effects of global change on human health and welfare and human systems: final report, synthesis and assessment product. Report by the U.S. climate change science program and the Subcommittee on Global Change Research, Washington, DC. http://www.climatescience.gov/Library/sap/sap4-6/default.php. Accessed 22 Dec 2011

Green MA, Waldbusser GG, Reilly SL, Emerson K, O'Donnell S (2009) Death by dissolution: sediment saturation state as a mortality factor for juvenile bivalves. Limnol Oceanogr 54:1037–1047

Hall LW, Anderson RD (1995) The influence of salinity on the toxicity of various classes of chemicals to aquatic biota. Crit Rev Toxicol 25:281–346

Harvell CD, Kim K, Burkholder JM et al (1999) Emerging marine diseases-climate links and anthropogenic factors. Science 285:1505–1510

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162

Hutchins DA, Teyssii J-L, Boisson F, Fowler SW, Fisher NS (1996) Temperature effects on uptake and retention of contaminant radionuclides and trace metals by the brittle star *Ophiothrix fragilis*. Mar Environ Res 41:363–378

IPCC (2007) In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change, 2007. United Nations Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. Accessed 22 Dec 2011

Islam MD, Tanaka M (2004) Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Mar Pollut Bull 48:624–649

Jezierska B, Lugowska K, Witeska M (2009) The effects of heavy metals on embryonic development of fish. Fish Physiol Biochem 35:625–640

Khan MAQ, Ahmed SA, Catalin B, Khodadoust A, Ajayi O, Vaughn M (2006) Effect of temperature on heavy metal toxicity to juvenile crayfish, *Orconectes immunis* (Hagen). Environ Toxicol 21:513–520

Kovats RS, Edwards S, Hajat S, Armstrong B, Ebi KL, Menne B (2004) The effect of temperature on food poisoning: time series analysis in 10 European countries. Epidemiol Infect 132:443–453

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. Biol Lett 6:688

Lleonart J, Maynou F (2003) Fish stock assessments in the Mediterranean: state of the art. Sci Mar 67:37–49

MacKenzie L, Holland P, McNabb P, Beuzenberg V, Selwood A, Suzuki T (2002) Complex toxin profiles in phytoplankton and Greenshell mussels (*Perna canaliculus*), revealed by LC-MS/MS analysis. Toxicon 40:1321–1330

Maes J, de Meulenaer B, Van Heerswynghels P, De Greyt W, Eppe G, De Pauw E, Huyghebaert A (2005) Removal of dioxins and PCB from fish oil by activated carbon and its influence on the nutritional quality of the oil. J Am Oil Chem Soc 82:593–597

Marcos M, Tsimplis MN (2008) Comparison of results of AOGCMs in the Mediterranean Sea during the 21st century. J Geophys Res 113:C12028

Marques A, Teixeira B, Barrento S, Anacleto P, Bandarra N, Mendes R, Carvalho ML, Nunes ML (2010a) Compositional characteristics of spider crab *Maja brachydactyla*: human health implications. J Food Compos Anal 23:230–237

Marques A, Nunes ML, Moore S, Strom M (2010b) Climate change and seafood safety: human health implications. Food Res Int 43:1766–1779

May RM (1973) Stability and complexity in model ecosystems. Princeton University Press, Princeton

McLaughlin JB, DePaola A, Bopp CA, Martinek KA, Napolilli NP, Allison CG, Murray SL, Thompson EC, Bird MM, Middaugh JP (2005) Outbreak of *Vibrio parahaemolyticus* gastroenteritis associated with Alaskan oysters. N Engl J Med 353:1463–1470

Modassir Y (2000) Effect of salinity on the toxicity of Mercury in mangrove clam, *Polymesoda erosa* (Lightfoot 1786). Asian Fish Sci 13:335–341

Monserrat J, Bianchini A (1995) Effects of temperature and salinity on the toxicity of a commercial formulation of methyl parathion to *Chasmagnathus granulata* (Decapoda, Grapsidae). Braz J Med Biol Res 28:74–78

Moon H-B, Kim H-S, Choi M, Choi H-G (2010) Intake and potential health risk of polycyclic aromatic hydrocarbons associated with seafood consumption in Korea from 2005 to 2007. Arch Environ Contam Toxicol 58:214–221

Mubiana VK, Blust R (2007) Effects of temperature on scope for growth and accumulation of Cd, Co, Cu and Pb by the marine bivalve *Mytilus edulis*. Mar Environ Res 63:219–235

Nadal M, Kumar V, Schuhmacher M, Domingo JL (2008) Applicability of a neuroprobabilistic integral risk index for the environmental management of polluted areas: a case study. Risk Anal 28:271–286

Nye J (2010) Climate change and its effects on ecosystems, habitats and biota: state of the gulf of Maine report. Gulf of Maine Council of the Marine Environment. http://www.gulfofmaine.org/state-of-the-gulf/docs/climate-change-and-its-effects-on-ecosystems-habitats-and-biota.pdf. Accessed 22 Dec 2011

Onuma Y, Satake M, Ukena T, Roux J, Chanteau S, Rasolofonirina N, Ratsimaloto M, Naoki H, Yasumoto T (1999) Identification of putative palytoxin as the cause of clupeotoxism. Toxicon 37:55–65

Oren OH (1957) Changes in the temperature of the Eastern Mediterranean Sea in relation to the catch of the Israel trawl fishery during the years 1954/55 and 1955/56. Bull Inst Océanographique Monaco 1102:1–12

Oterhals A, Solvang M, Nortvedt R, Berntssen MHG (2007) Optimization of activated carbon-based decontamination of fish oil by response surface methodology. Eur J Lipid Sci Technol 109:691–705

Rainbow PS (2002) Trace metal concentrations in aquatic invertebrates: why and so what? Environ Pollut 120:497–507

Rajamani S, Siripornadulsil S, Falcao V, Torres M, Colepicolo P, Sayre R (2007) Phycoremediation of heavy metals using transgenic microalgae. Adv Exp Med Biol 616:99–109

Rao DGVP, Khan MAQ (2000) Zebra mussels: temperature potentiation of copper toxicity. Water Environ Res 72:175–178

RASFF (2010) The Rapid Alert System for Food and Feed (RASFF) annual report 2009. European Commission. http://ec.europa.eu/food/food/rapidalert/docs/report2009_en.pdf. Accessed 22 Dec 2011

Romano J-C, Bensoussan N, Younes WA, Arlhac D (2000) Thermal anomaly in waters of the Gulf of Marseilles during the summer of 1999. A partial explanation of the mortality of certain fixed invertebrates? CR Acad Sci 323:415–427

Ronzitti N (1999) Le zone di pesca nel Mediterraneo e la tutela degli interessi italiani. Riv Maritima 6:96

Sevault F, Somot S, Déqué M (2004) Climate change scenario for the Mediterranean sea. Geophys Res Abstr 6:1–10

Simopolpoulos AP (1997) Seafood from producer to consumer, natural aspects of the fish. In: Lutten JB, Borrensen T, Oehlenschläger J (eds) Seafood from producer to consumer, integrated approach to quality, vol 38. Elsevier, Amsterdam

Sioen I, Leblanc JC, Volatier JL, De Henauw S, Van Camp J (2008) Evaluation of the exposure methodology for risk-benefit assessment of seafood consumption. Chemosphere 73:1582–1588

Sokurenko EV, Gomulkiewicz R, Dykhuizen DE (2006) Source-sink dynamics of virulence evolution. Nat Rev Microbiol 4:548–555

Spatharis S, Tsirtsis G, Danielidis DB, Chi TD, Mouillot D (2007) Effects of pulsed nutrient inputs on phytoplankton assemblage structure and blooms in an enclosed coastal area. Estuar Coast Shelf Sci 73:807–815

Stirling DJ (2001) Survey of historical New Zealand shellfish samples for accumulation of gymnodimine. N Z J Mar Freshw Res 35:851–857

Sullivan JK (1977) Effects of salinity and temperature on the acute toxicity of cadmium to the estuarine crab *Paragrapsus gaimardii* (Milne Edwards). Aust J Mar Freshw Res 28:739–743

Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S (2011) Climate change impacts on the biophysics and economics of world fisheries. Nat Clim Change 1:449–456. doi:10.1038/NCLIMATE1301

Tin T, Giannakopoulos G, Bindi M (2005) Climate change impacts in the Mediterranean resulting from a 2 °C global temperature rise. Report of WWF. http://www.panda.org/downloads/climate_change/medreportfinal8july05.pdf. Accessed 22 Dec 2011

Wang J, Chuang C-Y, Wang W-X (2005) Metal and oxygen uptake in the green mussel *Perna viridis* under different metabolic conditions. Environ Toxicol Chem 24:2657–2664

WHO (1992) Health risks from bathing in marine waters. Report of a joint WHO/UNEP meeting, Athens, 15–18 May 1991. Document EUR/ICP/CEH 103. World Health Organization Regional Office for Europe, Copenhagen. http://www.who.int/water_sanitation_health/bathing/recreadis.pdf. Accessed 22 Dec 2011

WHO (1995) Health risks from marine pollution in the Mediterranean, Part II, review of hazards and health risks, Document EUR/ICP/EHAZ94 01/MT01(2). World Health Organization Regional Office for Europe, Copenhagen. http://bases.bireme.br/cgi-bin/wxislind.exe/iah/online/?IsisScript=iah/iah.xis& src=google&base=WHOLIS&lang=p&nextAction=lnk&exprSearch=54757&indexSearch=ID. Accessed 22 Dec 2011

WHO (1996) Assessment of the state of microbiological pollution of the Mediterranean Sea. MAP technical reports series no.108, Athens. http://www.unepmap.org/index.php?module=library&mode=pub&action=results&_stype=3&s_category=&s_descriptors=Microbiological%20pollution. Accessed 22 Dec 2011

WHO (2001) WHO surveillance programme for control of food-borne infections and intoxications in Europe. In: Schmidt K, Tirado C (eds) Seventh report 1993–1998. http://www.bfr.bund.de/internet/7threport/7threp_ctryreps_fr.htm. Accessed 22 Dec 2011

Yasumoto T, Satake M (1998) New toxins and their toxicological evaluations. In: Reguera B, Blanco J, Fernandez ML, Wyatt T (eds) Harmful algae. Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, Paris

Zago C, Capodaglio G, Ceradini S, Ciceri G, Abelmoschi L, Soggia F, Cescon P, Scarponi G (2000) Benthic fluxes of cadmium, lead, copper and nitrogen species in the northern Adriatic Sea in front of the river Po outflow, Italy. Sci Total Environ 246:121–137