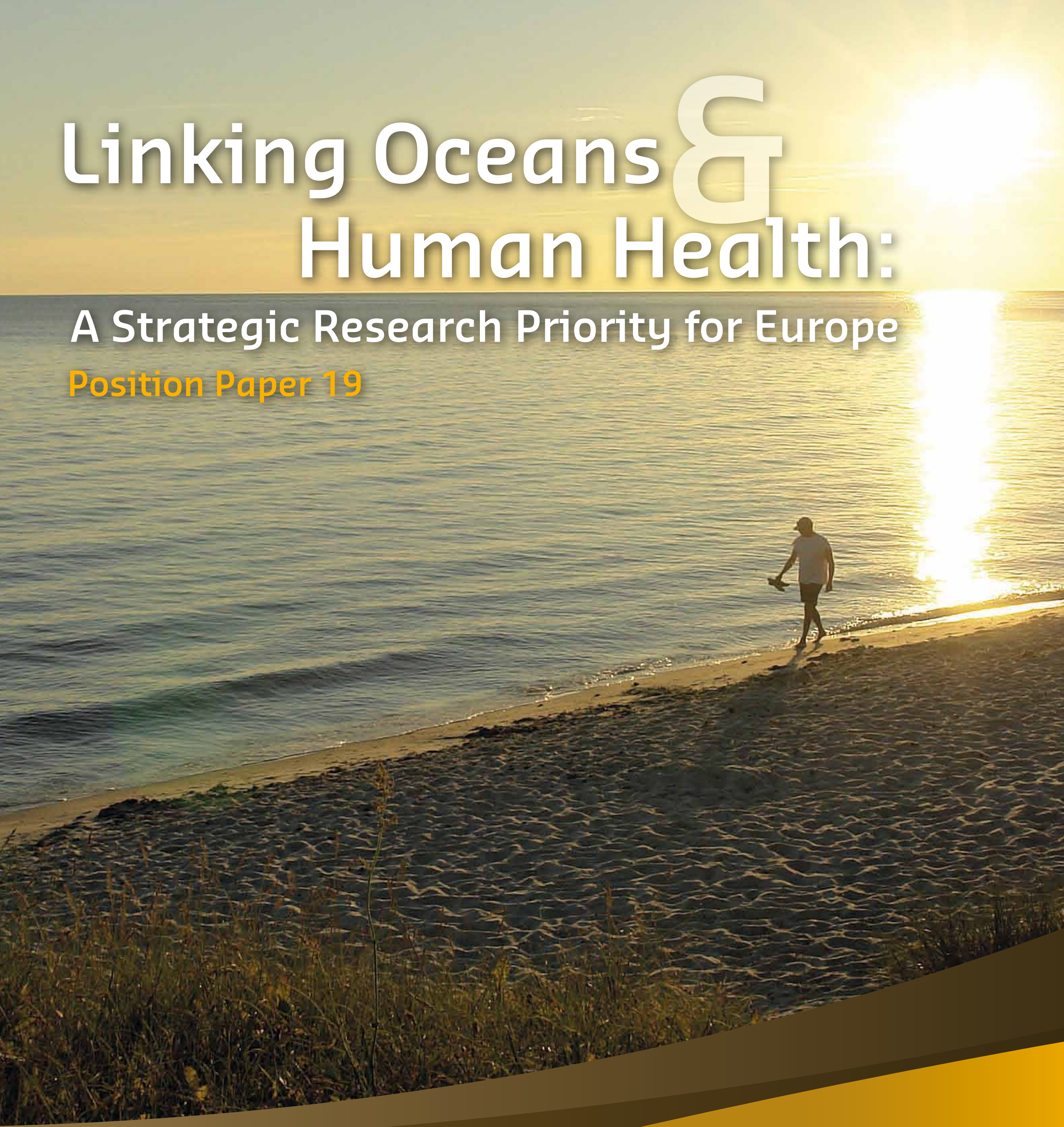
Linking Oceans & Human Health:

A Strategic Research Priority for Europe

Position Paper 19



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Linking Oceans and Human Health: A Strategic Research Priority for Europe

European Marine Board Position Paper 19

This Position Paper is based on the activities of the Marine Board Working Group Oceans and Human Health (WG OHH).

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Foreword

There has been a growing recognition within the scientific community of the need for a more holistic and coherent approach to understanding the complex links between the seas and oceans on one hand, and human health and well-being on the other. Extreme weather events such as coastal storms and flooding, and human exposure to marine-borne pathogens and chemical pollution, pose significant threats to human health. At the same time, the seas provide numerous benefits to human health and well-being in the form of ecosystem services, including the supply of resources such as food and raw materials. Biotechnology is opening opportunities to exploit marine genetic resources with potential for new drugs and nutraceuticals. Research is also beginning to identify the mental health benefits of interacting with the coastal environment. Understanding this complexity can only be achieved with an interdisciplinary approach, drawing from expertise across a diverse range of disciplines within natural, social and economic sciences, public health and medicine.

During the last decade, there has been a significant investment in multi-disciplinary oceans and human health research programmes in the USA. This has included the establishment of seven Centers for Oceans and Human Health (COHH) and a complementary National Oceanic and Atmospheric Administration (NOAA) Oceans and Human Health Initiative (OHHI) to conduct, coordinate and communicate research in this new integrative field. The European Marine Board has recognized that Europe does not currently support a similar coherent oceans and human health research framework and has published this paper as a first step in raising the profile of this issue amongst policy makers, research funders and the scientific community. The paper identifies the key research needs and priorities to support the development of a holistic and coherent transnational oceans and human health research effort in Europe. For consistency, the paper uses the "oceans and human health" terminology first coined in the US, but it is clear that much of this interaction is at the level of coasts and coastal seas. Hence, in this context, "oceans" refers to the marine and coastal environment in its totality.

If there is one key message of this position paper, it is that human health and well-being is intrinsically connected to, and impacted by, the seas and oceans which surround our continental landmass. To manage this relationship, we need an effective policy framework, linking maritime and public health policies. While Europe has made significant strides in developing an Integrated Maritime Policy, we do not yet take sufficient account of human health aspects in maritime policy-making. Hence the concerted European research effort advocated by this paper does not just represent an interesting scientific challenge, but is essential to ensure that improving public health and achieving Good Environmental Status (GES) in European seas are linked and mutually supporting policy objectives.

I extend sincere thanks to the authors of this paper, operating under the auspices of the European Marine Board working group on Oceans and Human Health, for their time and commitment in delivering this important publication. I am particularly grateful to the Chair of the working group, Professor Michael Moore, for his hard work and dedication throughout the writing process and in presenting the messages of the paper at meetings and conferences in Europe and beyond. As always, I thank the EMB Secretariat for its coordination and support of the entire effort from concept to delivery. At the time of publication, there are a number of follow-up activities in the pipeline to promote the key messages of the paper. I hope that this marks just the beginning of a process to embed the human health implications of our interaction with the seas and oceans in the scientific and maritime policy agendas. In the context of rapidly changing seas and growing coastal populations, this represents an important societal challenge.

Kostas Nittis
Chair, European Marine Board

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Executive Summary

The marine environment contributes significantly to human health through the provision and quality of the air that we breathe, the food we eat, the water we drink and in offering health-enhancing economic and recreational opportunities. At the same time, the marine environment is under pressure from human activities such as transport, industrial processes, agricultural and waste management practices. Evaluation and management of the resultant impacts, on both marine ecosystems themselves, and on human health, have largely been undertaken as separate activities, under the auspices of different disciplines with no obvious interaction. Hence, many of our perceptions of the relationships between the marine environment and human health are limited and still relatively unexplored, leaving critical knowledge gaps for those seeking to develop effective policies for the sustainable use of marine resources and environmental and human health protection.

To address the considerable knowledge gaps that exist, research in Oceans and Human Health (OHH) must be directed at elucidating key environmental processes, and providing a predictive capability for both biotic and abiotic environmental influences on human health and well-being. This can only be achieved through the mobilization of interdisciplinary competencies around Europe and ensuring that the necessary scientific and technical capabilities are available.

The main high-level recommendation of this Position Paper is that a consolidated European Oceans and Human Health Research Programme should be developed and supported to ensure the scale of investment and collaboration necessary to address the major challenges of understanding and dealing with the immense complexity of the relationship between the marine environment and human health. The establishment and implementation of such a programme will ultimately allow us to:

- improve our understanding of the potential public health benefits from marine and coastal ecosystems;
- reduce the burden of human disease linked with marine environmental causes; and
- anticipate new threats to public health before they become serious.

The complex and causal interconnections between marine environment and human health requires a systems approach addressing all levels of organization from genes to ecosystems. Such an integrated systems approach must draw on the skills and expertise of many scientific disciplines as well as the social and economic sciences.

In this position paper, the European Marine Board Working Group on Oceans and Human Health (WG OHH) has identified a number of key research targets to build the necessary OHH research capability in Europe (see Executive Summary Box 1). These targets should therefore constitute the main objectives of the proposed European Oceans and Human Health Programme.

**EXECUTIVE SUMMARY BOX 1.
Recommended strategic research targets of a proposed European Oceans and Human Health Research Programme**

1. Innovative monitoring and surveillance techniques which allow much greater provision of relevant and accurate datasets (e.g. remote observation systems for coastal and marine ecosystems, detection of chemical / material pollutants, biogenic and microbial toxins and human pathogens, and improved testing for seafood and water safety).

2. Improved understanding of the physical, chemical and biological processes involved in the transport and transmission of toxic chemicals and pathogenic organisms through the marine environment to humans.

3. Improved understanding of the direct and indirect causal relationships between degradation of the marine environment and the incidence of human disease.

4. Improved environmental models to determine the patterns and extent of natural dispersion of sewage, agricultural effluents and industrial waste.

5. Expert systems to link existing models with our experience and knowledge of the connectivity between the marine environment and human health.

6. Appropriate indicators in support of sustainable development where environmental, social and economic measures are linked.

7. Methods and mechanisms which demonstrate the value (economic, cultural, aesthetic, etc.) to human well-being of marine environments from coastal seas to global oceans.

To successfully realize the objectives of a large interdisciplinary European research programme on Oceans and Human Health, it will be necessary to support a range of enabling actions and capacities (see Executive Summary Box 2).

Much has already been done to address the research targets summarised in Executive Summary Box 1, both at the scientific and policy level. Hence, when developing the European research capability in OHH, there is a need to build on, support and complement past and current efforts and existing policy and regulatory frameworks that share the same research targets.

This will require consideration of the long and diverse set of policies and regulations relevant for OHH in a more integrated way than hitherto achieved. One of the first steps should, therefore, be a thorough analysis of the various policies and legal instruments which have a bearing on the complex relationship between our marine environment and human health, to identify weaknesses, gaps and overlaps, and consider mechanisms to strengthen their interactions to improve effectiveness. Such an analysis should provide the basis for identifying how a coordinated European research effort in Oceans and Human Health would support the refinement and implementation of the current EU policies, including, but not restricted to, the Marine Strategy Framework Directive.

From an EU perspective, a key policy framework for developing a coordinated and science-based approach to the link between oceans and human health is the Marine Strategy Framework Directive (MSFD). Key European programmes which have the capacity to support an Oceans and Human Health initiative include Horizon 2020, the EU's next programme for research and technology development (2014-2020), and the relevant European Joint Programming Initiatives. However, national research programmes should also provide support for the rapid development of and capacities in the area of Oceans and Human Health.

A European Oceans and Human Health Programme should also encourage international collaboration (e.g. with the NIH/NSF and NOAA programmes in the USA) as this will facilitate synergies and added value.

Securing human health by reducing the burden of disease and improving the quality of the global environment are two grand challenges which top the policy agenda of governments worldwide. Nevertheless, recognition of the importance of the marine environment for human health and well-being is currently limited. Moreover, the research community required to address Oceans and Human Health challenges in Europe remains very fragmented and this lack of coordination results in a failure to adequately support evidence-based policy making in the areas of marine management and public health. Failure to effectively address this situation will impact adversely on efforts to alleviate poverty, to sustain the availability of environmental goods and services, and to improve health and social and economic stability.

One of the ways in which the marine environment contributes to human health is through the food we eat. ©Parc Marin de la Côte Bleue

EXECUTIVE SUMMARY BOX 2.
Enabling actions and capacities required to maximize the efficiency and impact of an Oceans and Human Health Research Programme

- Provide adequate support for **interdisciplinary research** and training of young investigators to build capacity and improve our knowledge base on the relationship between the marine environment and human health. A particular focus should be on developing modelling capacities (e.g. to design early warning systems) and linking experts in fields as diverse as oceanography, marine ecology, ecotoxicology, epidemiology and public health. Where relevant and possible, collaborative links should be developed with the private sector, for example by establishing co-funded PhDs and research fellowships;

- Increase **knowledge management** and the capacity to conduct expert horizon scanning for emerging problems, benefits and technologies in relation to the marine environment which may impact on human health and well-being;

- Build bridges between relevant stakeholders, for example by **involving stakeholders** early on during project formulation, allowing for the co-evolution and joint construction of knowledge;

- Develop specific interdisciplinary Oceans and Human Health **networking actions** to overcome the fragmented research capability in Europe;

- Stimulate creative thinking and develop opportunities to **explore alternatives to standard risk assessment procedures;**

- **Improve communication**

  a) within the scientific community to support the development of a European Oceans and Human Health research community;
  b) between research community and public authorities with competency for environmental protection, food safety and human health; and
  c) to raise public awareness regarding the complex relationship between oceans and human health. This includes supporting activities to promote Ocean Literacy which entails public outreach to improve the understanding of the importance of the oceans and, more specifically, the risks and benefits of human interactions with the marine environment (e.g. through citizen science-public participation, beach watches, etc.).

1
Introduction and policy context

1.1 Background and rationale

For millennia humans have been dependent on seas and oceans as a source of food and a means of expansion. However, the oceans and coastal seas are like a double-edged sword when it comes to interactions with human health. Natural events such as hurricanes, severe storms and tsunamis can have devastating impacts on coastal populations, while pollution of the seas by pathogens and toxic waste can cause illness and death. An estimated 250 million cases of gastroenteritis occur worldwide each year as a result of bathing in contaminated water, and 50,000-100,000 people[1] die annually from infectious hepatitis. In terms of productivity (lost working days), the overall global burden of human disease caused by sewage pollution of coastal waters has been estimated at 4 million lost person-years annually.

On the positive side, the oceans provide humans with many benefits including food for around a third of the global population, the air that we breathe and our climate system which enables habitation of much of the planet. The marine environment can also be the source of potential health benefits through the provision of healthy food, novel pharmaceuticals and related products derived from marine organisms, as well as through a contribution to general well-being from a close association with the coastal environment (i.e. recreational and psychological benefits, or the "Blue Gym" effect) (White *et al.*, 2010; Depledge & Bird, 2009; Fleming *et al.*, 2006).

Environmental change and human health

Changes in the marine environment have direct and indirect impacts on human health and well-being, but in many cases we are not aware of how actions in one place affect other parts of the ecosystem. Factors that may have a negative influence on ecosystem function and ecological integrity, for instance, will not necessarily be linked to adverse effects on human health or well-being (Figure 1.1; Moore *et al.*, 2011, 2013). Environmental changes are often regarded as unavoidable or as the unforeseen consequences of economic and cultural changes. However, there is much that we can do through policy interventions to manage human impacts on the marine environment and this has been dealt with in depth by the MAES Working Group[2] which has proposed a conceptual framework that responds to EU policy questions regarding ecosystem assessment and services. In this paper, we argue that further research on the complex relationship between the oceans and human health, and on the capacity to protect public health through holistic maritime policies and management actions, is essential to manage the challenges we face resulting from humans interacting with the marine environment.

[1] UNEP Our Planet 14(4) on Water, Sanitation, People http://www.ourplanet.com/imgversn/144/vandeweerd.html

[2] Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020 Discussion paper http://biodiversity.europa.eu/ecosystem-assessments/about-1/an-analytical-framework-for-ecosystem-assessments-under-action-5-of-the-eu/download

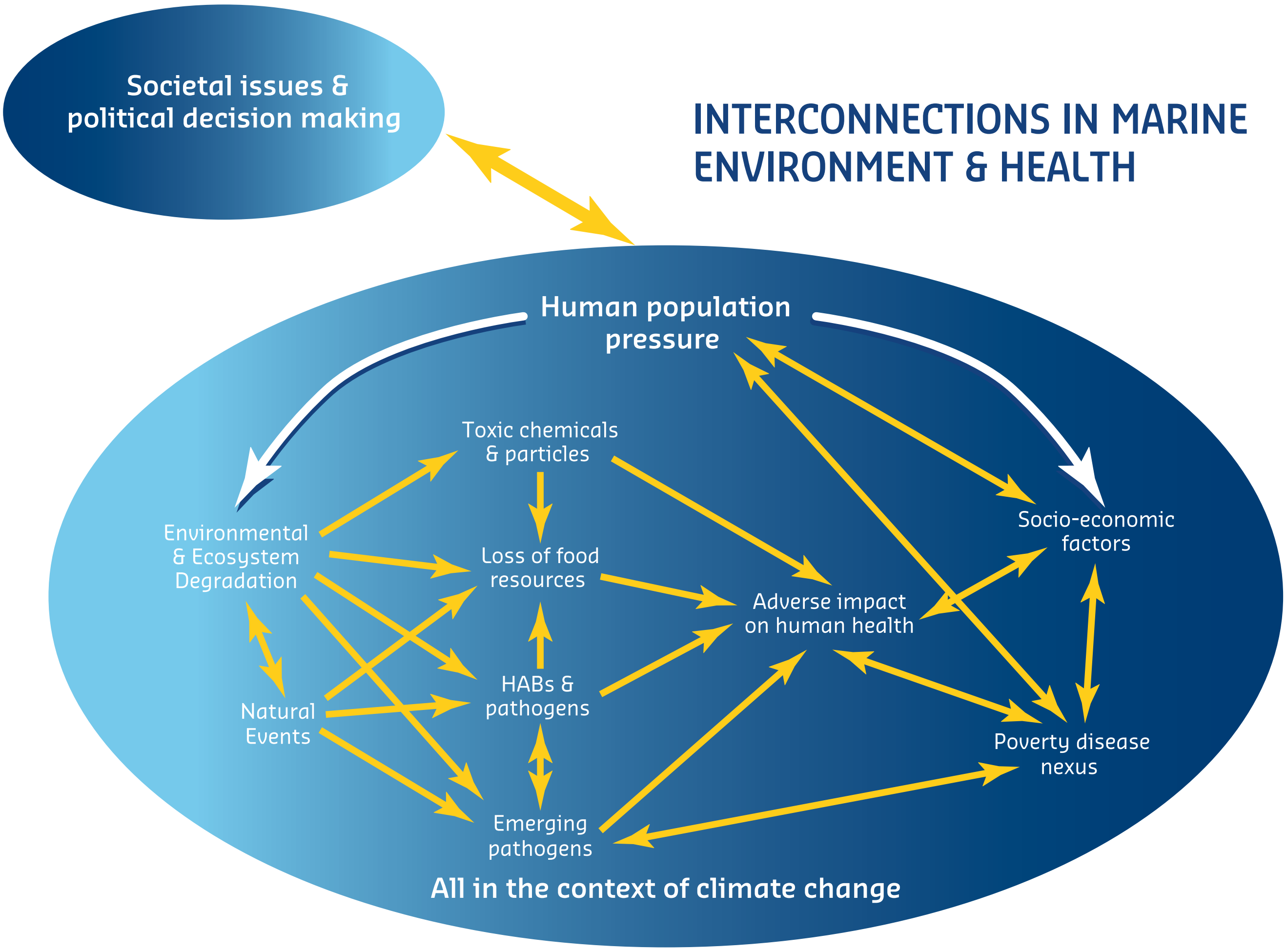


FIGURE 1.1.
A summary of the interconnectivity of the key processes of public health relevance in the marine environment (adapted from Moore *et al.*, 2011)
(HABs: Harmful Algal Blooms)

In the new Anthropocene[3] age, the influence of humans on the global environment is arguably greater than that of any other species, and so are the effects of environmental change on human health and well-being. Human impact on our environment is shaped by our social actions, governance, economic forces, international trade, land use and industrial and urban development (Roodman, 1998; Torres & Monteiro, 2002). Societal factors responsible for the deterioration of the health of marine ecosystems include: economic failure leading to reduced efforts in management and protection; inadequate governance including non-enforcement of existing environmental protection laws; haphazard industrialization and urbanization resulting in run-off of polluted wastewater and contamination of land, rivers and coastal waters; poor public education and understanding of the problems; and the strongly sectoral structure of government policies and institutions which generally presents a barrier to integrated solutions (Bryant *et al.*, 1995; Burke *et al.*, 2000; Mee, 1992; United Nations Environment Programme, 1991). High density human occupation of the coastal zone often lies at the heart of these problems (Figure 1.1; United Nations Population Division, 1999; World Bank, 1995).

Historically, research and regulatory concern has concentrated on the impact of human activities on the marine environment, particularly through anthropogenic pollution and the over-exploitation of resources. A significant proportion of the human population lives in close proximity to the coastal zone (up to 70%, depending on the definition of "coastal zone", in this case within 200km of the coast) and coastal population densities are increasing globally. High-density human settlements are

[3] The term Anthropocene is an informal term coined by the Nobel Prize-winning atmospheric chemist Paul Crutzen to reflect that the influence of human behaviour on the Earth system in recent centuries has been so significant that it can be considered to constitute a new geological epoch.

often found in the vicinity of large estuaries and river deltas and often depend on the fishing industry for food, employment and wealth generation. The rapid growth in coastal populations, often accompanied by extensive urban and industrial development, means that coastal and shelf sea areas are the most impacted and hence the most vulnerable zones of the ocean (Figure 1.2; Cassar, 2001; McGlade, 2001; Moore & Csizer, 2001; Population Reports, 2000).

Coastal waters receive a multitude of human and zoonotic pathogens and biogenic and chemical waste inputs originating from industrial, domestic and agricultural land-based sources, all of which are difficult to estimate quantitatively (Windom, 1992). A complex mix of other toxic chemical pollutants is also introduced through shipping activities, offshore oil and gas extraction, and atmospheric inputs of airborne particles of industrial origin (Roose *et al*., Marine Board Position Paper 16, 2011; Bowen & Depledge, 2006). To further complicate this already complex picture, coastal zones include the most diverse and productive ecosystems in our oceans. Previous economic studies have placed a higher value on coastal zones (US$ 12.6 trillion/year for coastal zones out of a global total of US$ 33.3 trillion/year) than any other compartment of our environment (Costanza *et al*., 1997).

There is evidence of a significant increase in marine environmental disturbance owing to both natural and anthropogenic pressures (Bowen & Depledge, 2006) and it is often the combination of, or interaction between, natural and human pressures which increases the potential for human health impacts. Important stressors include: domestic sewage and agricultural faecal waste runoff; sea-level rise; ocean acidification; chemical contaminants including medical and veterinary pharmaceuticals; radionuclides; natural biogenic toxins (e.g. from harmful algal and cyanobacterial blooms – HABs); sound and light pollution; climate change and extreme weather; increased UV-radiation; nutrient enhancement or deprivation; hypoxia; habitat disturbance (e.g. from commercial fishing activity); and microbial run-off (Figures 1.1 and 1.2; Fleming *et al*., 2006; Todd, 2006; Maso & Graces, 2006; Orr *et al*., 2005; McGlade, 2001; Moore & Csizer, 2001). In fact, environmental disturbance will frequently comprise various combinations of such stresses (Di Giulio & Ben-

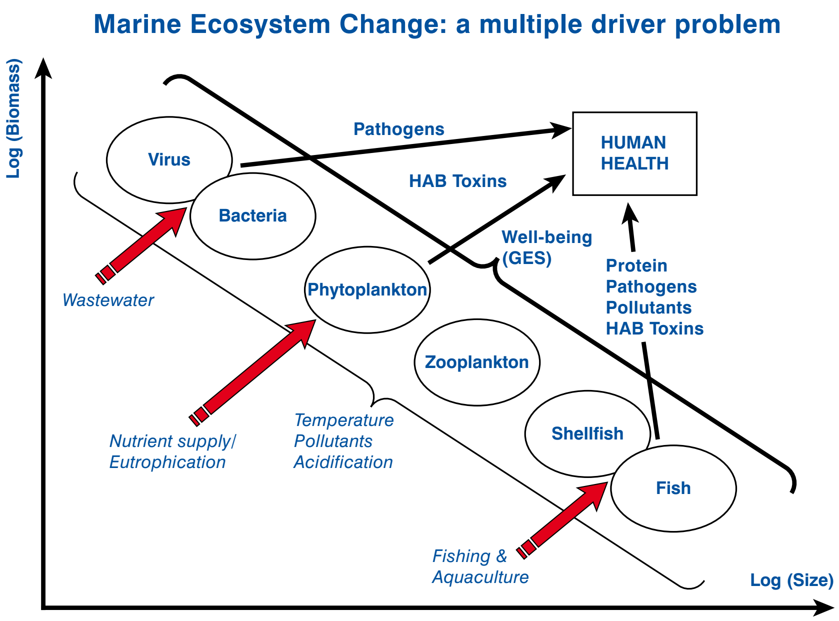


FIGURE 1.2.
Schematic diagram illustrating the multiple drivers underlying the various processes contributing to the interactions between marine ecosystems and human health (Allen, 2011)

INFORMATION BOX 1.1.
Key areas at risk from human and natural pressures central to the interaction between marine environmental health and human health

- Ecosystem services (environmental, economic, cultural, etc.) as a result of human and environmental pressures and impacts;
- Quality of life, including the economic, social and health implications of deteriorating marine environments;
- Habitats and environmental resources (e.g. salt marshes, coral reefs, large estuaries and deltas), which are under pressure from unprecedented land use and urbanisation at a time of sea level rise and coastal erosion;
- Coastal biodiversity of land and aquatic animals and plants;
- Environmental quality (e.g. due to contamination with chemical and endocrine disrupting properties);
- Aesthetics (e.g. oil and litter on beaches).

son, 2002). In terms of tangible consequences, insidious environmental degradation may be an important contributing factor leading to reduced well-being and a poor quality of life, which is itself associated with an increased risk of disease. Information Box 1.1 provides a summary of some of the key areas at the interface between marine environmental health and human health.
In order to develop a strategy for dealing with the potential problems, we need to consider how we can forecast and reduce risks. To date, public health policy and management actions have mostly relied on a simple univariate action-reaction model or, at most, multi-level relations but always with a clear directionality (Westra *et al*., 2008, Bowen & Depledge, 2006; Fleming *et al*., 2006; Torres & Monteiro, 2002). For example, following identification of an algal toxin in seafood, action will be taken to ensure that consumption of the seafood ceases until the threat has passed. Ecological interactions are, in fact, much more complex, and models of ecological and health interconnectivity require a much greater degree of sophistication (see Figure 1.1; Allen, 2011; Moore *et al*., 2011; Morris *et al*., 2006). This complexity underlines the need to adopt systems-level approaches when addressing the relationships between the marine environment and public health (see also Chapter 4).

Assessment and management of environmental change

The assessment of impacts of environmental disturbances on ecosystems and organisms (including humans) requires an understanding of stress effects throughout the hierarchy of biological organization, from the molecular and cellular to the organism and population levels, as well as the community and ecosystem levels (Di Giulio & Benson, 2002; Moore *et al*., 2004). In the past, damage to the environment has largely been identified retrospectively, in response to acute events such as major disasters (e.g. industrial accidents like Seveso and Bhopal; and oil spills such as the Amoco Cadiz, Exxon Valdez and Gulf War, and chemical pollution of the Great Lakes) (Moore & Csizer, 2001; Moore *et al*., 2004). Generally, these have been measured in terms of human health impacts and visible changes resulting from the loss of particular populations or communities. However, long-term and chronic exposure to environmental stress (including chemical pollutants or other anthropogenic factors) will seldom result in rapid and catastrophic change (Bowen & Depledge, 2006; Moore *et al*., 2004; Orr *et al*., 2005). Rather, the impact will be gradual, subtle, and frequently difficult to disentangle from the process and effects of natural environmental change (Figure 1.3). This latter problem has been a major stumbling block in assessing environmental impact since such investigations began in the 1960s.

The Ecosystem Approach is considered one of the most important principles of sustainable environmental resource management, which is the management of the interaction and impact of human societies on the environment. Environmental resource management aims to ensure that ecosystem services are protected and

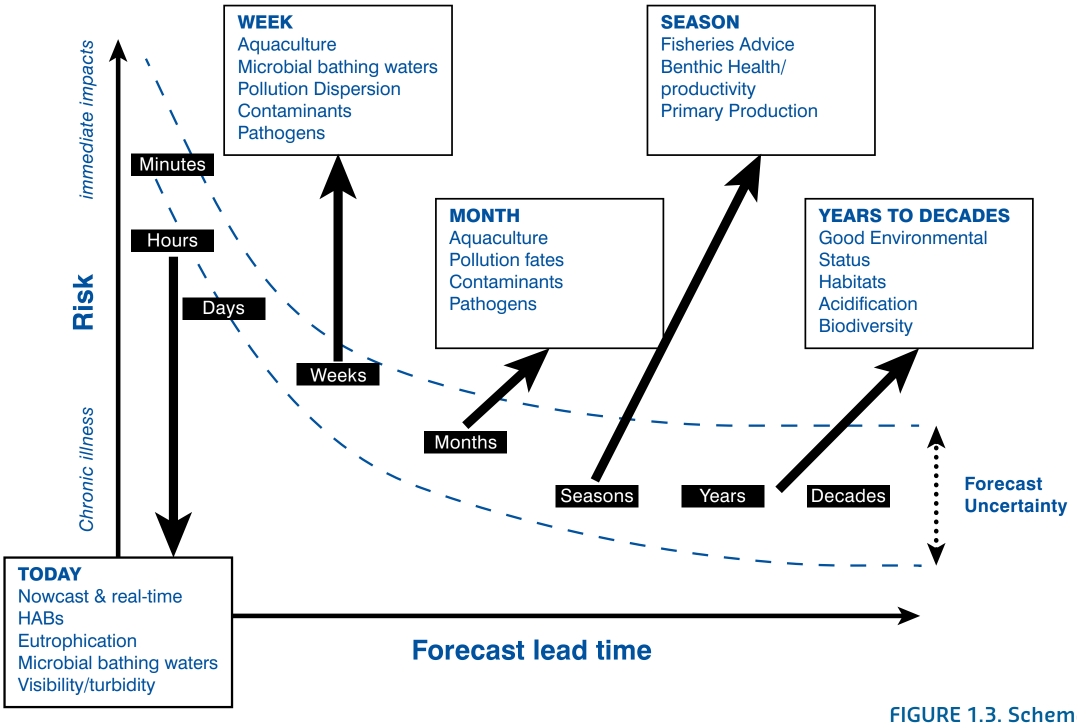


FIGURE 1.3. Schematic diagram illustrating the timescales of forecast pertinent to marine ecosystems and human health (Allen, 2011)

maintained for equitable use by future human generations, and also to maintain ecosystem integrity in its own right by taking into consideration ethical, economic, and ecological variables (Pahl-Wostl, 2007; Morris *et al*., 2006). Environmental resource management tries to identify the factors that have a stake in the conflicts that may arise between meeting societal needs and protecting environmental resources. The ecosystem approach provides a sound management framework within which efforts to reduce the risks to human health posed by marine environmental degradation can and should be progressed, and has been at the heart of some important EU policy instruments listed below.

1.2 Scientific challenges and research questions

As a starting point, the OHH Working Group compiled a list of key scientific challenges for consideration in this Position Paper and ultimately in a coordinated Oceans and Human Health Research Programme. These challenges were translated in research which are questions listed in Information Box 1.2 below and further discussed in more detail in the following chapters together with the related policy drivers.

INFORMATION BOX 1.2.
Key research questions for consideration in an Oceans and Human Health Research Programme

1. Can we demonstrate associations between ecosystem health and human health?
2. How does climate change impact on health and what are the public health consequences?
3. How do adverse natural events (such as earthquakes, volcanic eruptions, flooding, tsunami, severe storms) impact on public health?
4. How does eutrophication from land-based nutrient influx impact on seafood security and safety?
5. How do harmful algal blooms (HABs) and other biogenic toxins cause direct-contact toxicity and impair seafood safety and other impacts on human health?
6. What are the transmission routes and public health consequences of pathogens (helminths, protozoans, bacterial, rickettsial and viral)?
7. Are there negative impacts of aquaculture on the environment and public health?
8. Are there risks from contamination of seawater and seafood by micro- and nanoparticles and conventional chemical pollution, including complex mixtures?
9. What are the risks from radio-nuclides, including direct risks and food safety and security as a result of the expansion of the nuclear energy industry?
10. Are there common pathways for transport and uptake of pathogens and chemical/particle pollutants?
11. What are the impacts of food safety and food quality (nutritional components)?
12. Can problems with food security (over-exploitation, environmental degradation and biodiversity loss; reduction in adaptive capacity through loss of genetic diversity) be effectively managed to prevent loss of biological resources (fisheries)?
13. Does proximity to the seas and coasts have health benefits? - the so called “Blue Gym” effect
14. Can environmental, social and economic interactions (quality of governance, pressures from coastal zone overpopulation and sustaining critical coastal ecosystems) be predicted?

1.3 Policy context

Oceans and human health research not only covers a wide range of scientific domains, but also touches upon many different policy areas. A complex set of EU Policies and regulations relevant in this context are currently in place. Some are entirely oriented towards the marine and coastal environment while some are not specifically focused on seas and oceans but are partly or indirectly relevant.

At the core of these policies is the EU Integrated Maritime Policy (IMP), adopted in 2007, which aims to stimulate the development and management of sea-related activities in an integrated and sustainable manner. The IMP was initiated recognizing the need for an integrated ecosystem-based approach to reduce environmental pressures, and constitutes an important step forward in developing a more coherent approach to managing maritime activities across a range of sectors and policy areas. It provides a powerful framework which is in line with the integrated approach necessary to better understand and manage the intricate relationship between the oceans and people's health. The IMP provides an overarching maritime policy framework within which further more focused policy instruments are supported. These include the Marine Strategy Framework Directive (2008), the European Strategy for Marine and Maritime Research (2008), Marine Knowledge 2020 (2012)[4], the Proposed Directive on a Framework for Maritime Spatial Planning and Integrated Coastal Zone Management (2012)[5]and the EU Blue Growth Strategy (2012)[6].

The environmental pillar of the IMP, the Marine Strategy Framework Directive (MSFD), offers a suitable operational policy framework for developing a coordinated and science-based approach to elucidate and better manage the relationship between oceans and human health. The MSFD came into force in June 2008 and recognizes that the seas and oceans are complex but entirely interconnected environments, and that activities such as fisheries or dredging will have impacts on the whole ecosystem rather than on individual parts of the ecosystem or restricted only to the location of that activity. The MSFD is designed primarily to address the declining environmental health status of European marine waters and sets an ambitious target of "Good Environmental Status" of European marine waters by 2020. Good Environmental Status (or GES) will be measured according to eleven descriptors of "health", against which appropriate indicators and targets must be developed for specific marine regions identified in the Directive. While all of these targets have relevance to human health, the health and well-being of coastal populations is not directly addressed by most of them (save for the threats to human health posed by contaminated seafood).

The regional sea conventions such as OSPAR and HELCOM have also played, and will continue to play, an important role in terms of monitoring and protecting the European marine environment at the level of the European Sea Basins. In terms of protection of human health, a number of Directives are applied across the EU for particular stressors. For example, the Bathing Water Quality Directive[7] focuses on water quality in the context of pathogens while the Shellfish Directive[8] focuses on the quality of the shellfish growth conditions in EU coastal waters.

In relation to reducing pressures from overfishing, a landmark agreement between the Council of Ministers and European Parliament was reached in 2013 on the reform of the Common Fisheries Policy (CFP) which represents another major policy development. The overarching aim of the reformed policy is to end overfishing and make fishing sustainable. A key element of the policy entails the banning of discards to bring fish stocks above sustainable levels. The new policy enters into force on 01 January 2014 with a progressive implementation of the new rules.

[4] Marine Knowledge: http://ec.europa.eu/maritimeaffairs/policy/marine_knowledge_2020/index_en.htm

[5] Marine Spatial Planning and ICZM: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0133:FIN:EN:PDF

[6] Blue Growth: http://ec.europa.eu/maritimeaffairs/policy/blue_growth/index_en.htm

[7] EU Bathing Water Quality: http://ec.europa.eu/environment/water/water-bathing/index_en.html

[8] Shellfish Directive: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:376:0014:0020:EN:PDF

Other complementary policy efforts and legislation not specifically focused on the marine environment include the EU Water Framework Directive (WFD) and other freshwater legislation, the Habitats and Birds Directives, legislation to limit nutrient and waste water pollution inflows into EU coastal waters such as the Nitrates Directive[9] and the Urban Waste Water Directive[10], the EC Regulation on chemicals and their safe use (REACH legislation)[11] which entered into force on 1 June 2007 and the Stockholm Convention on Persistent Organic Pollutants (UNEP – POPs). In fact, given environmental degradation and human health are inextricably linked, all environmental policy and legislation is relevant to some extent and will need to be taken into account when considering policy options to improve the sustainability of human-sea interactions. This also encompasses wider policies and strategies in the area of Climate Change and Biodiversity (e.g. the EU Climate and Energy package and the EU 2020 Biodiversity Strategy).

Further policy priorities in the EU in the general area of environment and health policy have also been articulated within the EU Action Plan on Environment and Health (Hester and Harrison, 2011), which covered the period between 2000 and 2010. Priorities with relevance to the marine environment include better understanding of the links between environmental quality and human health (particularly for vulnerable groups such as children), the development of tools to better characterize causal links (e.g. environmental health indicators, biomonitoring approaches) and the need for integrated monitoring approaches for the environment (including food), to allow the determination of relevant human exposure. Endocrine disruption is a specific area where more information is needed, as are the effects of chemical mixtures in the environment (Howard, 1997; Kortenkamp & Altenberger, 1998).

Most of the above mentioned policies and regulations are addressed individually where appropriate throughout this position paper. However, as much as there is a need for integration of the oceans and human health science, there is a need to further consider and address policy developments in an integrated way. Unfortunately, the list of relevant regulations and policies is as long as it is diverse and has not previously been considered in a holistic way.

One of the first steps ahead would therefore be to perform a thorough analysis of the various policies and legal instruments which have a bearing on the complex relationship between our marine environment and human health, to identify weaknesses, gaps and overlaps, and consider mechanisms to strengthen their interactions to improve effectiveness.

1.4 Towards a European Research Programme on Oceans and Human Health

It is clear that there is a complex but important relationship between the marine environment and human health which raises many questions and challenges both for scientists and for policy makers. Moreover, policy makers will rely on scientific research and advice to develop a deeper knowledge and understanding of the cause-and-effect relationships between marine environmental health and public health in order to frame appropriate and effective policy responses. This is not a national or even a regional problem, but is in fact a major global issue that will require trans-

[9] See EU Nitrates Directive overview page: http://ec.europa.eu/environment/water/water-nitrates/index_en.html

[10] The Urban Wastewater Directive: http://ec.europa.eu/environment/water/water-urbanwaste/index_en.html

[11] The REACH Directive: http://ec.europa.eu/enterprise/sectors/chemicals/reach/index_en.htm

national solutions if the marine environment is to remain ecologically functional and economically sustainable (Figure 1.1; Bowen & Depledge, 2006; Fleming *et al*., 2006; Todd, 2006; Moore & Csizer, 2001).

These challenges have been recognized for many years in the USA. A symposium held in 1999 at the Bermuda Institute for Ocean Science entitled, "The Interaction between Healthy Oceans and Human Health," led to a later funding programme developed as a collaboration between the US National Institute of Environmental Health Sciences (NIEHS) and the National Science Foundation (NSF). This programme supported the establishment of four Oceans and Human Health research centres at the universities of Hawaii, Washington and Miami and the Woods Hole Oceanographic Institute. In addition, the US National Oceanic and Atmospheric Administration (NOAA) funded three of its own centres in Washington State, South Carolina and the Great Lakes (Depledge *et al,* 2013).

Europe on the other hand has failed to develop any form of dedicated or coherent Oceans and Human Health Research collaboration, instead dealing with specific issues in a compartmentalized way through individual projects supported by generalized funding programmes (e.g. environment and human health). Over the years, the Member Organizations from the European Marine Board have recognized that Europe must urgently address the many challenges faced by a large and growing coastal dwelling population, in maintaining and improving their safety, health and well-being. In order to provide strategic advice on the key scientific priorities which should form the basis of a coordinated collaborative research effort on Oceans and Human Health in Europe, the Board therefore decided in 2010 to convene an expert Working Group on this topic. The tasks of the Working Group were to:

- Highlight the critical importance of the marine environment for health and welfare of European citizens;
- Identify societal, environmental and biomedical challenges linking human health with the marine environment and marine processes;
- Review research and existing initiatives worldwide to provide a global overview;
- Encourage growth, development and facilitation of interdisciplinary, systems approach to Oceans and Human Health research and training to address real-world problems, not just in Europe but globally;
- Identify strategic areas in Europe for Oceans and Human Health and marine ecosystems and improve European competiveness in this field;
- Provide recommendations to guide European research and training in the medium-term (2020);
- Develop recommendations to foster the process of policy formulation through improved Knowledge Transfer (KT) and Knowledge Exchange (KE) in order to facilitate decision-making in marine environment and health;
- Summarize the findings of the Working Group in a European Marine Board Position Paper targeted in the first instance at those people who determine and set the research agenda, including research funding organizations, programme managers and science policy advisors/developers both at the national and European level.

A key message of this paper is that Oceans and Human Health research requires strategic prioritization and resource mobilization at both the European and national level. Key European programmes which have the capacity to support a major Oceans and Human Health initiative include **Horizon 2020**, the EU's next programme for research and technology development (2014-2020), and the **Joint Programming Initiative on Healthy and Productive Seas and Oceans (JPI Oceans)**.

INFORMATION BOX 1.3.
A brief history of Oceans and Human Health (OHH) Programmes and related activities in the United States

The complex but important relationship between the marine environment and human health has long been recognized as a priority area for research in the USA. Several science programmes from the mid-1970s up to the 1990s focusing on issues such as seafood safety, harmful algal blooms (HABs), toxicology and the use of aquatic organisms in health-related research paved the way for OHH research to be recognized as a metadiscipline in the USA. In the late 1990s through the mid-2000s, a spate of activities and publications further catalysed the creation of thematic OHH programmes in the USA.

The 1999 publication of the National Research Council's report, *"From Monsoons to Microbes: Understanding the Ocean's Role in Human Health"* can be considered as a key stepping stone in the advancement of an OHH research capacity. Concerns in the research and public health communities summarized in this report and the 2004 final report of the US Commission on Ocean Policy, resulted in establishment or enhanced development of Oceans and Human Health (OHH) programmes in the USA. Other NRC reports and a number of high level workshops provided additional momentum. For example, in December 2001, the National Science Foundation (NSF) and National Institute of Environmental Health Sciences (NIEHS) sponsored a community workshop followed by a joint request for proposals for the creation of academic centres of excellence in OHH. Shortly thereafter, the US Congress appropriated funding to the National Oceanic and Atmospheric Administration (NOAA) for establishment of its Ocean and Human Health Initiative (OHHI).

As a result of the initial efforts by NSF, NIEHS, NOAA, and others, in 2004 the USA developed a national network of seven competitively-funded OHH centres of excellence in academia and government. At the same time, the US Commission on Ocean Policy (USCOP), in its final report, called for the development of national research programmes in this arena. This prompted the US Congress to pass the Oceans and Human Health Act (OHHA), with the stated aim to "...improve understanding of the role of the oceans in human health." Subsequently, NOAA fully developed its OHHI and began concentrating on its three primary goals:

(1) development of early warning systems to forecast threats and predict long-term risks to human health throughout US coastal and Great Lakes waters;

(2) investigation of health benefits from the sea; and

(3) development of a robust OHH community working across disciplines and institutions to improve public health.

To stimulate the development of this interdisciplinary OHH research community, NOAA inaugurated its OHH Traineeship Programme in

2007- 2008 making awards specifically targeted to the interdisciplinary education and training of doctoral and post-doctoral scholars in OHH, as part of a long-term strategy to build a new cadre of OHH scientists.

The year 2008 also saw publication of the first OHH textbook for use in new academic courses in OHH, and the first Gordon Research Conference (GRC) and Graduate Research Seminar (GRS) devoted exclusively to the new OHH metadiscipline. These conferences have continued at regular 2-year intervals since, with the latest held in the summer of 2012, indicating strong community recognition of OHH as an important area of scientific inquiry and discovery. The next OHH GRC/GRS is being planned for the summer of 2014 and plans are already developing for an OHH GRC to be held in Europe in 2016.

Following more than a year of intensive interagency work, on 19 July, 2010, President Obama issued Executive Order 13547 to establish a “National Policy for the Stewardship of the Ocean, Our Coasts and the Great Lakes”, also referred to as the National Ocean Policy (NOP). The NOP references several OHH issues, such as HABs, pathogens, chemical contaminants, and disease, and uses the term “human health” 17 times. The first paragraph of the NOP states that “America’s stewardship of the ocean, our coasts, and the Great Lakes is intrinsically linked to environmental sustainability, **human health and well-being**, national prosperity, adaptation to climate and other environmental changes, social justice, international diplomacy, and national and homeland security.” Hence, linkages between oceans and human health are now firmly embodied in the ocean policy of the US.

The text in this information box is largely based on Sandifer *et al.* (2013). For additional information please consult:

- the website of NOAA’s Oceans and Human Health Initiative at http://oceansandhumanhealth.noaa.gov/
- the website of Woods Hole Oceanographic Institution (WHOI) on joint Centers for Oceans and Human Health (COHH) at http://www.whoi.edu/science/cohh/
- relevant pages of the National Institute of Environmental Health Sciences (NIEHS) at http://www.niehs.nih.gov/research/supported/dert/programs/oceans/index.cfm

1.5 About this Position Paper

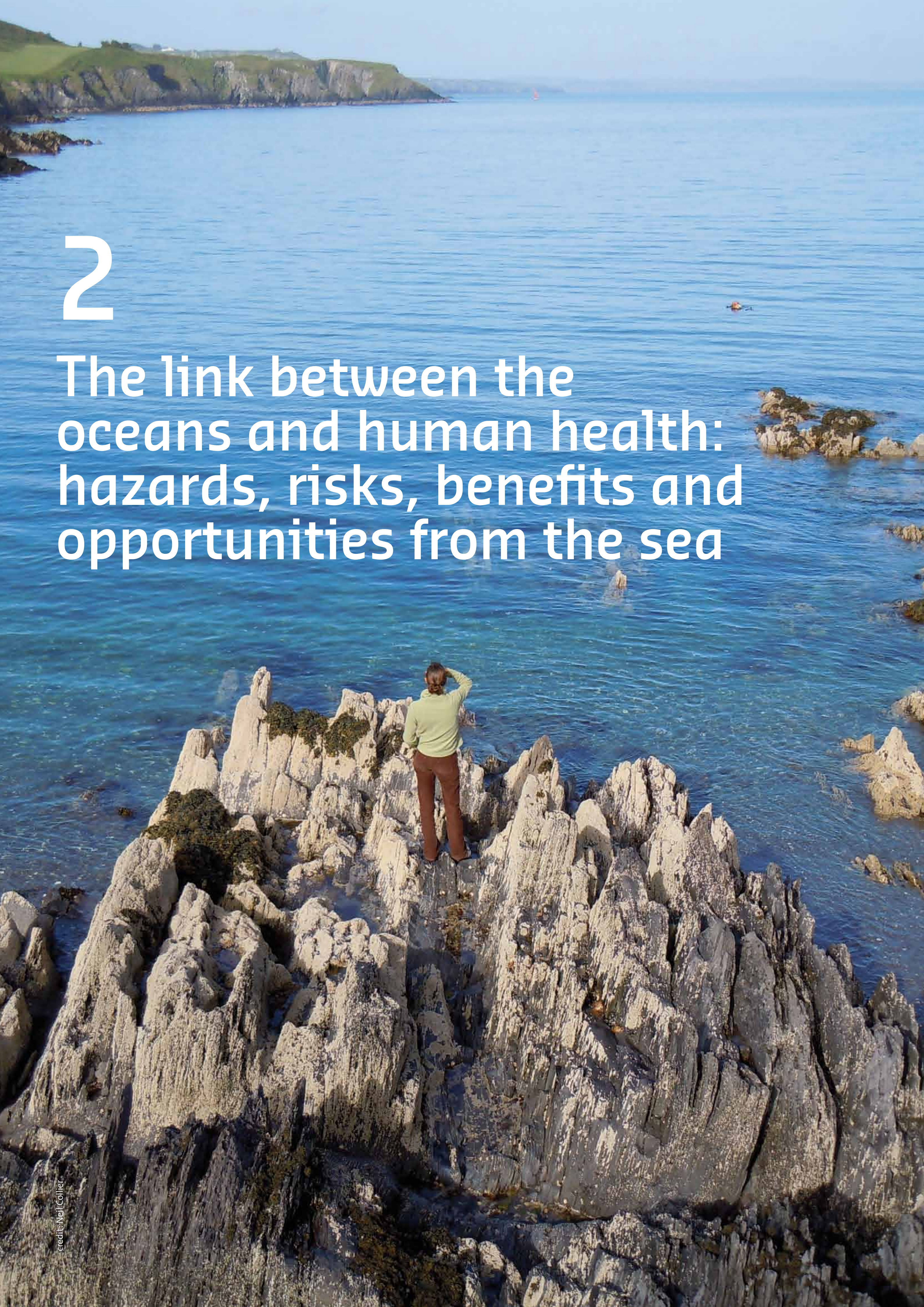
This Position Paper is not intended to be a comprehensive review of public health concerns connected to the marine environment which has already been covered in more detail by other sources and authors (Bowen & Depledge, 2006; Fleming et al., 2006; Roth & Rosenthal, 2006; Todd, 2006; McGlade, 2001). Rather, it is aimed at identifying critical scientific and policy challenges associated with the interconnection between the marine environment and public health. The following chapters will add detail to the questions outlined in Information Box 1.3, identifying some of the key societal challenges and related research questions. While much of the discourse concerning the relationship between oceans and human health has traditionally revolved around the risks and negative impacts of marine pollution, disease associated with marine-borne pathogens and harmful algal blooms, this paper also addresses some of the positive health benefits afforded to humans by the marine environment, including the "Blue Gym" effect (see Section 2.6). Chapter 2, therefore, provides an overview both of the emerging health benefits and opportunities of the oceans as well as the health hazards and risks they entail. Chapter 3 focuses on what can and should be done to address the public health challenges presented by the seas and oceans and includes an analysis of some of the tools and approaches that may help to meet the societal and scientific targets. Finally, Chapter 4 summarizes the recommendations of the Working Group which should form the basis of a future research programme on Oceans and Human Health.

FIGURE 1.4.
Man and Sea are inextricably bound
(Credit: Josef Stuefer / NWO)

FIGURE 1.5.
This position paper is aimed at identifying critical scientific and policy challenges associated with the interconnection between the marine environment and public health.

2

The link between the oceans and human health: hazards, risks, benefits and opportunities from the sea



credit: Neil Collier

2.1 Climate change, natural events and human health

Although the scientific validity of global climate change has been increasingly accepted within the international scientific community for several decades, other audiences (ranging from policy makers to the general public) have been less convinced. Moreover, there has been a relative lack of research into, and information about, the human health impacts of climate change. Over the past decade, there has been increasing attention paid to this issue, focusing on both direct and indirect health impacts and their consequences (McMichael, 2011; IWGCCH, 2010; Haines, 2009; Epstein, 2005; Haines, 2004; Bunyavanich, 2003).

It is now clear that the oceans are inextricably intertwined with both global climate change and its impacts on human health and well-being (Kite-Powell, 2008; Fleming, 2006a; Fleming, 2006b). Human populations are both moving to, and growing in, ocean, estuarine and coastal areas globally, particularly in developing nations. Consequently, there is an increased reliance on, and use of, these coastal resources, ranging from fishing and aquaculture activities to desalination for drinking water and recreational use of beaches and inshore waters. Therefore, not only are these coastal areas highly exploited, but there are increasing numbers of people depending on the coasts for their living place, food, and livelihood. This creates highly vulnerable populations in light of projected sea-level rises, temperature extremes, ocean acidification, and other potential effects of climate change.

The most obvious impact of global climate change on human health is from extreme weather events such as cyclones which, as a result of climate change, appear to be increasing in both incidence and intensity and with variable predictability. While frequently attracting disproportionate media attention, such events can still cause significant ecological damage and impact severely on human health in affected locations (UNISDR[12]; Population Reports, 2000).

Recently, Hurricane Katrina (August 2005), the Burmese cyclone (May 2008) and Hurricane Sandy (October 2012) have demonstrated that coastal populations, particularly of socially deprived groups in both developing and developed nations, are highly vulnerable to the morbidity and mortality associated with extreme coastal events. The 2004 Indian Ocean tsunami killed more than 230,000 people in 14 countries. The health impacts of such major events can be acute (e.g. trauma, drowning, starvation, water-borne and vector-borne diseases) and are often followed by more chronic issues such as mental illness, malnutrition and population migration, which can last for years (Berry *et al*., 2010). Improvements in modelling capabilities coupled with remote-sensing should help to provide better early-warning capacity in the future.

Sea-level rise, another major impact of global climate change, is also likely to impact in significant and complex ways on the health and well-being of coastal populations, particularly those in low-lying coastal zones. At the most basic, physical level, the extent of sea-level rise predicted by the Intergovernmental Panel on Climate Change (IPCC, 2013) will cause substantial disruption of coastal infrastructure, ranging from ports to sewage treatment plants to housing. At the same time, sea-level rise and ocean acidification are expected to impact on coastal fisheries owing to direct and indirect destruction of habitats and nursery grounds, leading to decreased nutritional and occupational opportunities in coastal communities. As sea levels rise, the freshwater supplies of many coastal communities will become contaminated with salt water, rendering them unusable or only usable with expen-

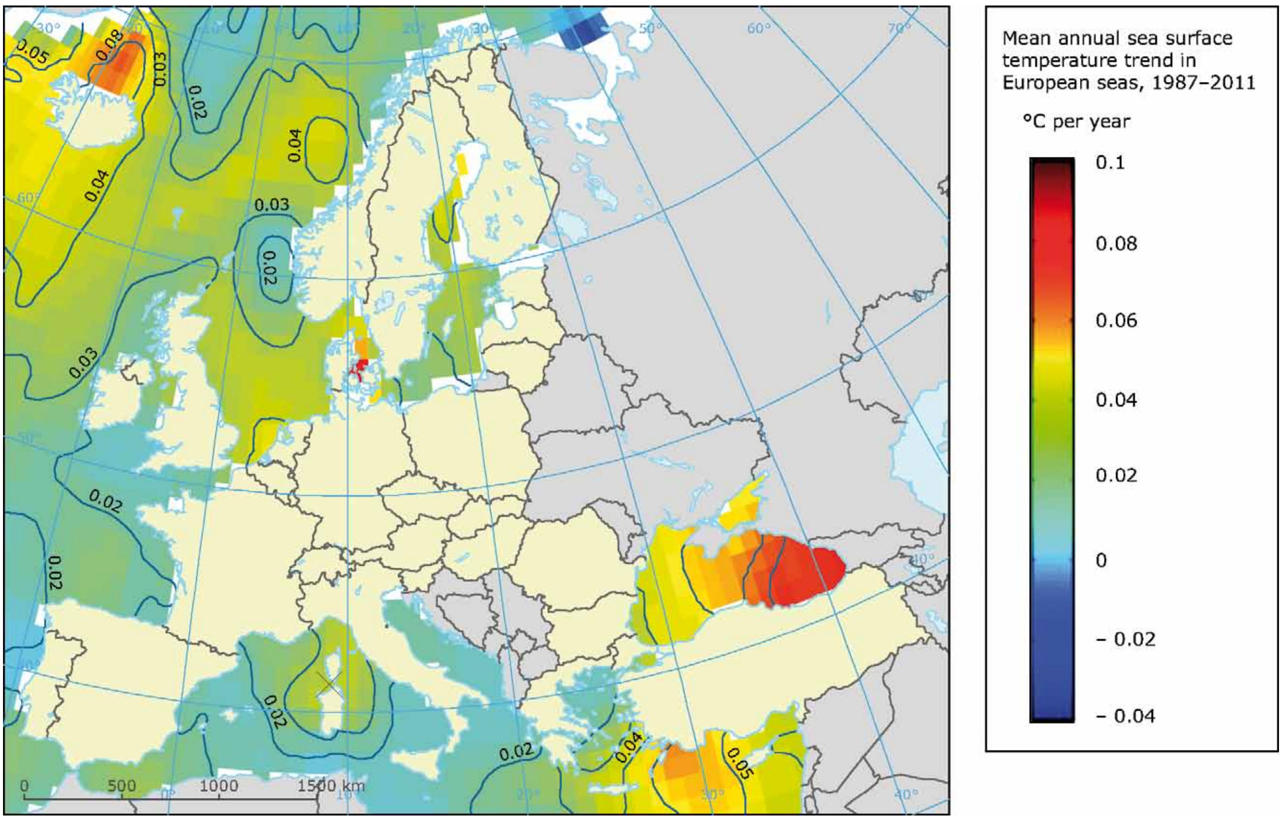
[12] United Nations International Strategy for Disaster Reduction (UNISDR)
www.unisdr.org

sive desalination procedures. Some indirect health impacts may also arise through the release of toxic waste and human pathogens from inundation of coastal landfill sites, agricultural land, and disturbance of estuarine sediments (Population Reports, 2000; Zhou *et al*., 1998, 1999).

Another key climate change impact concerns that of **rising water temperatures** in the marine environment. Rising water temperatures are already having a significant impact on the marine environment which will ultimately have implications for human health. Changes in the distribution of fish stocks will have direct impacts on coastal fisheries and hence human livelihoods and diet. Harmful algal blooms (HAB) are also projected to increase in frequency and intensity, in part due to the increasing temperatures (caused by climate change), and in part due to the increased microbial pollution from coastal populations and the resulting nutrient load. This will lead to acute and chronic illness in humans and other organisms associated with exposure to seafood, water and marine aerosol contaminated with the potent natural HAB toxins and microbial pathogens, leading to additional threats to the nutrition and occupations of coastal communities (Moore, 2008). Further discussion of the human health implications of HABs is included in section 2.4.

FIGURE 2.1.
Satellite pictures of the coast of Bandah Aceh before (top) and after the tsunami struck (bottom) on 26 December 2004 (©digiglobe)

Figure 2.2.
Spatial distribution of sea surface temperature trend over the past 25 years (1987-2011) for the European seas as calculated from the HADISST1 dataset. (Credit: Instituto Nazionale de Geofisica e Vulcanologia (INGV)).



Thus, increasing water temperatures caused by climate change may have negative implications for marine organisms and human health, but may also have some "positive" effects. There is growing evidence, for example, that increasing temperatures may reduce the toxicity of organic pollutants such as pesticides, pharmaceuticals and aromatic hydrocarbons, in turn reducing their environmental impacts (Lartigues & Grarrigues, 1995; Kitts *et al*., 1992). With increasing water temperatures, numerous organic xenobiotic chemicals may be more rapidly "aged" by oxidation in the environment or in living organisms. However, the resulting degradation products may represent an additional problem at the environmental level. In some cases, they may become less toxic (reduced bioavailability, higher excretion level from the organisms), but may also represent compounds capable of interacting with genetic material at a nuclear level. This interaction may lead to DNA strand breaks and to the formation of micronuclei due to chromosomal damage (i.e. the chemicals may be transformed into substances able to stimulate / participate in tumour genesis). In addition to this, temperature increases may also render some inorganic chemicals and non-degradable organic contaminants more toxic (Gomiero *et al*., 2012; Negri *et al*., in press). This complex antagonism between the positive and negative effects of increasing water temperatures requires significant further research, not least to assist in the generation of more accurate predictions on the future consequences of climate change in the marine environment and the implications for human health.

TABLE 2.1.
The potential impacts of climate change on human health and their potential connections to the oceans.

Direct Connections
Weather-Related Morbidity & Mortality
Mental Health and Stress-Related Disorders
Waterborne Diseases
Foodborne Diseases & Nutrition
Indirect Connections
Heat-Related Morbidity & Mortality
Vectorborne & Zoonotic Diseases
Asthma, Respiratory Allergies, & Airway Diseases
Neurological Diseases & Disorders
Unclear Connections
Cancer
Cardiovascular Disease & Stroke
Human Developmental & Reproductive Effects

2.2 Marine chemical polution

Marine coastal environments are characterized by the presence of different pollutants originating from terrestrial, atmospheric and marine sources (Islam & Tanaka, 2004). Human-produced chemical inputs to coastal waters include industrial, domestic and agricultural nutrients, pesticides, road run-off, personal care products, disinfectants, pharmaceuticals and novel chemicals. It is clear that monitoring and controlling chemical pollution in marine ecosystems is a critical issue for sustainable environmental management, particularly in light of the EU Marine Strategy Framework Directive (Directive 2008/56/EC). To date, the monitoring of European seas has been based primarily on the measurement of chemical concentrations in water, sediments and biota (Roose *et al.*, 2011). However, in practical terms, complete screening of chemical contamination is not possible. There are about 100,000 chemicals produced for sale in Europe, of which about 30,000 have a production volume of higher than one tonne per year and have been on the market for more than 20 years (Roose *et al*., 2011). The list of substances classified by the American Chemical Society as toxic includes more than 282,000 compounds (CAS, 2011). Yet, the number of chemicals normally analyzed during characterization campaigns is around 100-120 compounds.

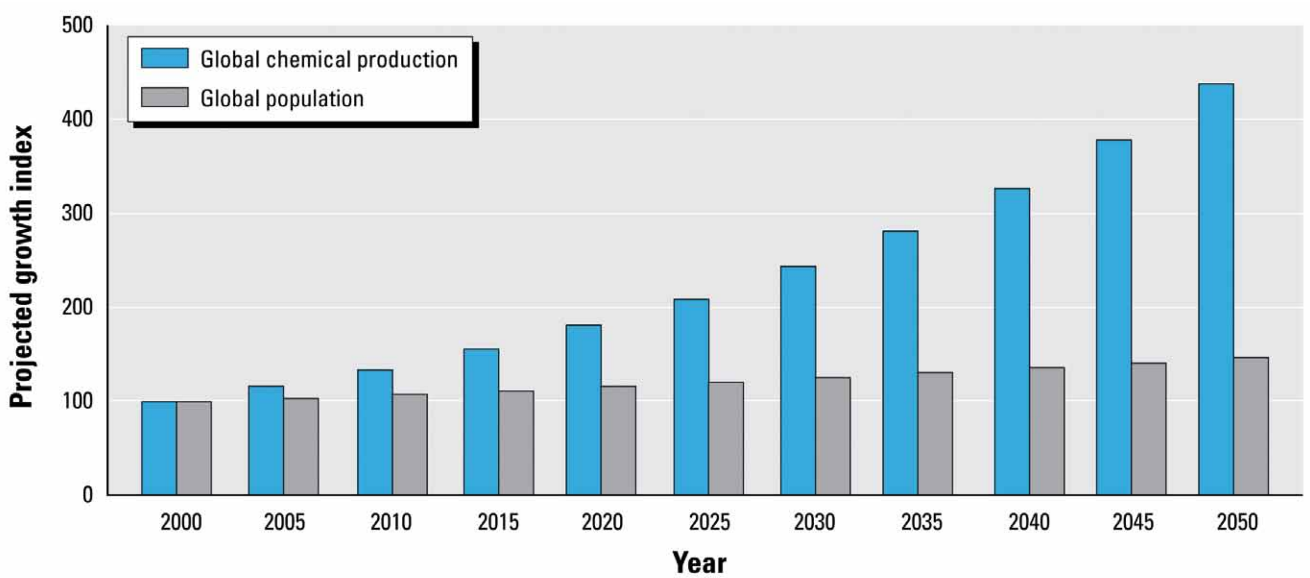


FIGURE 2.3
Global chemical production is projected to grow at a rate of 3% per year, rapidly outpacing the global population growth. On this trajectory, chemical production will double by 2024, indexed to 2000. (From Wilson and Schwarzman, 2009)

The reliability of the chemical approach in the assessment of marine ecosystem quality is also questionable because monitoring of chemical concentrations alone provides little information on the ecosystem effects of chemical pollution (Roose *et al.*, 2011). Furthermore, toxicity resulting from interactions among chemicals in a pollutant mixture (e.g. additive, antagonistic, synergistic, etc.) is only partially estimable from analytical data (Jonker *et al.*, 2005). Chemicals entering seawater and accumulating in the sedimentary compartment undergo different chemical-physical processes able to alter their molecular structure and their toxicity (Jonker *et al.* 2006, Pempkowiak *et al.*, 1999). Moreover, sediments are a key matrix to assess the impacts of contamination in marine coastal environments. In fact, many pollutants can be sequestered in the sedimentary matrix as a result of environmental processes driven by different factors (i.e. pH, redox potential, oxygen concentration, temperature, etc.), by forming insoluble or poorly soluble compounds, or by adsorbing onto suspended particles (Chapman & Anderson, 2005). The levels of pollutants in marine sediments can be considerably higher than those detected in the water column, where contaminant concentrations are often near analytical detection limits (Zoumis *et al.,* 2001). However, the resuspension of sedimentary particles due to the mechanical action of waves and currents as well as human activities such as sediment dredging can lead to the mobilization of pollutants accumulated in sediments towards the water column, with consequent impacts on biota (Eggleton & Thomas, 2004).

The real ecosystem impact of chemical pollution can only be properly determined by coupling exposure (i.e. chemical concentrations) and effects (i.e. ecotoxicological tests), allowing increased reliability in the determination of risks due to contamination (Lyons *et al.,* 2010; Chapman, 2007). Although some studies exist, there is still a significant, but scientifically challenging, lack of understanding of the interactions between various environmental stressors and their ecological consequences. A major challenge in impact and risk assessment as part of environmental management is to link harmful effects of pollution (including toxic chemicals) in individual sentinel animals to their ecological consequences (Moore *et al.*, 2004). Part of the solution may lie with the use of diagnostic, clinical-type, laboratory-based ecotoxicological tests or biomarkers (e.g. Rapid Assessment of Marine Pollution, RAMP; Depledge, 2000), utilizing sentinel animals as integrators of pollution, coupled with direct immunochemical tests for contaminants. These rapid and cost-effective ecotoxicological tools can provide information on the health-status of individuals and populations based on relatively small samples of individuals. In the context of health of the environment, biomarkers are also being used to link processes of molecular and cellular damage through to higher levels (i.e. prognostic capability), where they can result in pathology with reduced physiological performance and reproductive success.

FIGURE 2.4.
Mussels are often used to measure the biological effects of pollution in the marine environment. The IMW (International Mussel Watch) for example, actually started in 1991-1992, but data were already available since 1965 from earlier programmes. Left: mussels in monitoring cage (© Karen Rappé / Inram). Right: marine blue mussel, *Mytilus edulis,* showing some of the inner anatomy (©Rainer Zenz)

Complex issues are involved in evaluating environmental risk, such as the effects of the physico-chemical environment on the speciation and uptake of pollutant chemicals and inherent inter-individual and inter-species differences in vulnerability to toxicity (Moore *et al.*, 2004). Effectively linking the impact of pollutants through the various hierarchical levels of biological organization to ecosystem and human health requires a pragmatic integrated approach based on existing information that either links or correlates processes of pollutant uptake, detoxification and pathology with each other and with higher level effects (Moore *et al.,* 2011).

Generic quantitative models may provide a partial solution to the problem of predicting the dynamics and risk of adverse impacts of chemical pollutant stressors through the development and implementation of computational models. Such models could be used to simulate pollutant pathways in the human food chain, and could be adapted to investigate environmental transport of human pathogens and their viability, and the interactions between pollutants and microbial populations that may lead to increased biogenic toxin production. The kinetics and dynamics of harmful carcinogenic and toxic chemicals in fish and shellfish species that are harvested for human consumption could also be characterized and modelled, as could pathological reactions (molecular to tissue level) to known pollutants and potentially hazardous novel particles, chemicals and radionuclides. The systems approach is essential if we are to effectively interpret reductionist chemical and biological data in a meaningful holistic context for prediction of risk to consumers of seafood and recreational users of the marine environment. This step is necessary to ensure that the social and economic implications of reductionist chemical and biological data are understood, and to encourage the application of these data in an environmental management context.

This approach will allow us to explore the use of measures of environmentally induced pathological deterioration in flesh quality or "health status" of seafood, particularly filter-feeders (bivalves) and bottom-dwelling fish, due to pollutants or pathogens, as predictors of risk to human health. A methodological co-evolutionary "synthesis through modelling" approach will facilitate targeted experimental design and field sampling, as well as the effective integration of multiple environmental datasets and their subsequent interpretation. This synthesis is viewed as a crucial step towards the development of explanatory frameworks for prediction of outbreaks of human pathogen-related diseases, potential for low-level chronic exposure to biogenic and anthropogenic chemical contaminants, as well as environmental impact on animal health status as a surrogate measure for human health risk. Therefore, the novel use of biogeochemical and molecular measurements of pollutant kinetics and dynamics, high-throughput molecular methods for tracking pathogens and determining their viability, and new probes for molecular, cellular and tissue pathological reactions to environmental stressors, coupled with simulation modelling, is proposed as a practical step in the development of a pre-operational toolbox. The overall goal should be to provide a toolbox that will facilitate an environmental management regime that maintains both food security and appropriate public health management for human use of the marine environment.

As mentioned above, sediment management is a key issue in marine coastal policy due to the large amount of material collected during maintenance dredging from harbours, estuaries and channels. The development of an objective framework to correctly support decision-making in planning the re-use or remediation of collected materials, allows for a clear improvement in environmental management in the light of sustainability as requested in the framework of MSFD (Directive 2008/56/

EC). The role of such decision support systems is to objectively integrate chemical and ecotoxicological data into numerical indices useful in supporting decision-makers in managing contaminated marine coastal sediments and, eventually, in planning the necessary remediation activities.

Chemical contaminants remain high on the agenda of environmental threats due to emerging pollutant issues such as changes in environmental burdens and effects of contaminants with climate change, and better-known substances with "new" mechanisms of action (endocrine disruption, reproductive and developmental toxicity). The next steps necessary for a correct application of approaches in the monitoring, study and management of contamination in marine and coastal areas entail the definition of a set of bioassays[13] (or bioassay battery) to be applied in marine coastal studies as well as the definition of common Environmental Quality Standards for the most diffuse pollutants throughout Europe.

INFORMATION BOX 2.1.
Criteria for the selection of appropriate components of bioassays for reliable determination of the biological effects induced by pollutants

To guarantee a complete and reliable determination of the biological effects induced by pollutants, the selection of a set of bioassays (or bioassay battery) should take into account the following criteria:

- Acute and chronic tests should be balanced, the former being useful to gain a rapid understanding of the sediment hazard to the biota and the latter, being more sensitive, are also able to underline cases where long-term effects are present;
- The selection of model organisms should consider the composition of the community under study and, in particular, the food-web in the area e.g. grazing food web in the water column and detritus food web in the sedimentary compartment; the effects of pollutants on developing embryos should also be evaluated;
- The ecotoxicological battery should include some sub-lethal biomarkers capable of describing the stress syndrome evolution in the model organisms and objectively assessing the biological vulnerability of the system: this offers an insight into the potential risk to biota;
- The use of particular core biomarkers, such as genotoxicity biomarkers, endocrine disruption parameters, immunotoxicity and bioaccumulation of pollutants in marine organisms for human consumption, is a key recommendation to link environmental risk with human health hazard.

Radionuclides

There are many ways in which the public may be exposed to human-generated and naturally occurring radioactivity. Within the EU there are numerous nuclear facilities which produce waste. Such facilities include power stations, hospitals, defence manufacturers and reprocessing plants. Disposal of the waste from those operations into the environment may be made under licence and results from monitoring such discharges have been assessed (e.g. European Commission 2002, 2010). The EC has embraced the concept of protecting those people who are potentially most

[13] Bioassay, commonly used as shorthand for biological assay, is a type of scientific experiment typically conducted to measure the effects of a substance on a living organism. Bioassays are essential in the development of new drugs and in monitoring environmental pollutants.

exposed, the so-called 'Critical Group' or 'Representative Group'. Increased exposure may occur through the consumption of contaminated seafood and occupancy of intertidal areas e.g. house boat dwelling or bait digging. These pathways may be additive and are usually assessed by the use of site-specific habit surveys (Leonard, 2012).
Without doubt, the most significant sources of radionuclides entering the sea from authorised discharges occur from reprocessing plants e.g. Sellafield (UK) and La Hague (France). Smaller contributions are made from nuclear power stations, hospitals, defence facilities, and have resulted from nuclear bomb testing during 1950s and 1960s and the Chernobyl accident in 1986. In addition, the public may be also exposed to naturally occurring radionuclides.

The EU has encouraged decreases in discharges from nuclear sites and national governments have made commitments towards progressive reduction of human exposure to ionising radiation arising from radioactive discharges. On the basis of these commitments, a representative member of a critical group of the general public should not be exposed to more than 0.02 millisieverts (mSv) per year from liquid radioactive discharges to the marine environment made from 2020 onwards. However, the way that the public is protected depends on the knowledge available and the interpretation of such information. Over the years many studies have assessed the significance of such pathways and there is a need to continue such work. Future studies should include sufficient focus on (i) programme design; (ii) sampling and *in situ* measurement; (iii) laboratory analysis; (iv) description of the pathways to humans; (v) radiation dosimetry; and (vi) calculational and presentational error.

Developing a clearer understanding of the pathways of radioactive contamination from the marine environment to humans should form a key component of a coordinated European research effort on oceans and human health.

2.3 Material pollution, including marine litter and nanoparticles

Marine Litter

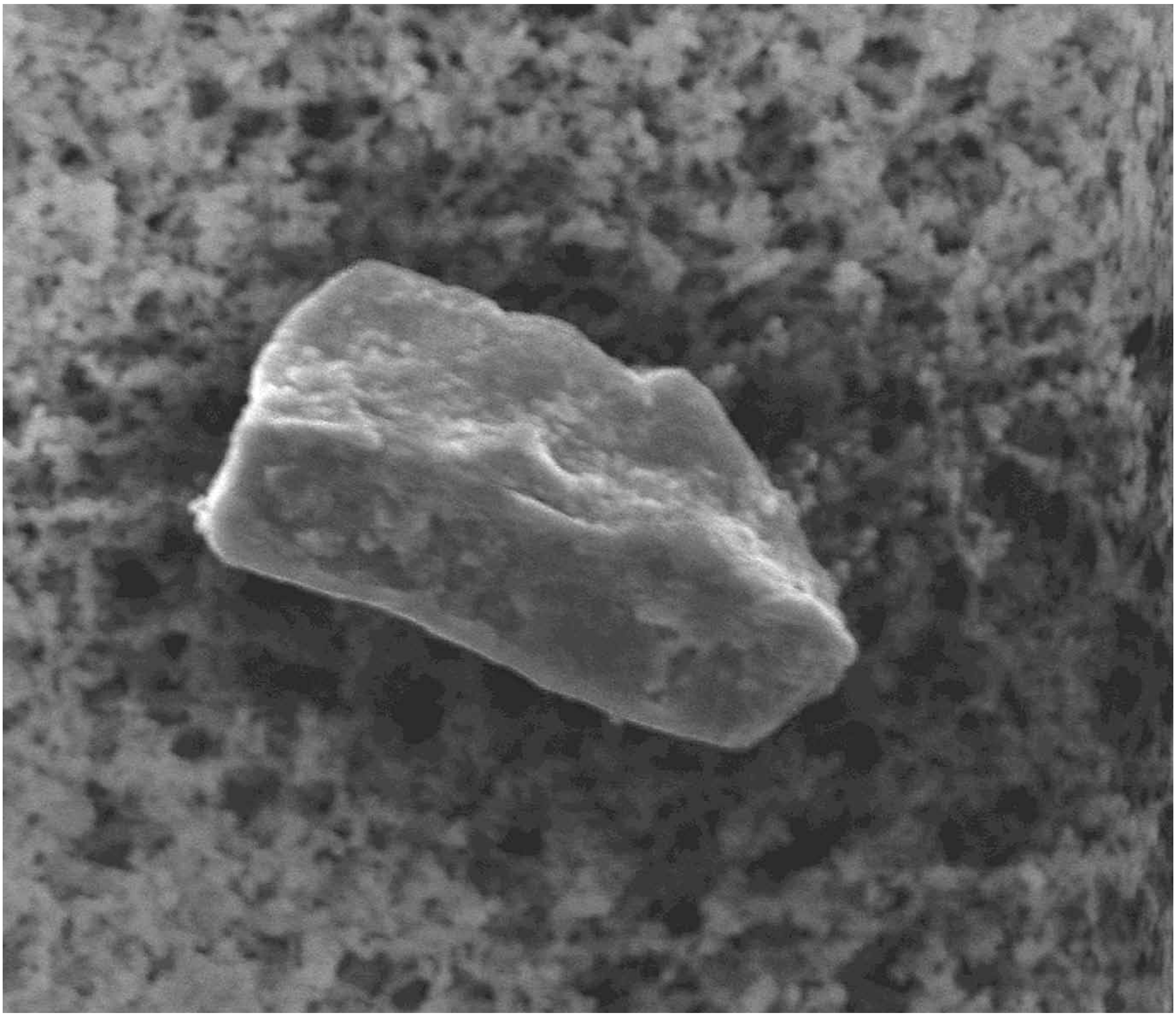
Marine litter, which consists of persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine environment (Galgani *et al.,* 2010), has been considered to represent an increasing pollution problem since the end of the 1960s. However, only in the last two decades has it been recognised that marine litter, most of which is plastic residues, represents a major problem for marine ecosystems, especially in coastal areas (Carpenter *et al.*, 1972). Global production of plastics (synthetic organic polymers) has risen in the past 30 years and this has coincided with a proportional increase in the levels of plastics pollution observed in all components of the marine environment. In benthic sediments the presence of plastic particles can affect gas exchanges between the water column and interstitial water in the sediments which can reduce the oxygen concentration and affect ecosystem functioning (Goldberg, 1994).

Recent reports demonstrate that at least 267 marine species are adversely affected by plastic contamination. Ingestion of plastics by marine organisms is known to affect their physiology. As far back as 1997, Laist (1997) identified that floating macroplastics (> 5nm) affect 86% of all sea turtle species, 44% of all seabird species, and 43% of all marine mammal species. Experimental and field studies have demonstrated that plastics ingestion may reduce food consumption in seabirds, thus reducing fat deposition and consequently their fitness and reproductive effort (Gramentz, 1988; Moser & Lee, 1992). Physical entanglement in plastic debris can also cause death in marine animals (Schrey & Vauk, 1987; Connors & Smith, 1982). While we have some insight on the impacts of plastics pollution on various species of fish, birds (Figure 2.5), and mammals (Azzarello & Van-Vleet, 1987), little is known about the possible effects on invertebrates and microorganisms (Ryan, 1987).

FIGURE 2.5.
Plastics ending up in the coastal and marine environment are commonly ingested by birds, sometimes leading to death of the animals (top: seagulls may ingest plastic from their environment - Credit: Neil Collier -; bottom: A decaying sea bird carcass with plastic debris in its stomach – Credit: Chris Jordan)

In recent years it has been found that in the marine environment (in the surface and the water column as well as in the sediments even of deep sea environments) plastics are increasingly present as "microplastics," also called "plastic dust," i.e. plastic fragments of a diameter less than 5mm (Secchi & Zarzur, 1999; Spear *et al.,* 1995). Microplastics are accumulated in marine organisms including invertebrates such as polychaetes, crustaceans and molluscs (Coleman & Wehle, 1984). It has been demonstrated that mussels exposed to microplastics (<1mm) accumulate particles in the gut and that during the detoxification period, the particles move to the circulatory system for approximately three days but persist in the haemolymph for more than 48 days (Browne *et al.*, 2008). In a recent investigation by the University of Ghent, mussels retrieved from the North Sea contained about one particle of microplastic per gramme of tissue. Particles can enter the human blood circulation and can even be transferred through the placenta after consumption of mussels with microplastic contaminants (Claessens *et al.,* 2013, *in press*).

FIGURE 2.6.
Scanning electron microscope (SEM) image of a microplastic particle recovered from deep-sea sediments in the Atlantic Ocean (scalebar represents 100µm; credit: Colin R. Janssen)



Because of their surface physical-chemical characteristics, plastics are able to absorb organic lipophilic xenobiotic compounds. With their higher surface-to-volume ratio, microplastics provide a medium for the transfer and accumulation of persistent organic pollutants (POPs) such as Polychlorinated Biphenyls (PCBs) and Polycyclic Aromatic Hydrocarbons (PAHs) in the tissues of marine organisms with potential consequences for both environmental and human health (the latter in the case of ingestion of contaminated seafood) (Ryan *et al*., 1988). Data have also been reported on the role of plastics in assisting invasion of alien species (Irish & Norse, 1996).

Nanoparticles

The toxicity of a new class of emerging contaminants called nanoparticles, i.e. particles with a size ranging from 1nm to 100nm in at least one dimension, is based not only on their chemical composition but on their physical characteristics of shape and size (SCENIHR, 2005, Joner *et al.,* 2007, Moore M.N., 2006). Nanoparticles (both inorganic and organic) have been shown to be toxic for animals (Novack *et al*., 2007), plants (Daohui *et al*., 2007) and microbes (Novack *et al*., 2007; Jingyuan, 2007; Handy R.D. *et al*., 2008). Usually nanoparticles are assumed in the animals' cells by phagocytosis. In the cytoplasm they may alter the functions of different organelles, thus affecting the cell physiology (Heilaan *et al*., 2008). This may reduce the survival and/or the reproduction rate of the organisms (Singh *et al*., 2010). Effects at nuclear level have been also well established (Reeves, *et al*., 2007). The level of nanoparticle-induced stress in the different organisms may greatly vary for different types of nanoparticles depending on their composition, dimension and shape. For inorganic nanoparticles, often the inorganic ions released in the external medium or in the cytosol of the cells contribute to their toxicity (Bystrzejewska-Piotrowska *et al*., 2009; SCENIHR, 2005).

Nanoparticles may reach the marine environment both through direct release into coastal waters or as an input from riverine and estuarine inflows. They may also be transported in the air and enter the marine system through the air-sea interface (Handy R.D. *et al*., 2008). Due to extensive industrial use, nanoparticle contamination is now widespread in the marine environment and their number of particle types has rapidly increased from fewer than 10 a decade ago to more than 1200 today. It is increasingly clear that nanoparticles represent an important problem in terms of biological effects at the ecosystem level and on human health.

On the basis of chemical composition they are categorized as organic nanoparticles, such as C90 carbon nanotubes (CNT), and inorganic nanoparticles containing cations, such as Ag, Cu, and Ti (Joner *et al*., 2007). However, the number of particles characterized by an inorganic core and an organic envelope has rapidly increased in recent years.

Various methods have been used to identify and characterize nanoparticle contamination in the marine environment and in marine organisms. In purified preparations, the location and the shape of nanoparticles may be determined using techniques such as Transmission Electron Microscopy (TEM) or Scanning Electron Microscopy (SEM) (Rose, 2007). In the presence of nanoparticles which have an inorganic core, Energy-dispersive X-ray spectroscopy (EDX) may allow for the identification of the elemental composition. Atomic Force Microscopy (AFM) has been also used in the analysis of nanoparticle sizes and shape and their surface charge measured as Zeta potential (Rose, 2007).

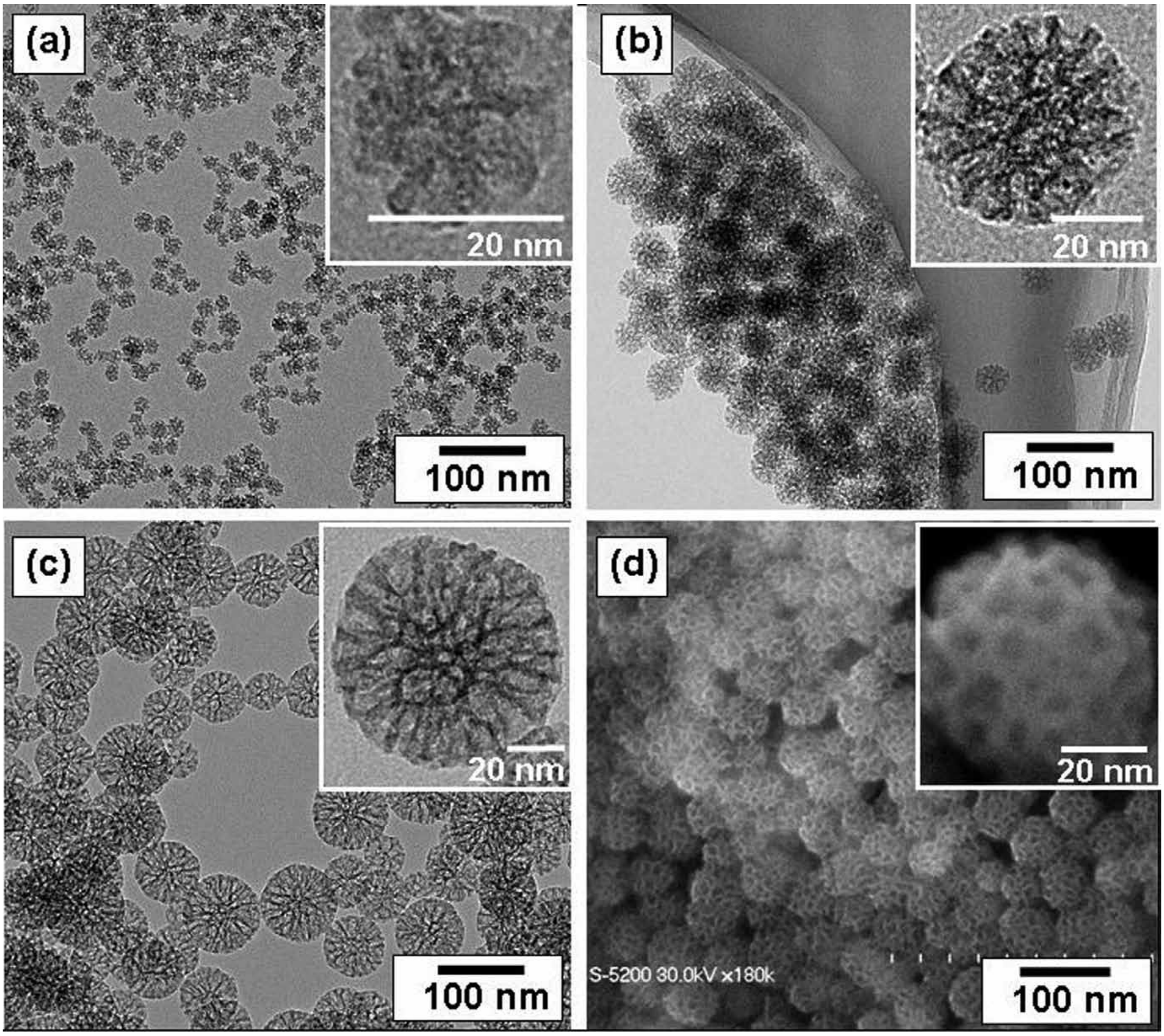


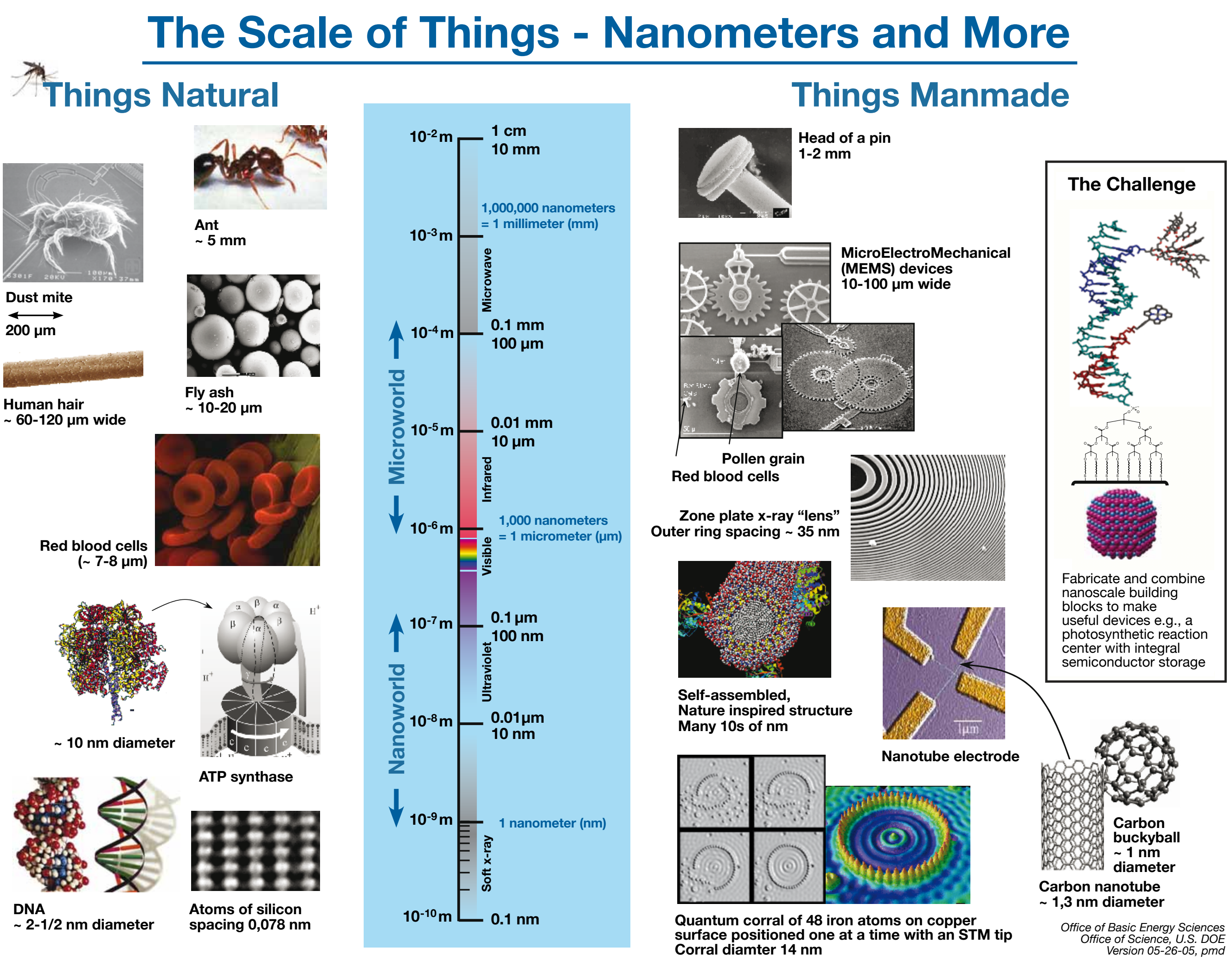
Figure 2.7.
Transmission electron Microscopy (TEM) (a, b, and c) images of prepared mesoporous silica nanoparticles with mean outer diameter: (a) 20nm, (b) 45nm; and (c) 80nm. SEM (d) image corresponding to (b). The insets are a high magnification of mesoporous silica particle (© Nandiyanto)

The detection of inorganic nanoparticles in environmental matrices and in wild organisms could be achieved using methods such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) which is used to identify metal/compound concentrations. However, the levels of different metals cannot solely be attributed to nanoparticle contamination (Novack *et al.,* 2007). The detection and quantification of carbon-based nanoparticles in marine organisms may be even more difficult. Fullerene[14] nanoparticles may be extracted from environmental matrices using organic solvents and then analysed by fractionation using High-Performance Liquid Chromatography (HPLC) coupled with a UV detector (Fortner *et al*., 2005) or electrospray Time-of-Flight Mass Spectrometry (TOF MS) (Kozlovski *et al*., 2004). CNT may be detected with UV-vis spectrometry (Jiang *et al*., 2003) and more recently by RAMAN spectroscopy (Xue *et al*., 2012). However, while the above methods detect nanoparticles in the tissues of different organisms and prove the presence of these contaminants, they do not allow for quantification of the amount of nanoparticles accumulated in the organisms.

[14] Composed entirely of carbon, in the form of a hollow sphere, ellipsoid or tube.

Finally, research has identified that organic nanoparticles, with their lipophilic nature, usually represent a sink of organic pollutants such as Aromatic Polycyclic Hydrocarbons, Polychlorinated biphenyls (PCBs) and dioxins (Pulskamp *et al*., 2006). On the other hand, inorganic nanoparticles tend to release their metal content (Pokhrel *et al*., 2009) into the environment and in the tissue of an organism (Soenen *et al*., 2010). Taking this into account, the best way to study the biological risk of contaminants is to associate chemical data with studies of the biological effects of the total amount of contaminants bioavailable to the organisms.

FIGURE 2.8.
Nanoparticles in the scale of things (designed by the Office of Basic Energy Sciences (BES) for the U.S. Department of Energy)



2.4 Biological hazards to human health

Phytoplankton

Phytoplankton is an intricate component of marine ecosystem complexity and it is widely recognised that phytoplanktonic organisms provide ecosystem services, both in a positive sense (e.g. oxygen generation, carbon dioxide sequestration, fish and shellfish productivity) and in a negative sense (harmful and toxic algae) (Millenium Ecosystem Report, 2005a to d). To date, few models have been developed which can predict the occurrence of any particular algal species. Anderson (2005) goes so far as to describe this as one of the major challenges of the 21st century. The intrinsic difficulties of modelling marine ecosystem complexity are most likely exacerbated by global change and, in particular, prolonged intensive fishing activities (top-down disturbance of marine ecosystems) and climate change (bottom-up ecosystem disturbance through changes in temperature, pH and turbidity).

From a human health perspective, phytoplankton organisms can be harmful in two ways either (i) through the production of potent biotoxins; or (ii) through the production of massive blooms which result in oxygen depletion leading to mass mortality of marine life (e.g. *Karenia mikimotoi*, Gentien *et al.*, 2007). To date, of the 5000 known algal species, more than 300 have been listed as being toxic or harmful (IOC, 2012). Natural toxins produced by microalgae exhibit a wide range of mechanisms and modes of action that affect human health through direct water ingestion/contact, aerosolized transport, and/or the consumption of a marine organism which has concentrated the toxins. Recently, the chemistry and toxicity (both acute poisoning and mechanistic considerations) of algal toxins have been systematically reviewed (Rossini and Hess, 2010). Many of the known algal toxins are neurotoxins, although some can cause skin and liver damage, and even cancer. The majority of human diseases associated with HAB toxins appear to be acute phenomena, although some can cause prolonged sub/chronic disease (e.g. ciguatera) (Backer 2003, 2005, 2010; Fleming 2011; Friedman 2008; Okamoto 2005; Watkins 2008). In the case of tetrodotoxin (TTX) at least, the origin of the toxin is not fully understood, with reports highlighting the bacterial origin of the toxin that is accumulated in vertebrates and invertebrates (Wang *et al.*, 2008).

The evolution and efficiency of phytoplankton and toxin monitoring systems in Europe have been reviewed by Hess (2011) as a function of legislative changes. The most common HAB toxins are regulated and monitored in European countries which have already substantially decreased the risk of illness arising from the consumption of shellfish, including illnesses such as PSP (Paralytic Shellfish Poisoning), ASP (Amnesic Shellfish Poisoning) and DSP (Diarrhoeic Shellfish Poisoning) (EU, 2004, 2005 and 2010). Other toxins such as cyclic imines (including spirolides, gymnodimines, pinnatoxins and pteriatoxins) and palytoxins are being studied but their toxicity and prevalence is not known and no regulatory limits have been established in Europe or anywhere in the world. Chronic toxicity data is needed in order to allow the establishment of Tolerable Daily Intake (TDI). Notably , the European Food Safety Authority has produced a series of risk assessments which outline current knowledge on the risks posed by regulated marine biotoxins (EFSA 2008 and b, 2009a to f) and the lack of knowledge in the area of emerging toxins (EFSA 2009g and 2010a to d).

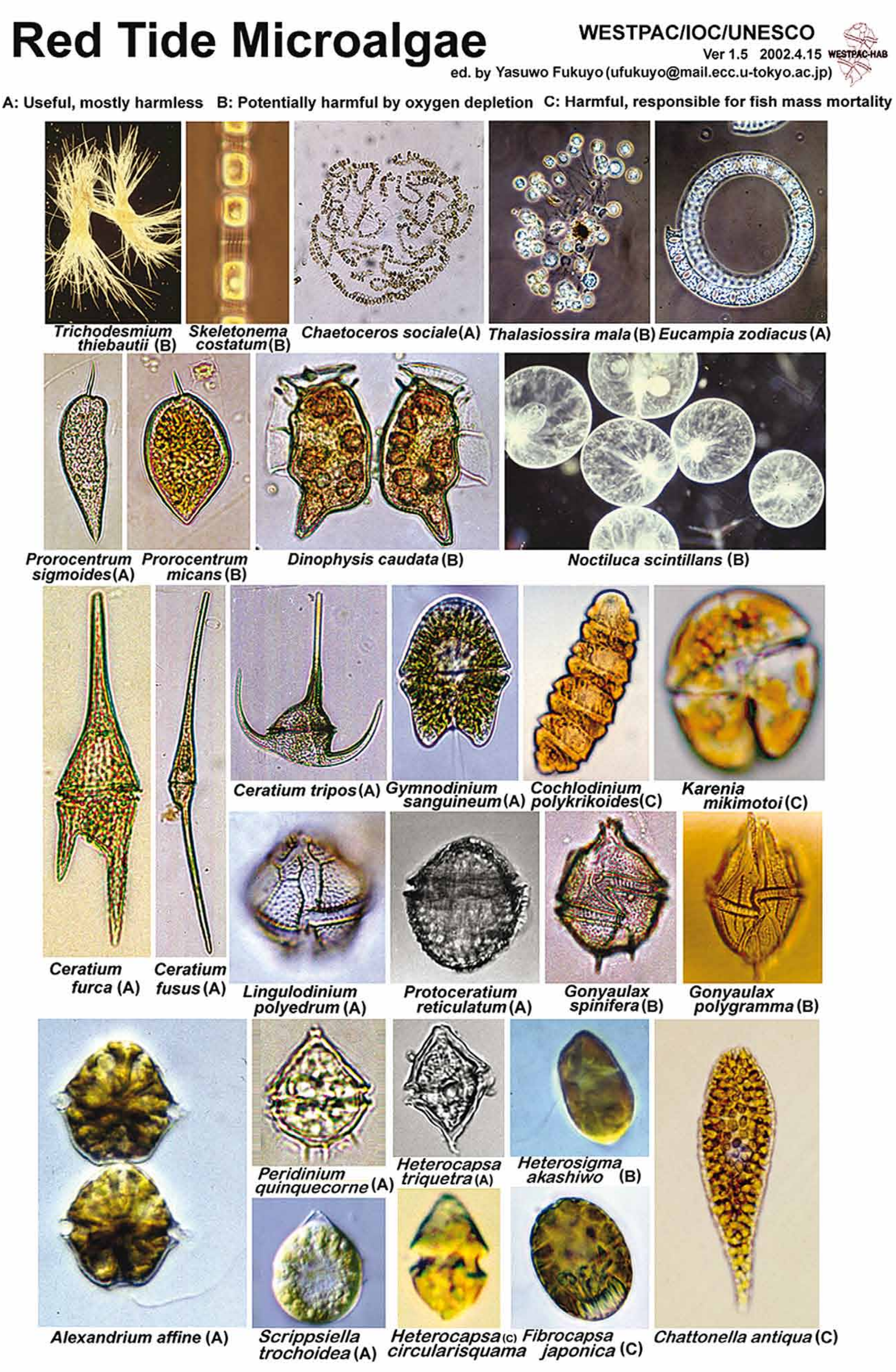

Red Tide Microalgae
WESTPAC/IOC/UNESCO
Ver 1.5 2002.4.15
WESTPAC-HAB
ed. by Yasuwo Fukuyo (ufukuyo@mail.ecc.u-tokyo.ac.jp)
A: Useful, mostly harmless B: Potentially harmful by oxygen depletion C: Harmful, responsible for fish mass mortality
Trichodesmium thiebautii (B)
Skeletonema costatum (B)
Chaetoceros sociale (A)
Thalasiossira mala (B)
Eucampia zodiacus (A)
Prorocentrum sigmoides (A)
Prorocentrum micans (B)
Dinophysis caudata (B)
Noctiluca scintillans (B)
Ceratium furca (A)
Ceratium fusus (A)
Ceratium tripos (A)
Gymnodinium sanguineum (A)
Cochlodinium polykrikoides (C)
Karenia mikimotoi (C)
Lingulodinium polyedrum (A)
Protoceratium reticulatum (A)
Gonyaulax spinifera (B)
Gonyaulax polygramma (B)
Alexandrium affine (A)
Peridinium quinquecorne (A)
Heterocapsa triquetra (A)
Heterosigma akashiwo (B)
Chattonella antiqua (C)
Scrippsiella trochoidea (A)
Heterocapsa circularisquama (C)
Fibrocapsa japonica (C)

FIGURE 2.9.
Red Tide Microalgae (A: Useful, mostly harmless; B: Potentially harmful by oxygen depletion; C: Harmful, responsible for fish mass mortality) © UNESCO/IOC/WESTPAC – Courtesy Dr. Yasuwo Fukuyo (WESTPAC IOC/UNESCO)

FIGURE 2.10.
Public notice warning in Florida, USA, against the consumption of shellfish from areas where biotoxin contamination is present (Credit: Lora Fleming, European Centre for Environment and Human Health, University of Exeter, UK).

There is also an increase on the number of reports on **emerging marine toxins** such as tetrodotoxin (TTX), ciguatera (CTX) and ovatoxin and palytoxin analogues (PlTX) in European waters (Ciminiello *et al*., 2008, Otero *et al*., 2010, Rodriguez *et al*., 2008, 2012; Silva *et al*., 2012). Most of these toxins are very toxic if ingested orally and can reach high levels in vertebrate or invertebrate species that enter the human food chain.

Although most of the marine toxins are neurotoxic, dermal toxicity through direct contact is also possible. Examples of such occurrences include dermal intoxication by palytoxin (PlTX) due to manipulation of corals (Hoffman *et al*., 2008, Deeds and Schwartz, 2009). In the Mediterranean there are reports on the intoxication of hundreds of people due to the presence of PlTX and ovatoxin-a in the marine aerosol (Ciminiello *et al*., 2008). However, there are few epidemiological studies or reports on dermal toxicity owing to the fact that symptoms can be similar to other waterborne or food-borne intoxications.

From a human health perspective, a major issue is the lack of systematic epidemiological surveillance, especially for emerging toxins, and thus baseline incidence rates for the HAB–associated human illnesses, both locally and globally. Recent efforts by the US Center for Disease Control (CDC) and other organizations to establish a coordinated human, animal and environmental health surveillance network known as HABISS[15] may improve this situation in the future. In Europe, the established monitoring programmes for HAB toxins screen for the major toxins but may miss emerging ones. In addition, detection methods for the HAB toxins either in the environment, or more importantly in humans, are either lacking completely (particularly human biomarkers), or are expensive and not widely available. Therefore, although HABs appear to be increasing worldwide, it cannot be easily determined whether HAB-associated human illnesses are increasing or not. Nonetheless, marine toxins have been responsible for more than 25% of all non-compliances in shellfish detected by the EU Food and Veterinary Office's "Rapid Alert System" over the period from 2006 to 2010. This represented a total of 71 cases of food complaints and violations of EU-levels (Hess, 2011). Hence, epidemiological studies together with broader monitoring programmes are urgently needed.

[15] See http://www.cdc.gov/nceh/hsb/hab/default.htm

FIGURE 2.11.
Toxic Harmful Algal Blooms (HABs) like red tides can make people sick, cause death in marine life and contaminate seafood with considerable risks for human health (credit: Ocean Champions)

The monitoring, management and prevention of both HABs and their possible human health effects are hampered by the lack of a broader HAB surveillance and improved detection methods (Backer 2008; Hess and Nicolau 2010; Kite-Powell 2008). While recent legislative changes in Europe have resulted in more effective detection of a range of known lipophilic toxins harmful to shellfish consumers (EU, 2011), the absence of biological screening will result in reduced protection of fish and shellfish consumers against emerging toxins. Therefore, novel approaches are required to increase our capacity to:

- Detect phytoplankton community changes in real time;
- Detect toxicity of algal communities, preferably using non-mammalian miniaturized bioassays and/ or functional assays;
- Detect emerging compounds amongst algal metabolomes (dereplication of natural products).

Marine-borne Pathogens

Humans may be exposed to marine microbial pollution (e.g. bacteria, viruses, and parasites) in many different ways. The routes of exposure include the consumption of contaminated seafood and direct and indirect exposure to contaminated seawater (e.g. skin, eye, respiratory, and oral contact) (Fleming, 2006). In the US, of the estimated 76 million foodborne illnesses occurring annually (resulting in 325,000 hospitalizations and 5,000 deaths with health-related costs up to $152 billion), seafood is implicated in 10-19% of these illnesses (Butt, 2004; Tibbetts, 2004; Iwamoto, 2010; Scharff, 2010). When a causative agent can be identified, viruses account for around half of these illnesses, although most hospitalizations and deaths are primarily associated with bacteria (particularly in susceptible subpopulations).

Based on risk assessments from the World Health Organization (WHO) and academic research sources, Shuval (2003) estimated that globally there are in excess of 120 million cases of gastrointestinal disease and 50 million cases of more severe respiratory diseases caused by swimming and bathing in wastewater-polluted coastal waters each year. Dwight *et al.* (2005) estimated that the economic burden

INFORMATION BOX 2.2.
Gram-negative bacterium *Vibrio parahaemolyticus* as an example of an important bacterial pathogen causing gastroenteritis associated with the consumption of seafood

The Gram-negative bacterium *V. parahaemolyticus* is a common inhabitant of temperate and warm estuarine European waters. Globally, *V. parahaemolyticus* is an important cause of bacterial gastroenteritis associated with the consumption of seafood. An established and common route of transmission includes the consumption of raw bivalve shellfish species, such as oysters and clams, or via wound exposure to seawater containing these bacteria.

The presence of *V. parahaemolyticus* in the marine environment is closely related to water temperature, with strains readily isolated when environmental temperatures exceed 15°C. Recent studies suggest that the number of *V. parahaemolyticus* infections are increasing in Europe (Baker-Austin *et al.,* 2010). However, few if any systematic or long-term ecological data exists on the temporal and spatial dynamics of these bacteria in the environment (Baker-Austin *et al.,* 2010 and references therein). Interestingly, because of the salinity tolerances of *V. parahaemolyticus*, which grows particularly well in lower salinity seawater (e.g. <30 ppt NaCl), few large-scale food borne outbreaks have been reported in high salinity yet temperate areas, such as the Mediterranean Sea.

Several recent studies have identified highly pathogenic 'pandemic complex' *V. parahaemolyticus* strains in European seafood produce with associated clinical infections (Martinez-Urtaza *et al.,* 2005; Ottaviani *et al.,* 2010). Because Europe contains many of the fastest warming coastal environments anywhere on Earth, there is growing concern regarding the spreading of these bacteria as well as the associated clinical risk.

per gastrointestinal illness (GI) was $36.58 while it was $77.76 per acute respiratory disease, $37.86 per ear ailment, and $27.31 per eye ailment (2001 values in Orange County, California). The authors then estimated the cumulative public health burden from the excess illnesses associated with coastal water pollution to be $3.3 million per year from just two recreational beaches on the Californian coast. Finally, Given *et al.* (2006) used epidemiological dose-response models to predict the risk of gastrointestinal illness at 28 beaches spanning 160km of coastline in Los Angeles and Orange County (California). They estimated between 627,800 to 1,479,200 excess cases of gastrointestinal illnesses occurred at these beaches each year, corresponding to an annual economic loss of $21m to $51m dollars (at year 2000 values).

Better control of human pathogens requires an understanding of their transport and ecology in the environment. Transfer of pathogens *via* faecal waste from farmed animals into waterways and, hence, into the marine environment is a potentially important hazard, particularly with the current trends for intensification of livestock farming, which can result in vastly greater amounts of waste entering the aquatic environment (Boxall *et al.*, 2009; Feldhusen, 2000; World Bank, 1995). Furthermore, irrigation and fertilization of crops with contaminated water or organic waste is a potential means of contaminating foodstuffs and waterways with enteric viruses, and studies have demonstrated that viruses can be transferred to the surfaces of plants and vegetables, and persist there for several days, following the application of sewage sludge or effluent (Defra, 2004; Rzezutka & Cook, 2004; World Bank, 1995).

Many human pathogens have reservoirs in the environment or are transmitted between humans by animal vectors or through animal intermediate hosts (Boxall *et al.,* 2009; Fleming *et al*., 2006; Todd, 2006). It is highly important, therefore, to try to anticipate new emerging diseases, a problem that is likely to become acute with global climate change, and increasing globalization with its concomitant rapid transfer of people and products throughout the world.

INFORMATION BOX 2.3.
Estimates of seawater and seafood related illness and economic cost

Seafood and seawater safety is directly linked to the quality of water in the European coastal zone. Infectious agents in coastal waters and seafood that can cause diarrhoea result in significant amounts of illness each year in Europe. It has been estimated that approximately 20% of the western European population is affected by diarrhoeic disease each year from all causes, which will have a significant economic impact in terms of treatment costs and loss of work-time (van Pelt *et al*., 2003; Roberts *et al*., 2003). Based on these studies, the estimated costs of treatment care and employment costs is approximately €80 billion (van Pelt *et al*., 2003; Roberts *et al*., 2003). While an, as yet unquantified, proportion of this diarrhoeic illness will be due to water-borne agents and contaminated seafood, comprehensive integrated estimates of economic impact are not directly available for the EU countries. This information can only be partially gleaned with considerable difficulty from a range of national and international sources, including from the Food and Agriculture Organization (FAO), the European Environment Agency (EEA) and the European Food Safety Authority (EFSA) (Cato, 1998; http://www.eea.europa.eu/publications/eea_report_2008_4;pp149-160CC2008_ch5-10_Human Health.pdf; EFSA, 2010).

This deficit in clear information represents a significant gap in our knowledge concerning the health-related economic impact of water-borne infectious diseases in the EU. Consequently, the production of effective estimates of seawater and seafood related disease should be an important driver for any future EU-focused effort in Oceans and Human Health as argued in this position paper.

Viruses

The sea can provide a vehicle for transmission of pathogenic viruses to humans. The viruses most adept at survival in the marine environment are those adapted to transmission by the faecal-oral route. These include a large and diverse group of viruses causing human gastroenteritis and other viruses, such as poliovirus or Hepatitis A virus, which although having a growth phase in the human gut, produce their main clinical symptoms elsewhere. Unlike bacterial and protozoal pathogens, the viruses which are recognized to be potentially transmitted via seawater are generally human in origin. Thus the role of the sea is in recycling human viruses back to humans. Faecally-orally transmitted zoonotic viruses (for example hepatitis E virus) have the potential for transmission via the marine pathway but this has not yet been conclusively demonstrated.

Given that viruses which grow in the gut (such as those causing gastroenteritis) generally produce vast numbers of progeny in faeces, faecal pollution is the main source of risk to human health. Human faecal pollution in the marine environment arises from municipal sewerage discharges and point sources such as septic tanks, boats, emergency and storm water discharges. However, close contact between humans, for example during swimming, may also be a risk factor. Awareness of the role of the sea in the transmission cycle of human pathogenic viruses relies on finding evidence for an epidemiological linkage between exposure to the sea (in some form) and a recognizable illness. Thus for illnesses with a long incubation period (e.g. Hepatitis), or which cause clinical symptoms in only a small percentage of those infected (e.g. many of the enteroviruses), or which cause chronic infections, the potential role of the sea as a transmission route may be impossible to verify. Consequently, of the many different viruses known to be transmitted by the faecal-oral route, in only two (Norovirus and Hepatitis A virus) has a marine route of exposure been unequivocally identified as a significant pathway.

Easily the most well documented vector for marine-borne viruses is transmission by filter-feeding bivalve molluscs. Bivalve molluscs grown in faecally contaminated waters concentrate human viruses in their digestive tract during normal feeding processes. Their consumption whole (including the digestive tract) and either raw (e.g. oysters) or lightly cooked (eg mussels and clams) combine to accentuate the risk. The literature contains abundant case reports of outbreaks associated with bivalve molluscs caused by both Norovirus and Hepatitis A virus (Lees, 2000). Such outbreaks continue to occur on a regular basis both in the UK and worldwide and can be high profile (Smith *et al*., 2011). The World Health Organization identified Norovirus and Hepatitis A virus as the viruses of primary concern with regard to seafood consumption (Anon, 2009).

The second main route of exposure to enteric viruses is through swimming in polluted seawater. However, in this case, despite extensive epidemiological investigations, it has proven difficult to unequivocally link a causative pathogen with the various (often minor) ailments reported by swimmers (Priiss, 1998). Given the symptoms reported and the ubiquitous nature of Norovirus, this virus is likely to be responsible for at least some of the illnesses described. However, this has yet to be confirmed.

Norovirus is the leading cause of gastroenteritis in the UK and probably world-wide. These viruses possess all the attributes of an ideal infectious agent being highly contagious, rapidly and prolifically shed, constantly evolving, evoking only limited immunity, and being only moderately virulent (Hall *et al*., 2012). Recent extensive studies suggest they are the leading cause of gastroenteritis in the UK, causing some 3 million cases annually (Tam *et al*., 2011), and are also probably the leading cause of foodborne disease (Scallan *et al*., 2011). Hospital outbreaks, resulting for example in ward closure, have been estimated to cost the UK National Health Service £115 million per year (Lopman *et al*., 2004). Although person-to-person is undoubtedly the main route of transmission, the contribution of the marine pathway (e.g. via bivalve molluscs) may be significant in introducing strains to previously unexposed susceptible populations (through world-wide trade) and in the emergence of new recombinant variants following a mixed infection, a common feature of seafood related illness (*Symes et al.,* 2007).

Compared to other enteric viruses, **Hepatitis A virus** has an extended incubation period of about 4 weeks and causes a serious debilitating disease progressing from a non-specific illness with fever, headache, nausea and malaise, to vomiting, diar-

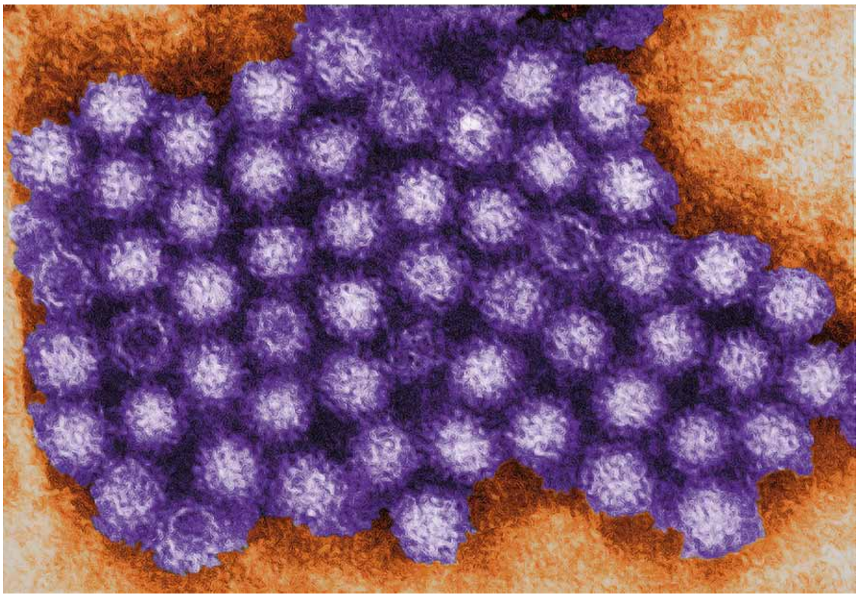


FIGURE 2.12.
Transmission Electron Micrograph (TEM) of ultrastructural morphologic components displayed by norovirus virions, or virus particles. Noroviruses belong to the genus Norovirus, and the family Caliciviridae. They are a group of related, single-stranded RNA, nonenveloped viruses that cause acute gastroenteritis in humans. (Credit: US Center for Disease Control (CDC)/ Charles D. Humphrey)

rhoea, abdominal pain and jaundice. Hepatitis A is self-limiting and rarely causes death but patients may be incapacitated for several months. Outbreaks associated with bivalve molluscs are well documented and still occur within the EU from time to time, both through imported shellfish (Pinto *et al*., 2009) and through consumption of products grown in EU waters (Guillois-Bécel *et al*., 2009). However, with the introduction of vaccines and improving hygiene standards, Hepatitis A virus is largely now non-endemic within EU member states.

The public health risks associated with eating contaminated seafood and bathing in polluted waters have been identified for many years. Hence, world-wide, these risks are controlled through food or environmental legislation. In the European Union, Regulation 854/2004 (Anon, 2004) specifies the controls required for production and placing on the market of live bivalve molluscs and Directive 2006/7/EC sets out the quality required for bathing waters (Anon, 2006). A key component of such legislation is the setting of water or seafood quality standards along with a requirement for monitoring to ensure compliance with these standards. In the case of faecal pollution, standards are based on the long-established bacterial faecal indicator concept (e.g. *E. coli* or intestinal enterococci).

Both Norovirus and Hepatitis A virus have been demonstrated to be robust persistent viruses surviving long periods in the environment. For example in a recent human volunteer study, Norovirus in groundwater was demonstrated to survive for more than 61 days (Seitz *et al*., 2011). Hepatitis A virus has been demonstrated to survive in seawaters for several weeks (Bosch, 1995). These characteristics are in contrast to the bacterial faecal indicator organism specified in food and environment legislation which generally persist for a few days at most in the marine environment (Vasconcelos and Swarmz, 1976). Thus in many viral illness outbreaks caused by consumption of bivalve molluscs, the responsible seafood batches are found to be in full compliance with the faecal indicator legislative standards (Lees, 2000).

The recognized limitations of the faecal indictor approach for controlling virus risks has led to many years of research into methods for direct detection of viruses in environmental samples. For seafood this is now well advanced with standard methods based on quantitative PCR, suitable for use in EU food legislation, now available (Lees *et al*., 2010). Similarly, methods for detection of viruses in water samples have been developed, although not yet standardized to the same extent. Unfortunately, application of these methods to surveys of commercial bivalve mollusc production has uncovered alarmingly high levels of Norovirus contamination in several EU countries (EFSA, 2012). Similar surveillance has not yet been conducted for bathing waters. These studies suggest that Norovirus contamination is a regular occurrence in bivalve molluscs in Europe (and probably world-wide). Hence, the introduction of legislation controlling virus contamination, depending on the standards set, could potentially have a devastating impact on current commercial production within the EU. By contrast available evidence suggests that Hepatitis A virus contamination of bivalve molluscs produced within the EU is currently a rare event. Since hepatitis A virus is no longer endemic in most EU countries, this reflects the low level of infection in the general population. In this case, a standard based on absence of virus would be appropriate and would protect the population against introductions through consumption of seafood.

In general, most of Europe's coastal areas are affected to some degree by human activity and pollution. High human population densities, combined with other land uses such as farming, result in significant faecal loadings in coastal waters. Although major infrastructure investments have been made, driven by the need to address failures of bacterial indicator standards (both in shellfish and bathing waters), growing evidence suggests that tackling viral contamination may be even more problematic and costly in the long-term. Considering the economic cost and impact of such measures to the European area, it seems crucial to have a better understanding of the nature and behaviour of viral contamination.

INFORMATION BOX 2.4.
Research priorities to better inform the development of European policies for control and mitigation measures of viral pathogens

Research in the following areas would inform development of European policies for control and mitigation measures of viral pathogens and thus potentially significantly contribute to improving public health:

- Development of standardized methods for detection of Norovirus in bathing and marine waters with the potential for adoption into monitoring programmes;
- Determination of the relationship between test results based on quantitative PCR and human health consequences;
- Investigation of the epidemiological contribution of Norovirus to bathing water and food borne illness;
- Establishment of baseline contamination rates for Norovirus in designated EU shellfish and bathing waters;
- Investigation of the effectiveness of sewage treatment processes for Norovirus removal and the fate, behaviour, persistence and reservoirs of Norovirus following its release into the marine environment;
- Testing the effectiveness of food treatment and/or processing methods (e.g. depuration) that can control enteric viral hazard;
- Determination of how best to incorporate virus testing into legislative control programmes (eg sampling strategies and focus, etc.).

2.5 Products from the Sea

The Complex Relationship between seafood production, consumption and human health

Hunger was an increasing problem even before the present food and economic crises and remains among the most devastating problems in the world. Estimates from the Food and Agriculture Organization (FAO) suggest that 1.02 billion people worldwide were undernourished in 2009, a higher number than at any time since 1970 (FAO, 2009). Seafood, supplied by both capture fisheries and aquaculture, is a crucial component in the goal of achieving global food security. Fish accounted for 15.7% of the global population's intake of animal protein in 2007 and 6.1% of all protein consumed (FAO, 2009, 2010). In some low-income, food-deficient countries (LIFDCs), fish proteins are absolutely essential to food security as they comprise a significant share of a low-level of animal protein consumption. Moreover, seafood provides micronutrients, minerals and essential fatty acids which, if they are available from other sources at all, are most likely too expensive for widespread consumption.

On a global basis, employment in fisheries has been increasing since 1980, and in 2008 some 44.9 million people were directly engaged in fisheries or aquaculture production. Including the secondary sectors, fisheries and aquaculture support the livelihood of 8% (circa 540 million) of the global population (FAO, 2010). Thus, these industries contribute significantly to food security, both in terms of directly providing food, as well as serving as crucial sources of income and livelihood for hundreds of millions of people.

FIGURE 2.13.
Capture fisheries provide a critical supply of animal protein worldwide and are an important source of employment. Top: North Sea trawler (© Clicks/istock); bottom: Seafood on sale in Milan, Italy (© Jean-Joseph Renucci/istock)

It is evident that a continued dependence on the ocean to ensure food security depends on healthy aquatic ecosystems. Today, one of the biggest single threats to the marine ecosystems, including biodiversity, is overfishing. The proportion of marine fish stocks overexploited, depleted or currently recovering from overfishing increased from 10% in 1974 to 32% in 2008. During the same period, the proportion estimated to be underexploited or modestly exploited declined from 40% to 15% in 2008 (FAO, 2010). It is clear that global fisheries are at, or close to, their maximum sustainable production levels, with no room for further expansion. Moreover, global climate change and changes in ocean temperature and currents are expected to affect the productivity of fisheries by altering both the geographical distribution as well as the total amount of available fish. Loss of biodiversity may reduce the adaptive capacity of commercial fish species to cope with increasing temperatures resulting from climate change.

Despite these challenges, the FAO estimates that seafood production needs to increase by 8-10% annually to meet the requirements of a rapidly rising global population. Put another way, we need to increase production of seafood by approximately 27 million tonnes by 2050 in order to maintain the present per capita consumption, when the forecasted rise in the global population is taken into account. With fisheries production already stretched to the limit, farmed fish are an increasingly important source of seafood, accounting for more than 50% of world seafood production in 2012, and steadily increasing. The growth in global, per capita production of farmed fish has increased from 0.7kg in 1970 to 7.8kg in 2008. Thus, forecasted future increases in per capita consumption of fish will depend on aquaculture.

Increasing aquaculture production itself may have consequences for the health of the marine environment and consequently for human health. For example, the traditional use of fish-derived raw materials in aquaculture, such as fish meal and fish oil, is not sustainable in the long-term. An increase in production volumes, therefore, will depend on the development and use of alternative feed ingredients (Tacon *et al*., 2006). However, replacing marine feed ingredients with agricultural alternatives will alter the composition of the final seafood product both nutritionally and in terms of possible contamination, and may have profound consequences for the health effects of seafood. This may be viewed as an opportunity as there is a strong potential for using aquaculture to produce tailored farmed fish products targeted at consumer groups with particular nutritional needs (functional foods). Essential nutrients, such as vitamins and minerals, can be increased and contaminants kept low in farmed fish using specially designed aquaculture feeds.

According to the World Health Organization (WHO, 2008), non-communicable diseases, commonly referred to as lifestyle diseases, including cardiovascular diseases, cancer, osteoporosis, chronic respiratory diseases and diabetes, currently cause 60% of all deaths. Today, obesity is a leading and preventable cause of death and is considered as one of the most serious public health problems of the 21st century. Of note, the number of total deaths from lifestyle diseases is projected to increase by a further 17% over the next 10 years (Figure 2.14). It is of great importance to note that up to 80% of the cases of heart disease and type 2 diabetes can be prevented by reducing risk factors. Together with physical inactivity and smoking, diet is an important risk factor which can be improved to reduce the risk of developing lifestyle diseases. Dietary changes might thus be an important factor in curbing the global burden of non-communicable diseases.

Projected incidence of non-communicable diseases

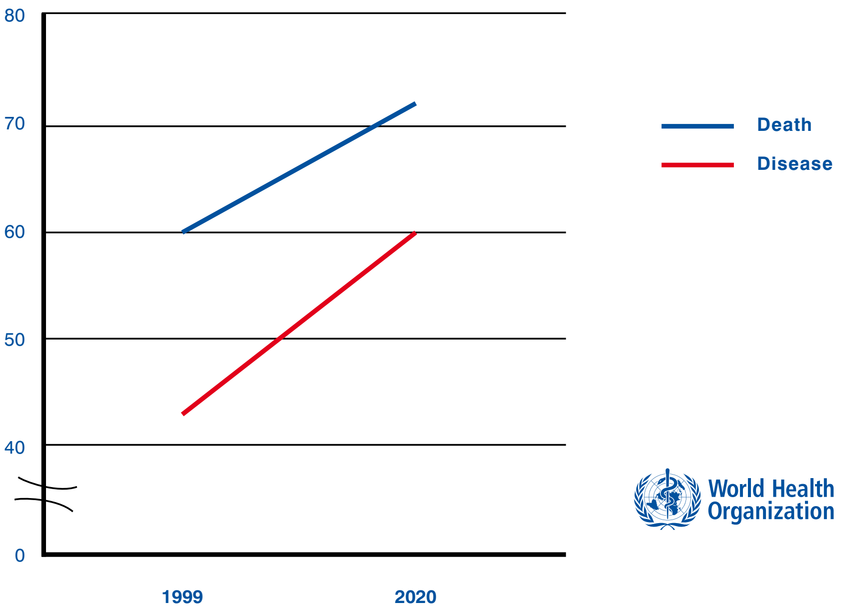
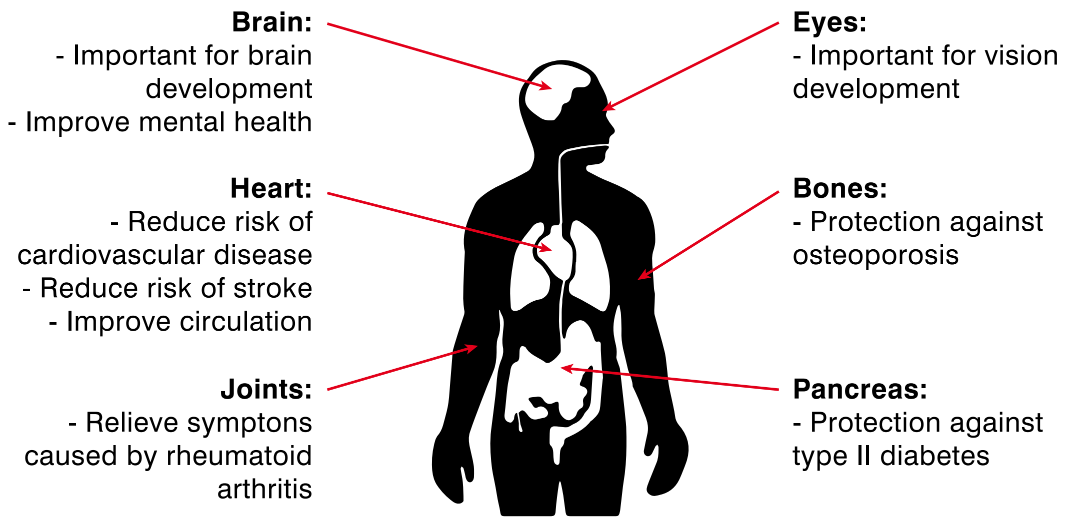


FIGURE 2.14.
World Health Organization (WHO)
projection of trends in lifestyle diseases

FIGURE 2.15.
The recognized importance of marine oils
in human health

The role of omega-3 fatty acids, proteins and micronutrients from seafood on human health



It is evident that seafood represents an important part of a healthy diet. So far, the majority of work on the beneficial health effects of fish consumption focuses on fish oil, and various health benefits are thereby attributed to marine oils rich in omega-3 fatty acids (Figure 2.15). The importance of marine oils in the prevention of cardiovascular diseases is well documented and recognized, and seafood, obviously, is the only dietary source of such oils.

In addition to marine oils, other dietary benefits of seafood should be taken into account. First and foremost it should be recognized that seafood is an excellent protein source, as marine proteins contain all essential amino acids, as well as having high biological values. Secondly, seafood is a good nutritional source of several key micronutrients, such as vitamins D and B_{12}, and minerals including selenium and iodine. Vitamin D and iodine are good examples of marine nutrients deserving further research. Through its stimulation of calcium absorption and bone formation, vitamin D has traditionally been recognized as an important factor for proper bone health and prevention of osteoporosis. More recently, reduced vitamin D status has also been associated with mental disorders, insulin resistance and obesity in humans. However the mechanisms involved are not clear and further investigation is warranted.

Whereas the vitamin D concentration is highest in the fillet of oily fish and in fish liver, the highest levels of iodine are in the fillet of lean fish. Iodine is an important constituent of the thyroid hormones which play a basic role in regulating the basal metabolic rate in humans. According to the WHO, iodine deficiency is the world’s most prevalent, preventable, cause of brain damage and mental retardation. In addition to iodizing table salt, an increased knowledge of the impact of consuming lean fish may contribute to reducing this global health problem.

Like any food item, seafood also has the potential to cause diseases by acting as a matrix for viral, bacterial and parasitic pathogens. Although such agents to a large extent originate from pollution, some occur naturally in the aquatic environment. The health implications of Harmful Algal Blooms (HABs), in particular, have been discussed in section 2.4 of this report.

Another matter of concern which has arisen during the last decades is the presence of toxic contaminants including heavy metals and persistent organic pollutants (POPs) in seafood. The Stockholm Convention, a global treaty designed to protect human health and the environment from POPs, initially included twelve groups of compounds for priority action. However in 2009 this list was expanded to twenty-one groups, now including brominated flame retardants, fluorinated compounds and endosulfan, which was included under the Convention in 2011. Limited information is available regarding the toxicity of these compounds to humans and it is not possible to establish tolerable intakes of these contaminants by consumers without further research.

From the above it is clear that human consumption of seafood is a double-edged sword when it comes to human health. Nutritional benefits and contamination risks of eating seafood have been dealt with separately above but there is an increasing awareness that future challenges in risk assessment include the interaction of contaminants and nutrients (Figure 2.16). This is especially important for food chain risk assessment where contaminants are responsible for altering nutrient matrices, which will affect the toxic outcome. Nutrients (e.g. tocopherols, flavonoids and fatty acids) are known to interact and even protect against contaminant (e.g. polycyclic aromatic hydrocarbons and pesticides) toxicity. Thus, pathway identification is essential to assess how nutrients interact with contaminants.

Dietary guidance to pregnant women, for example, is an important issue in this context. Most international public guidelines advise pregnant women to increase their intake of seafood and oily fish in particular due to its high levels of beneficial nutrients, as there is ample evidence of detrimental effects linked to maternal nutritional deficits during gestation. However, the opposite holds true in some countries such as Sweden, where the high levels of mercury[16] in fish have resulted in recommendations for pregnant women to reduce their consumption of fish. In light of the rich source of nutrients in seafood, the potential ameliorating effect of dietary nutrients on the toxic response to environmental contaminants needs to be further evaluated.

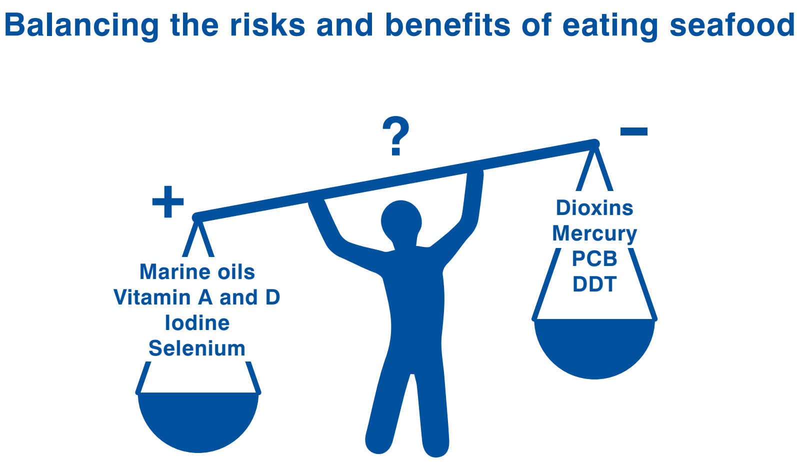


FIGURE 2.16.
Positive and negative aspects of dietary seafood

INFORMATION BOX 2.5.
Parasitic Infections from consumption of seafood

Human consumption of raw, marinated or undercooked fish and shellfish can result in parasitic infections, which may result in severe symptoms or even death. The parasites of most concern are nematode worms (e.g., *Anisakis* species), tapeworms (e.g., *Diphyllobothrium* species) in the flesh of a range edible finfish, and protozoan parasites, such as *Cryptosporidium* species and *Giardia duodenalis* assemblages A and B, of which the spores and cysts respectively can accumulate in filter feeding mussels, clams and oysters (Gómez-Couso *et al.*, 2004; Huss *et al.*, 2004; Lucy *et al.*, 2008). These types of parasites can all cause severe gastro-intestinal infections ranging from asymptomatic or mild gastric or bowel discomfort to diarrhoea or dysentery; and some can cause fatalities, such as *Giardia* and *Cryptosporidium*. Human infection with Anisakid worms in Northern Europe was a significant problem prior to the 1970's but with the introduction of flash freezing of herring and other hosts of the larval worms (e.g., cod and salmon) the problem was greatly reduced (Huss *et al.*, 2004). More recently Anisakiasis and associated gastro-allergic reactions has become more prevalent in Southern Europe and is an issue of seafood hygiene and safety (Mattiucci *et al.*, 2013; Valero *et al.*, 2006).

These types of infections are not just a European problem as they occur worldwide. Consequently, with increasing globalisation and the frequent sourcing of seafood products from many regions of the world, there needs to be an enhanced awareness of the potential for human parasitic infection or accidental introduction of alien parasitic organisms into European ecosystems. Furthermore, physicians may fail to correctly diagnose the symptoms of these infections as they are often not trained to associate the symptoms with seafood-borne parasites.

Most of these parasitic infections can be avoided or minimised if appropriate food hygiene measures are implemented as outlined by Huss *et al.* (2004).

Focus on the impacts of aquaculture on human health

Aquaculture has been one of the world's fastest-growing food producing sectors in recent decades. Global output has increased from less than 1 million tonnes in 1950, to 52.5 million tonnes in 2008 (FAO, 2010). Aquaculture is also an increasingly important source of nutrients for the global population and serves as an important provider of employment and income in LIFDCs in particular. Of note, developed countries produced only 3.92 million tonnes, accounting for 7.5% of global aquaculture production in terms of quantity, although this accounted for 14.6% of production value. In the European Union, aquaculture contributes approximately 20% of the total EU fish production, yet represents only 2% of global aquaculture production. Nevertheless, Europe has a number of key strengths in aquaculture as there is a strong focus in the sector on technology, research and training of highly skilled employees. In addition, the environmental quality standards in Europe are rigorous to ensure that aquaculture products are both healthy for the consumer and environmentally sustainable.

There are many different techniques used to farm a broad array of fish, shellfish (predominantly molluscs and crustaceans) and more recently algae, but two fundamental factors dictate the environmental impact of any aquaculture operation, namely water processing and feeding regime. By economic necessity, most inland facilities use a flow-through system where water is diverted from surface waters (lakes, rivers) or underground reservoirs. For farmed species held in natural water bodies, restrictions generally reflect site selection because water quality is dependent on natural water flows in and around the farm. In terms of the impacts of aquaculture on the marine environment, effluents from rearing ponds and the impact of cage farming are the most relevant.

Even if aquaculture is a valuable contributor to food security issues, the sector faces increasing conflicts with other users of the marine environment. It is well known that intensive aquaculture operations may lead to water pollution as accumulation

[16] Mercury in fish (and other food) is considered and important risk for human health. Therefore, the European Food Safety Authority (EFSA) establish Tolerable Weekly Intakes (TWIs) in 2012 intended to protect consumers from adverse health effects posed by the possible presence of the main forms of mercury found in food—methylmercury and inorganic mercury.

of fish faeces and feed waste below sea cages, for example, can lead to oxygen depletion and contribute to harmful algal blooms. In order to expand aquaculture in European coastal waters, a strong emphasis must be placed on the development of farming techniques which have a reduced environmental impact.

For cage culture of fish, escape of the farmed animals is a continuous threat, both for the farming business and the surrounding environment. Escapees can have detrimental impacts on the genetic integrity of wild populations of the same species. Interbreeding between escaped and farmed fish may thus affect genetic diversity, leading to reduced disease resistance and adaptability. At its most serious extent, the decline or elimination of a native species through competition or predation by farmed organisms can occur, resulting in changes in biodiversity and ecosystem functioning. Moreover, escapees from farms represent a danger for transmission of trans-boundary aquatic animal diseases. EU FP7 project, Prevent Escape[17] has focused entirely on reducing the threats and impacts of farmed fish escapes but it is clear that further efforts both to limit escapes from fish farms as well as research on the impact of the escapes on wild stocks are warranted.

Although escapees may have harmful genetic and ecological effects on biodiversity, fish culture can also be used to re-stock populations through the release of cultured larvae or juveniles into the wild to strengthen natural populations ("stock enhancement"). However, exploring the possibilities of genetic conservation of endangered stocks warrants further attention.

A critical concern for public health surrounds the intensive use of antimicrobial agents to combat and treat infections in farmed fish. Such concern is primarily linked to a possible transfer of antimicrobial resistant bacteria to consumers of

FIGURE 2.17.
Finfish aquaculture farm on Frioul island near Marseille, France (© Ekaterina Krasnikova / istockphoto)

[17] www.preventescape.eu

farmed fish. Secondly, the presence of antimicrobial drug residues in food products represents a potential health hazard, and may lead to development of allergies, toxic effects and changes in the colonization patterns of human-gut flora (WHO, 1999). The use of antibiotics does not only relate to aquaculture, as it is an integral part of all intensive animal husbandry. In Europe, the European Medicines Agency authorizes veterinary medicines and establishes Maximum Residue Limits (MRLs). The MRL is the maximum concentration of residue accepted by the European Union in a food product obtained from an animal that has received a veterinary medicine. The assessment of the safety of residues is carried out by the by the Committee for Medicinal Products for Veterinary Use (CVMP). There has been considerable effort in Europe to reduce the use of veterinary medicines in farmed fish, primarily through the development of vaccines to restrict prophylactic use.

INFORMATION BOX 2.6.
Oceans and Allergies

Negative health affects after consumption of seafood include true food allergy (including Type I IgE-mediated hypersensitivity), as well as food intolerance (i.e. non-immunologic hypersensitivity) (Fleming 2001, Lopata 2010, Hajeb 2012). The development of allergy is complex, influenced by genetic, environmental, and demographic factors and potentially by gene-environment interactions; nevertheless, shellfish and fish allergies are in general more common in adults than children, except in Asia (Ben-Shoshan, 2012). An estimated 3% of three-year old Finnish children are allergic to fish and the prevalence of fish allergy is close to 1/1000 in the general Norwegian population (Zinn 1997). The approximate prevalence of shellfish allergy is estimated at 0.5-2.5% of the general population across several countries, depending on degree of consumption (Woo, 2011). Symptoms range from acute cutaneous disorders (such as hives) to gastrointestinal complaints to respiratory symptoms and anaphylaxis, even death (Woo, 2011). Although most seafood-associated allergies occur after consumption, shellfish protein in particular is a potent allergen with symptoms occurring after inhalation or skin contact. The reported prevalence of occupational asthma in shellfish-processing workers is 2-36% (Jeebhay, 2001).

Allergic reactions, ranging from hives to anaphylaxis, have been reported after the consumption of seafood contaminated with parasites (Fleming 2001). Acute and chronic intermittent allergic reactions occur after the consumption of fish with Anisakidae parasites, even when the parasitized fish has been cooked (Moreno Ancillo 1997). Scombroid fish poisoning can appear to be a severe allergic reaction, but it is actually due to the histamines elaborated by bacteria in improperly stored fish.

Although not purely allergic reactions, contact with a number of marine organisms (e.g. some jellyfish) can be associated with skin rashes and hives (Perkins 2004); in some cases, these can progress to fatal anaphylaxis via the involvement of the immune system (Tibbals 2011). Other marine exposures can appear to be allergic. Skin reactions are seen with excessive exposure to UV light (i.e. sun burn); skin infections with bacteria, fungus, and even parasites (e.g. Toxicara canis) can also be acquired at the beach (Plano 2013).

It is worth noting that most modern food scandals have started with contamination of an animal feed (EU, 2000). Contaminants found in feed can be transferred to fish and thus affect seafood safety. As farmed fish in the future will constitute an increasing proportion of the overall fish consumption, there is an ongoing effort to change the composition of aquaculture feeds in order to rely less on marine fish feed ingredients such as fish meal and fish oil. Vegetable ingredients, including genetically modified plants, animal by-products, and even algae may constitute alternative protein and lipid sources for fish feed. Replacing fish oil in aquaculture feed with alternative lipid ingredients will alter both nutrient and contaminant composition, and may have profound consequences for the health effects of seafood. Novel feed ingredients will introduce new challenges for food safety, for example in the control and regulation of pesticides, mycotoxins and medicine residues.

There is a continuous need for analytical methods and safety evaluation of emerging risks in seafood. This includes studying the transfer of undesirable compounds to the edible product that may affect consumer health. Other undesirable components in the feed produce such as additives from fish feed and feed raw materials are also an important area requiring further research. An understanding of the ways in which these substances are transferred from feed to fillets and their effects on farm animal and consumer health is vital to ensure seafood safety. Furthermore, toxicological evaluations of undesirable compounds have traditionally focused on one compound at the time. However, food contains an abundance of compounds, with both positive and negative implications for human health. Risk-benefit assessments are necessary to enable an integrated evaluation of the positive and negative compounds present in seafood (EFSA, 2010).

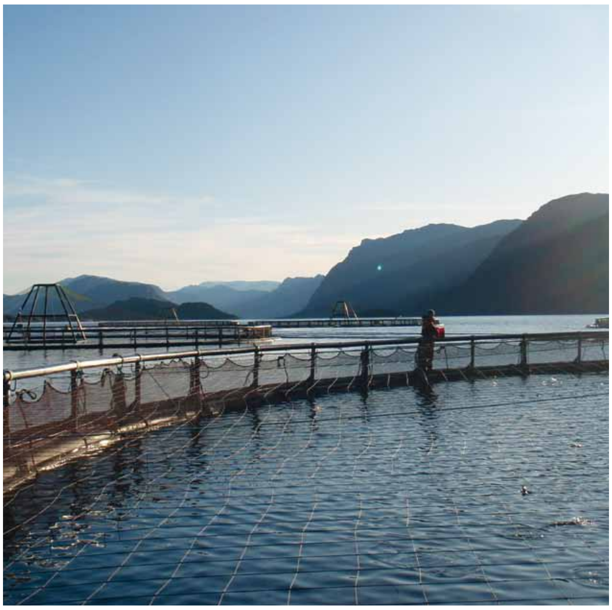


FIGURE 2.18.
Left: Fish feeding at a Norwegian fish farm (Credit: Research Council of Norway / Marine Harvest); Above: feeds used in aquaculture (picture from www.clextral.com). The feed used in aquaculture influences the health and composition of the farmed fish, and hence the nutritional value and potential health risks for consumers. With an increasing proportion of fish protein provided by aquaculture, there is an ongoing effort to change the composition of aquaculture feeds in order to rely less on marine fish feed ingredients such as fish meal and fish oil.

A significant proportion of feed for farmed fish still relies on both fishmeal and fish oil as essential components. Although the major source of fishmeal is pelagic fish species and by-catch not normally consumed by humans, the sustainability of the sector is increasingly tenuous. This raises concerns both from an ecological perspective and from consumer demand, particularly in the world's richer economies, that fish are safe to eat and are derived from sustainable sources. Due to the pressure on wild fish stocks, and hence the limited availability and variable prices of fishmeal and fish oil for the rapidly growing global aquaculture industry, there has been a focus on the development of aquafeeds that rely less on fishmeal and fish oil (Torstensen *et al.*, 2008). Data from The European Commission's 6th Framework Integrated Project AQUAMAX[18] show that the use of plant oils and meals reduces levels of known persistent organic pollutants in Atlantic salmon, but also introduces other contaminants not previously associated with salmon farming (Berntssen *et al.*, 2010). Furthermore, the use of novel sustainable plant feed ingredients in aquafeeds will potentially affect fish health and fillet composition. As both the nutrient and contaminant status of the fish is affected by the use of plant-based feed ingredients, it might be expected that consumer benefits of fish consumption are also altered. Aquaculture has great potential for food production and the alleviation of poverty, particularly for people living in coastal areas. A balance between food security, public health and the environmental costs of production should be addressed through an interdisciplinary approach.

Global environmental change is another issue which will need to be addressed in order to ensure long-term sustainability of the aquaculture sector. Farmed fish held in sea cages have limited possibilities to migrate from environmental changes, and environmental effects do directly affect the fish performance. Future effects of global warming at local level may increase incidences of elevated temperature and hypoxic conditions. In a recent experiment, Hevrøy *et al.* (2012) studied two groups of large salmon (about 2 kg average weight) after they had spent 56 days in seawater. One group lived in water at 19 °C, the other at 14 °C. The salmon were also fed diets with different fat content. It turned out that the fish at 19 °C, which ate little, also took up very little fat, drawing instead on their own reserves of fat, particularly polyunsaturated marine omega-3 fatty acids. High temperatures can thus have implications not only for growth, but can also lead to changes in product quality and how the feed resources are used. The direct effects of temperature or hypoxia is possible to predict with focused experimental design. But there is another aspect of climate change that would be difficult to see today, and that is the combined factors of ocean acidification and rainfall. How would this combination affect wild or farmed fish; and what would the future seafood problems look like? This will require further research effort.

Microbial Contamination and Eutrophication

An area that is worthy of more focused attention with regards to nutrients and human health effects, is the increasing impact of microbial contamination as a nutrient input associated with increased HAB incidence, environmental degradation, and the potential for human health effects from both the microbial pathogens and HABs. There is controversial evidence of increasing marine HAB occurrences and a documented increasing incidence of cyanobacterial blooms in freshwater bodies worldwide associated with nutrient contamination, and these have been associated with increased reports of deaths and illness of domestic and other animals. However, demonstrating a parallel increased incidence of human health events is more difficult (Stewart, 2011; Zaias, 2010).

[18] http://ec.europa.eu/research/biosociety/inco/projects/006_en.html

FIGURE 2.19.
Algal bloom at the Swedish coast in the Baltic Sea resulting from excessive nutrient loads entering the marine environment which may result in oxygen depletion and fish mortality. (Credit: istockphoto / Mikael Eriksson)

The loads of nutrient inputs into aquatic systems, due to the overuse of fertilizers, pesticides and treated and untreated wastewaters, can cause freshwater eutrophication which can, in turn, affect coastal waters. Moreover, the impact of land-based influx of nutrients and toxins on coastal eutrophication is neither well-known nor understood. Nevertheless, it is also important to consider that freshwater toxin-producing organisms may have a significant impact in estuarine and coastal systems by transferring toxins to marine systems that are usually found only in freshwaters.

Although most marine national monitoring programs deal with the most common toxins and their producers, they do not include toxins of strictly freshwater origin such as microcystins, cylindrospermopsin or anatoxin-a and its analogues. Recently, the occurrence of the neurotoxic amino acid β-N-methylamino-L-alanine (BMAA) produced by marine and estuarine cyanobacteria has been highlighted due to the potential implication on human neurodegenerative diseases (Cianca *et al*., 2012; Banack *et al*., 2007; Baptista *et al*., 2011). These toxins of freshwater origin can have a direct negative impact on public health if they occur in drinking or recreational waters, but in coastal waters they may also accumulate in seafood.

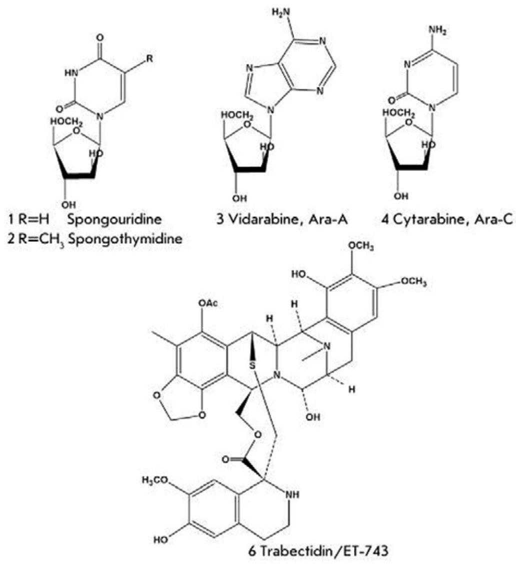
Among the seafood animals, bivalve molluscs probably cause the greatest human health problems due to their unselective feeding habits. In estuaries and coastal waters near eutrophic rivers they may feed on freshwater cyanobacteria responsible for the production of a variety of toxins. Mussels are very tolerant to toxic freshwater cyanobacteria. They may accumulate saxitoxins (Lassus *et al*., 1989), microcystins (Amorim and Vasconcelos, 1999), cylindrospermopsin (Saker *et al*., 2004) or anatoxin-a (Osswald *et al*., 2008), without any obvious harm to the mussel, but exposing humans who eat contaminated mussels to these toxins. Moreover, of these contaminants, only saxitoxins are subject to any form of monitoring anywhere. There is recent evidence that BMAA may enter the food chain in the Baltic Sea, with the highest levels in the brain and muscle of bottom dwelling fishes (Jonasson *et al*., 2010). Of all these toxins, the microcystins may be the most problematic due to the fact that they inhibit protein phosphatases 1 and 2a (MacKintosh *et al*., 1990) and consequently are potent tumour promoters.

Mechanisms for tracing freshwater toxins and their producer organisms in coastal environments will be needed in order to assess the risks for human and environmental health of land-based processes. Bioavailability, biodegradation and biomagnification of these toxins need to be investigated, especially in microcystins, BMAA and cylindrospermopsin, owing to their ubiquity, resistance and toxicity. In marine coastal waters, phytoplankton and phytobenthos analysis should be extended to freshwater species whenever signs of freshwater eutrophication are clear. Early warning molecular methods such as qPCR may be used because they detect reduced numbers of cells and toxin producing genotypes (Martins and Vasconcelos, 2011).

Pharmaceuticals from the Sea

Natural products from the environment, including the oceans, have been used by humans for thousands of years to treat and prevent illness, and as a source of nutrition. With issues of increasing antibiotic resistance of human pathogens and the need for new cancer chemotherapy and AIDS drugs over the past 2-3 decades, in a process also known as "bioprospecting," researchers have started to actively seek new pharmaceuticals and other compounds from the vast biodiversity of organisms found in the oceans (Galeano, 2011; Hughes, 2010; Jones 2009; Skropeta, 2008; Gerwick, 2008; Fenical, 2006; Marine Board, 2010). For example, more than 50% of the current anticancer drugs are natural products or derived from a natural origin, many of these originally from marine organisms (Mudit, 2011). Some ma-

FIGURE 2.20.
Left: A colony of the marine tunicate *Ecteinascidia turbinata* (left) which is the source of the anticancer agent trabectidin, commercially available as Yondelis® (© PharmaMar, S. A.). Right: Structures of antitumor and antiviral drugs created on the basis of marine natural products, including Trabectidin (from Stonik, 2009).



rine organisms are known to produce secondary metabolites with pharmaceutical potential (Fleming, 2006). Globally, the marine pharmaceutical pipeline consists of three US FDA-approved drugs, one EU-registered drug and thirteen natural products at various stages of clinical testing (Mayer, 2010). The technical and economical potential of using the marine biota for its therapeutic benefits is considerable, but will require inputs from many areas of clinical, pharmaceutical and marine science if this potential is to be exploited in the future.

Marine organisms are genetically highly diverse and have adapted to extreme environments ranging from deep sea vents to coral reefs (Thornberg 2010, Skropeta 2008, Gerwick 2008, Fenical 2006). These qualities make them ideal as sources of novel approaches to terrestrial problems. For example, marine sponges are sessile, but they have developed a wide range of bioactive products to protect themselves from predators; some of these compounds (e.g. discodermalide) can inhibit cancer cell growth at minute concentrations. The marine snail, *Conus magus*, has developed a powerful neurotoxin as a defense mechanism which has been licensed as Ziconotide for intractable neuropathic pain. Marine bacteria and other organisms are being explored for novel antibiotic compounds to address the increasing resistance of human pathogens to most currently available antibiotics. A very recent discovery is the ability of peptides from a marine algae and protozoan to induce an immune reaction to HIV (Su *et al*., 2013). Finally, the marine environment is also a source of other bioactive compounds ranging from natural antifouling substances to cosmetics, as well as important sources of nutrition and possible future biofuels (e.g. algae) (Camps, 2011; Gerwick, 2008; Fleming, 2006b).

Marine organisms can serve as sentinel species for human health, and as potential models of human disease (Walsh, 2008; Bossart, 2006; Fleming, 2006b; Grosell, 2006). For example, the *Aplysia* or "sea hare" is an organism with a very simple and well understood nervous system. These organisms have been used to explore the function of the developing and mature human nervous system, resulting in the awarding of the 2000 Nobel Prize in Physiology or Medicine to Dr Eric Kandel. In recent years, marine mammals such as dolphins and sea lions have demonstrated severe health effects ranging from infections and neurologic illness to cancer due to their exposure through the food chain and the ocean waters to mixtures of anthropogenic pollution ranging from antibiotic resistant bacteria to harmful algal bloom toxins to persistent organic pollutants. These animals serve as a warning or sentinel of both the harm to the oceans from humans, and the consequent potential harm to human health.

While there is clearly significant potential in marine biodiscovery, there are limitations to this harvesting of natural products and organisms from the world's oceans. As with many issues related to oceans and human health, it is clear that anthropogenic impact upon the oceans, both coastal and deep sea, can have significant and wide ranging consequences. In particular, the threat from microbial and chemical pollution, general environmental overuse and degradation, and global climate change threaten the diversity of marine life (Rogowska, 2010; Pandey, 2009; Fleming, 2006b). This loss will have direct impacts on our ability to explore and discover new compounds and organisms with direct and indirect benefits on human health and wellbeing.

The strategic development and research priorities for European marine biotechnology are set out in the 2010 European Marine Board position paper, "Marine Biotechnology: A New Vision and Strategy for Europe" (Marine Board, 2010).

2.6 Social and behavioural aspects: people and the sea

Managing and mitigating the effects of human activities on the structure and function of coastal and freshwater ecosystems in a whole ecosystem context is emerging as a unifying theme for environmental protection, resource management and integrated environmental management (Allen, 2011; Moore *et al.,* 2011). The overall problem is, how can we develop effective procedures for environmental management, impact assessment, and risk evaluation, which take account of human health, economic and other societal issues?

Effective coastal and estuarine management has the prerequisite of a sound foundation of scientific research and understanding of environmental processes. Moreover, programmes for environmentally sustainable management of coastal areas must engender a move away from the traditional sector by sector management practices towards a cross-sectoral approach. This requires collaboration between environmental managers (i.e. in national and international environmental protection agencies) and research centres with the strategic capability to understand processes of change and the impact of human activities upon the natural environment. In addition, it is important that the various governments, regional organizations (e.g. EU) and global UN organizations (e.g. the Global Environment Facility or GEF, the United Nations Development Programme UNDP, the United Nations Environment Programme or UNEP, IOC-UNESCO – Inter-Governmental Oceanographic Commission, United Nations Educational, Scientific and Cultural Organization; IMO – International Maritime Organization; WMO – World Meteorological Organization; WHO – World Health Organization; & UNIDO – United Nations Industrial Development Organization), which have interests in Intergrated Coastal Zone Management (ICZM) and marine spatial planning, harmonize their activities in order to affect synergies in this global activity.

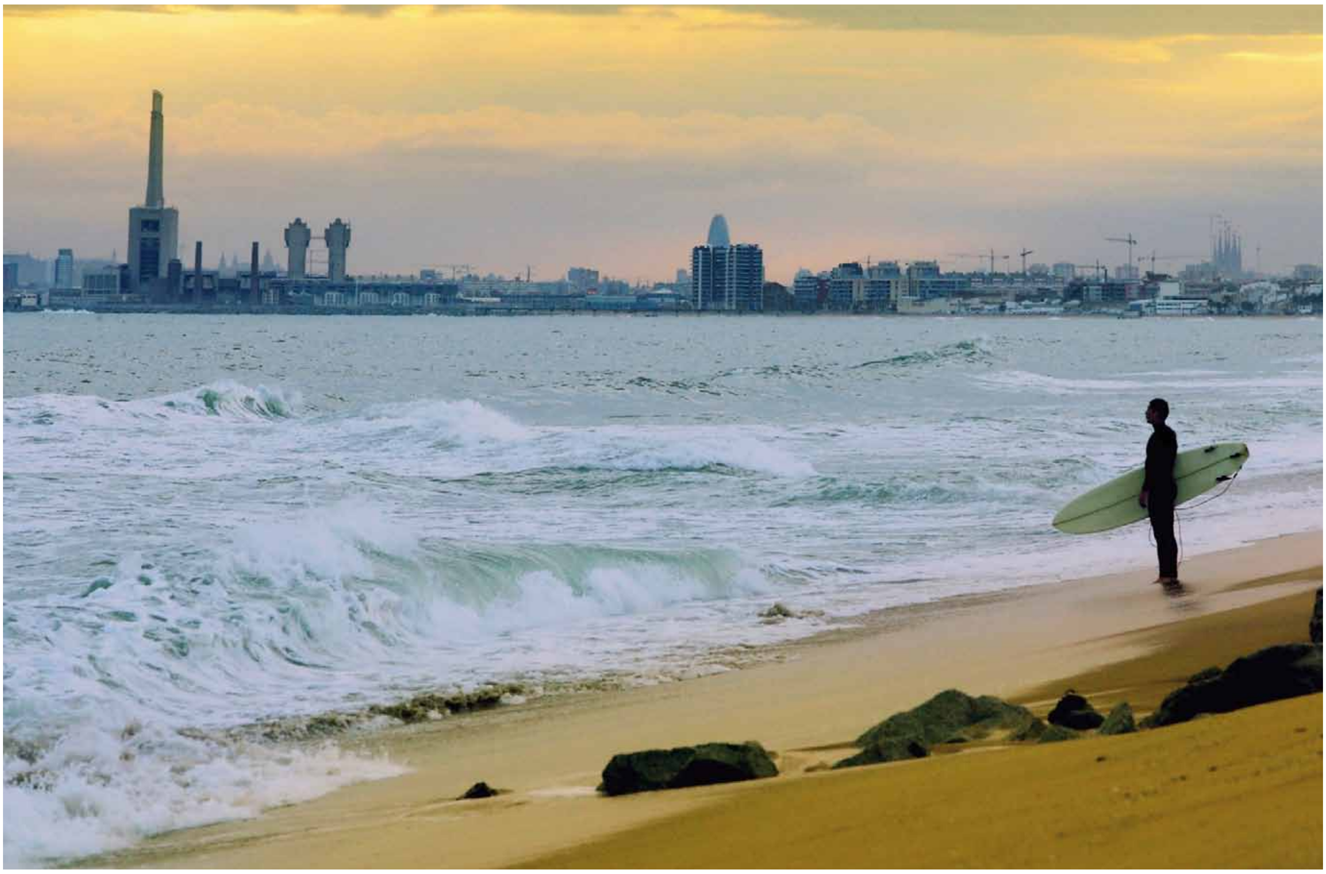


FIGURE 2.21.
Surfer at Barcelona beach in Spain. Various human activities converge on the seas and coastline such as tourism, recreation and maritime industry. (© istockphoto / Caracterdesign)

It is also considered crucial that research programmes address broader socio-economic issues involving people-orientated environmental health-related problems, such as human population pressure. Unfortunately, there is still a relative dearth of substantial epidemiological data that would permit a comprehensive understanding of possible causal links between human and ecosystem health (see *Millennium Ecosystem Assessment*[19], 2005, and World Health Organization[20]). We must work towards a better understanding of how we interact with our environment and what the consequences will be for sustainability of environmental goods and services, and ultimately, for human health. This goal requires that we have the necessary multidisciplinary capacity capable of resolving problems that are intrinsically interfacial in character. By effectively identifying and interconnecting the interdisciplinary elements we will see the emergence of new ways of solving problems in what, at present, are seemingly unrelated areas of environment and human health.

Finally, given the state of the oceans and their undeniable impact on human health, more research is needed on the best methods for changing human behaviour towards the environment on both the individual and societal level, particularly towards the oceans (WWF 2011, World Bank 2010). There are myriads of theories and examples of trying to move humans towards more responsible behaviour in relation to the natural environment. These have ranged for the pure communication of knowledge to the use of short-term financial or social status gains to environmental regulations and punitive laws, each with variable degrees of success. The developing movement in “Ocean Literacy” in Europe has potential to provide a more coordinated approach to improving peoples’ knowledge and appreciation of the oceans and the benefits they provide to human wellbeing.

The Blue Gym effect

There are currently global epidemics of obesity and depression that have arisen as we adopt more sedentary lifestyles, disconnected from nature and living in increasingly urban environments. Recent statistics show that 85% of the UK population live in cities, and recent UK Department of Health statistics indicate that adults now spend only 20% of their time outdoors (Lawton, 2011), while for children, that value is an alarming 9%. Research indicates that re-engaging people with the natural environment encourages greater physical activity (Thompson Coon, 2011), improves mental health (van den Berg, 2010), reduces disease prevalence (*Maas et al*., 2009), and increases life expectancy (Mitchell, 2008). However, this research has focused mainly on “green space” (woodlands, parks, countryside) and very little is known about the potential public health benefits of marine and other aquatic “blue space” environments (Depledge, 2011).

Marine environment and health has predominately been framed from the point of view of risks to health (e.g. chemicals, pathogens and other stressors). Literature in the field is dominated by studies identifying hazards, and assessing and managing risks. Marine products that promote health (including pharmaceutical development) provide an alternative avenue for research, but this is usually considered as a separate field of study. Far less research has been undertaken into the potential for marine and other aquatic environments to directly promote health and wellbeing (Volker and Kistemann, 2011).

The notion that the sea could have therapeutic properties, referred to as Thalassotherapy (from the Greek for sea, Charlier, 2009), was already recognised in ancient times (Jackson, 1990). Indeed by the late 18th Century an influential English doc-

[19] www.millenniumassessment.org/en/index.aspx

[20] www.who.int/topics/environmental_health/en/

FIGURE 2.22.
The Blue Gym is an innovative project originating in Cornwall (UK) utilizing the coastal environment as a resource to promote health and wellbeing by increasing physical activity, reducing stress, and building stronger communities (top: family walk on beach at sunset © Bruno Misseeuw; bottom: jogger on the beach – courtesy Ocean Champions)

tor (Russell, 1760) published a collection of case studies claiming Thalassotherapy could cure a variety of ailments leading to the establishment of several coastal hospitals, such as The Royal Margate Seabathing Infirmary in 1791. Although "spa" and coastal treatments of various kinds remained widespread in Europe for the next 150 years (Fortescue Fox, 1938) their popularity declined after the 1940s in part due to the development of antibiotics. However, faced with the complex health problems of modern populations and the decreasing effectiveness of various kinds of pharmaceutical treatments, there is a resurging interest in the health promoting potential of the coast through such projects as the "Blue Gym".

The Blue Gym[21] is an innovative project originating in Cornwall (UK), but now spreading worldwide, utilizing the coastal environment as a resource to promote health and wellbeing by increasing physical activity, reducing stress, and building stronger communities (Depledge, 2009). The Blue Gym programme is designed to promote health and wellbeing by re-engaging people with outdoor activities in and around coastal and other aquatic environments. The hypothesis is that this may encourage people to both improve their own health, and to value and conserve the marine and other natural environments. Early results are highly encouraging. For instance, analysis of the English Census data (with approximately 40million adults) found that people who lived within walking distance of the coast were healthier than those who lived inland (Wheeler, 2012). Moreover, analysis of an 18 year study of 12,000 adults in England found that the same individuals were happiest and healthiest in years when they lived near the coast (White, Alcock *et al.*, 2013).

In the laboratory, people rate marine and other aquatic scenes as more psychologically "restorative" than urban or green spaces, and are willing to pay more for homes and hotel rooms with aquatic views (White, 2010). Field studies find that visits to the coast elicit greater feelings of calmness and revitalisation compared to visits to urban parks and open countryside (White, Pahl *et al.*, 2013, Barton, 2010). These beneficial effects are consistent across weather conditions (White, Cracknell *et al.*, 2013), and appear to extend to sub-aquatic environments (Cracknell, 2013). Blue Gym interventions engaging disadvantaged youth from coastal communities with their local environment are also starting to show not just psychological benefits, but a greater awareness of the marine environment and the importance of protecting it (White *et al*., 2012). However, all of these results are from the UK, an island nation with strong cultural connections with the sea. Although we see no reason why the effects might not also exist throughout Europe's many coastal nations there is much work still to be done to explore how widespread and generalizable the effects are and the potential implications for coastal ecosystems and infrastructures if the coast were to be promoted for its health-enhancing properties.

[21] www.bluegym.org.uk

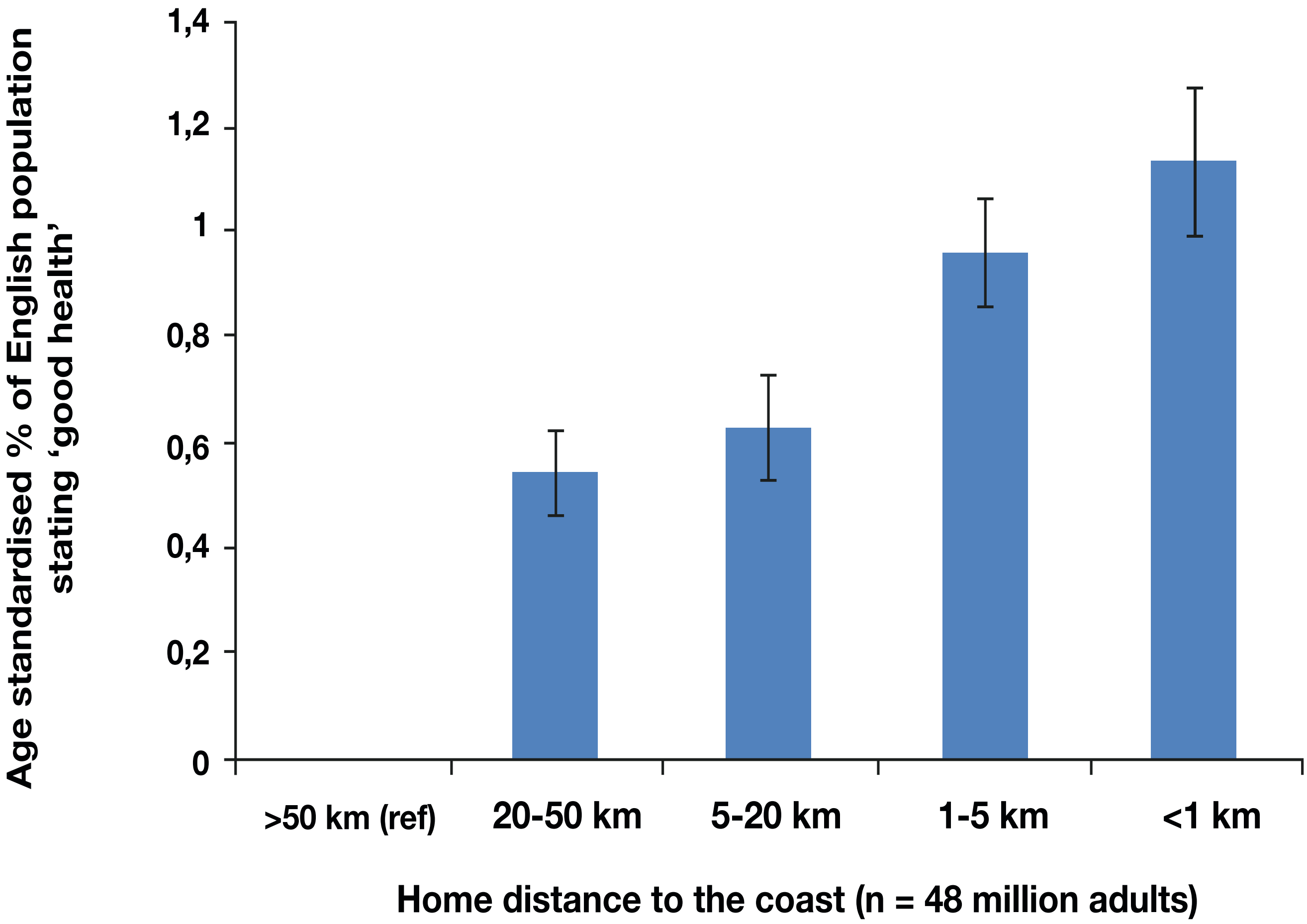


FIGURE 2.23.
English census data on relationship between coastal proximity and stated health status (adapted from Wheeler *et al.*, 2012)

3

Addressing the public health challenges presented by the seas and oceans

credit: Joanna Rodrigues

3.1 Interdisciplinary systems approach incorporating environmental, biomedical, socio-economic and epidemiological methods

Development of an integrated interdisciplinary framework

Ecosystems that encompass all modern human activity have been profoundly modified or completely altered to both the detriment and the benefit of human health and society. Therefore, society must weigh the benefits against the risks associated with development and progress and make sometimes difficult but necessary choices (International Risk Governance Council, 2010). However, the negative effects have not always been immediately obvious, given the difficulties inherent in "future-proofing". In many cases, the direct and indirect impacts on human and ecological health associated with urbanization have been subtle, and we were slow to recognize these stresses. Because we did not understand human-ecological interactions, we could not calculate appropriate risk-benefit ratios. Thus, an integrated explanatory framework for adverse changes in whole systems, from the physical environment to marine biodiversity to human health and ecosystems is required.

Whereas considerable progress has been made to address the more obvious problems, there is concern that the increasing effects of urbanization, poorly regulated industrial development and habitat destruction on human and ecological health may go undetected until more sensitive sectors of society or ecological indicators are adversely affected. Thus, in this chapter, a case is made for the identification, quantification, and application of biological indicators of ecological integrity, as well as to determine the similarities and differences in responses of various aquatic ecosystems to stress. Our objectives in this respect are two-fold:

1. Identify appropriate diagnostic and prognostic markers of health of the environment that might be used as sensitive indicators of the stresses that result in biological or ecological damage;
2. Reconcile various prognostic marker responses with ecological consequences that have a human-health relevance.

Integrated modelling tools required for effective health management and prediction

As already stated, a systems-based approach will be essential. This requires the development of a hierarchy of interacting and overlapping computational models, integrating those elements essential for effectively predicting ecological health risks. Achievement of this goal will require the integration of functional ecological expertise with that of environmental physics, chemistry, toxicology and epidemiology. Such an interdisciplinary approach can provide insights into the relationship between ecological and human health. As a sub-objective, it will also be necessary to derive new strategies for improving risk evaluation, as well as countering the new pollution problems that will arise though the expansion in the quantity and variation of chemical and material pollution entering the marine environment.

In the past decade, genomic and proteomic technologies have spectacularly expanded the methodology and explanatory capability of the biological sciences. One of the next major challenges will be to provide a mechanistic explanatory and predictive framework for the integrated expression of emergent function in whole systems such as cells, organs, animals and even ecosystems. System function emerges through the interactions among the components of the system in question (e.g. cellular proteins, cells, tissues, individual organisms, populations and assemblages or communities) and the integrative emergent properties or "biocomplexity" of the system are "computed" by these interactions. Consequently, the system can be viewed as a biological computer. Therefore, if we want to explain complex physiological or ecological functions, as well as various pathologies and diseases induced by environmental stressors (including pathogens and pollutants), then we must follow nature's computational example and develop a predictive simulative capacity that exhibits emergent behaviours alongside our existing experimental methodology.

This new methodology of biological systems modelling for human health is heavily reliant on cell-based physiological and pathological simulation. These types of simulation provide an essential complement to experimentation and will increasingly play a central role in the investigation of normal function, responses to environmental signals (eco-physiomics), environmental toxicology and disease processes. Novel modelling tools are needed that will allow physiologists, epidemiologists, epizootiologists and environmental toxicologists to search for possible pathological targets for environmental stressors in a rapid and rational manner. This search will be carried out in models of physiologically normal systems, as well as disease models, in order to facilitate prediction of relevant environmentally-related endpoints and synergies.

The need for an integrated approach in the development of effective environmental and public health policies on a regional and global scale

While it is recognised that healthy ecosystems provide basic goods and services to humans and other organisms, some of these are so basic (for example, air and water quality) that they are taken for granted when ecosystems are healthy. However, when the buffering capacity of aquatic ecosystems is exceeded, as in many highly industrialised areas, there is frequent evidence of compromised human health, particularly in the developing world (e.g. Bangladesh arsenic problem and water-borne diseases). It is probably a reasonable assumption that such phenomena have impacted other organisms as well.

Unfortunately, the necessary epidemiological data for pollutant impact on sentinel animals that should permit a comprehensive understanding of possible causal links between ecosystem integrity and human health, are often limited or fragmentary, both spatially and temporally. Consequently, alternative interdisciplinary approaches will be required to identify such links, but interdisciplinary thinking must indeed extend beyond the boundaries of individual scientific disciplines. Unless this can be effectively applied, disciplinary boundaries become impermeable to intellectual synergy and hinder the enlightenment we find only at the interfaces between disciplines.

Improving our understanding of the linkages between ecological integrity, environmental services and human health, will be necessary as we strive to achieve an acceptable standard of living for many more people, while at the same time ensuring that the ecological pillars which support our society and industries are protected and remain sustainable. We must successfully integrate social and natural systems on a local scale, while understanding the larger scale ramifications and consequences of decisions on a local, national and trans-national scale. Our knowledge of the biosphere and our connections with it must be adequate to inform policy and decision-making.

Harmful impacts of pollutants on ecological integrity are complex, often subtle, and may go undetected until a major problem arises. However, effective risk evaluation and forecasting of impact requires a capability for interpreting and integrating complex environmental information that is currently lacking (International Risk Governance Council, 2010). A practical solution to this problem lies in a "whole systems" approach to the development of early-warning strategies for assessing risk to aquatic ecosystem function and health, which effectively integrate physical, chemical and biological processes. To achieve this, we need an innovative approach and can use existing environmental data and diagnostic tools for the detection of "distress signals" and evaluation of "ecosystem health status" in novel ways. Integration of this complex information can be achieved using whole system-based simulation modelling; this will also facilitate the targeting of current "knowledge gaps" and how to fill them.

Consequently, a hierarchy of overlapping computational models will be needed, each capable of interacting with the others (Allen & Moore, 2004; Allen, 2011; Moore *et al.,* 2011). Development of these models will need to be hypothesis-driven and will, of necessity, integrate physical and chemical processes with ecosystem function using a systems biology approach. The aim here will be the development of an affordable pre-operational predictive toolbox to aid decision-making in a systems-based holistic way for advising environmental policy formulation. Achievement of this aim will require an interdisciplinary evaluation of the existing physical and chemical parameters, diagnostic and prognostic biomarkers of health status, and indices of biodiversity and ecosystem integrity currently used as indicators of biological and ecological damage. This process will also include an assessment of the ecological resilience of critical habitats, like river basins and coastal zones.

FIGURE 3.1.
Ecosystems that encompass all modern human activity have been profoundly modified or completely altered to both the detriment and the benefit of human health and society. Therefore, society must weigh the benefits against the risks associated with development and progress.

3.2 Improved tests for detecting pathogens in seawater and seafood

The marine environment contains millions of different types of microorganism that are both naturally occurring and foreign; and a number of these microbial agents have been linked to human diseases (Thompson *et al.,* 2006). Until recently, the identification of pathogens - including bacteria and viruses found in seawater and seafood - was a lengthy and labour-intensive process that frequently provided insufficient information to either identify pathogens of interest or to define precise relationships between particular strains. Such limitations are particularly problematic from the standpoint of many clinical, diagnostic and regulatory sectors, where it is often necessary to identify and categorise pathogens quickly, reliably, and cheaply, and often across a range of different matrices, such as seawater, seafood produce, clinical samples etc. Several new and improved approaches have circumvented many of these problems and form the basis of a new generation of methods in this field. These approaches can be broadly classified into identification and typing-based techniques, essentially based on the level of biological identification required (e.g. genus, species, strain etc.).

Among molecular methods, the polymerase chain reaction (PCR) has been used extensively now for almost three decades as a means to identify pathogens of interest. PCR remains the mainstay of molecular methodologies for identifying and typing bacterial and viral pathogens in most clinical, regulatory, diagnostic and food safety sectors. Essentially all clinically-relevant pathogens in seawater and seafood, including major bacterial groups (*E. coli*, Enterococcus, *Vibrio* spp. Salmonella spp. etc) and viruses (Norovirus, Hepatitis A and E, Enteroviruses, Sappoviruses, Polio viruses etc), have established and well characterised PCR test assays published in the peer reviewed literature. The last decade has seen the evolution of real-time PCR, which when linked to appropriate sample processing and nucleic acid extraction approaches has facilitated the accurate, reliable and quantitative identification of these pathogen groups in both seawater and seafood matrices. Again, the majority of marine-borne human pathogens (bacterial and viral) have established and well characterised real-time PCR methods available for such purposes.

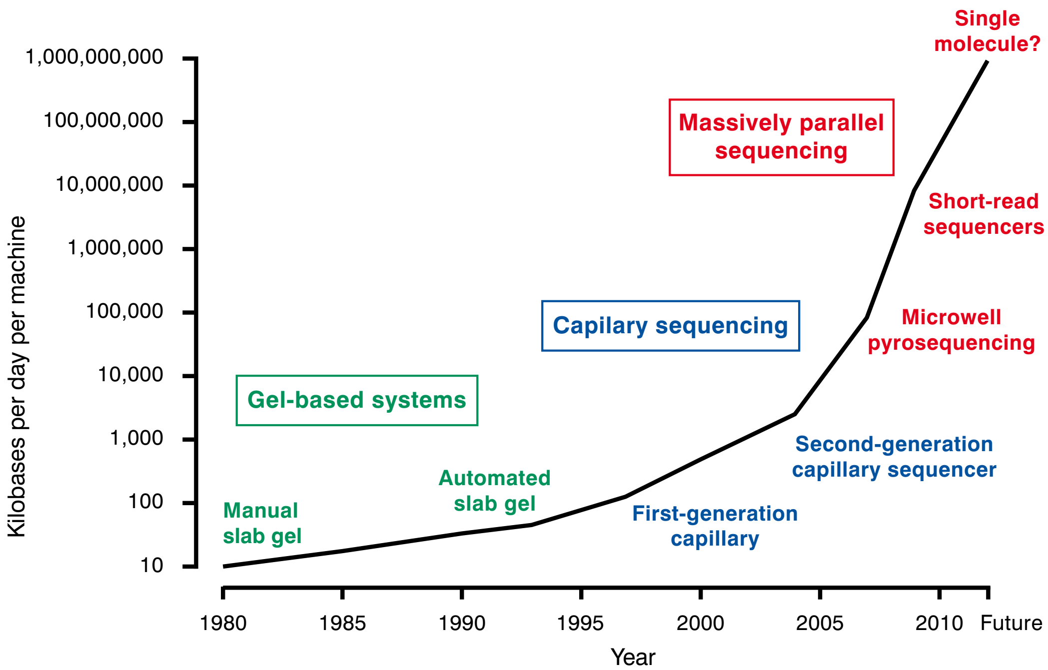
It is worth noting that molecular approaches are essentially the only reliable methodology to identify slow-growing or non-cultivable pathogens, such as human noroviruses. A pathogen detection method termed loop-mediated isothermal amplification (LAMP) was developed by Notomi *et al*. (2000). LAMP, which is carried out in a single tube, allows the rapid amplification of DNA with high specificity under isothermal (single temperature) conditions using a novel enzymatic reaction. LAMP has several advantages as a pathogen detection tool over other current and existing methods. Firstly, LAMP uses several specific targets, increasing the specificity of the reaction compared to other molecular approaches (Nagamine *et al.,* 2002). The enzymatic reaction is catalysed at 60-65°C, so the use of a PCR machine is not required. Detection is achieved using simple UV light; Bright fluorescence indicates a positive reaction, negating the need for cumbersome and complex visualisation techniques required for other tests. A wealth of reports have successfully used LAMP to detect important seafood pathogens such as *Vibrio cholerae* (Yamazaki *et al*. 2008), genotype I and II Norovirus (Fukuda *et al.,* 2006), *Vibrio vulnificus* (Han *et al.* 2008) and *Vibrio parahaemolyticus* (Chen and Ge, 2010). A key advantage of these tests is that they can be used as portable devices, potentially allowing the user to sample pathogens directly in the field.

A driving force behind the emergence of many molecular techniques is a regulatory need to provide rapid information to a range of different stakeholders in a timely manner. The assessment of water quality provides one good example. The

USA Environment Protection Agency (EPA) recently discussed the use of qPCR tests for enterococcus in surface waters, as part of their recommended recreational water quality criteria (RWQC), which is designed to protect human health in inland and coastal waters (EPA 2012). The EPA has subsequently developed and validated qPCR as a rapid analytical technique for the detection of enterococci, and provided information on its use and application (EPA Method 1611). Although there is currently no direct regulatory requirement for its use, this methodology is particularly promising as it may provide near 'real time' data for state-level management of faecal monitoring in a variety of site specific areas, such as beaches that regularly exceed regulatory water quality thresholds for *Enterococcus*. Another area where regulatory need has driven the evolution of new pathogen testing approaches is seafood safety. For the first time, a range of fit-for-purpose and robust molecular testing platforms are now available for major seafood pathogens, such as human Noroviruses (NoV), and hepatitis (Lees, 2010). These methods, utilising qPCR now offer quantification of enteric viruses in a range of shellfish matrices (among other food commodities), which will have major ramifications in food safety and international food regulatory sectors.

It is frequently necessary to identify not just a bacterium or virus present in a particular matrix, or implicated in a foodborne outbreak, but to provide more detailed information regarding the pathogen in question. A key development that is rapidly expanding the ability to type, analyse and track pathogens has been the advent of cheap and accessible high throughput sequencing approaches coupled to simplified downstream bioinformatics platforms (Köser *et al.,* 2012). These approaches can either be used in a targeted fashion, e.g. to identify and type strains directly from pure culture, or as part of a metagenome approach where particular matrices are fully sequenced, and pathogens of interest are mined *in silico* for bioinformatic identification and characterization purposes (Belda-Ferre *et al.,* 2011). This marked evolution in sequencing – used as a practical tool in epidemiological investigations –

FIGURE 3.2.
Improvements in the rate of DNA sequencing over the past 30 years and into the future (From Stratton et al., 2009, Nature 458:719-724)



was demonstrated by the rapid identification and tracking of the *Escherichia coli* O104:H4 strains responsible for serious foodborne outbreaks in Europe in 2011 (Grad *et al.,* 2012; Mellmann *et al.,* 2011) as well as the recent analysis regarding the origin and global spread of pandemic *V. cholerae* pathotypes (Mutreja *et al.,* 2011).

Several molecular approaches underpinned by the development of whole genome sequencing (WGS) as well as high-throughput typing methods, form the basis of a new generation of experiments that can be used to generate testable hypotheses regarding the routes of pathogen emergence, dissemination and evolution in the marine environment. Of these, the most applicable approaches involve high-throughput sequencing coupled to single nucleotide polymorphism (SNP) identification and phylogenetic determination of pathogenic strains. A major advantage of this approach is the ability to sequence hundreds of microbial genomes and compare them, rapidly and easily, using free open access software. In essence, this approach can be used to determine the geographical structure within particular pathogen lineage(s), the possible source as well as routes of geographical transmission of a particular pathogen and important clinical information such as carriage of antibiotic resistance or new or novel virulence attributes. Such information will have profound ramifications for infectious diseases, as well as microbial ecology.

In summary, molecular methods have revolutionized our capacity to detect, identify and quantify pathogens in seawater and seafood. They offer huge potential to address emerging and well recognised problems in this field. However, currently the uptake of such methods into a risk management and regulatory framework to improve human health protection is fairly limited. A significant research need, therefore, is for applied field studies demonstrating how these methods can be best applied in a real world risk management context. The US EPA have made an important contribution in this regard with molecular methods for faecal enterococci determination. By contrast, the EU has made little progress towards evaluation of molecular methods for risk management in, for example, bathing waters. The best example of progress towards molecular methods for pathogens is in the field of Norovirus contamination of bivalve molluscs. Similar studies for other pathogens and matrices is now required.

FIGURE 3.3.
New pathogen testing approaches for seafood will have major ramifications in food safety and international food regulatory sectors.
© Parc Marin de la Côte Bleue

3.3 Improved tests and protocols for harmful nanoparticles and chemical pollutants in seafood

In the past decades research has clarified how organisms reorganise their physiological processes to adapt to their environment in the presence of different types of stressors. Particular attention has been paid to the more important molecular and cellular responses to the more diffuse classes of organic xenobiotic pollutants. More recently, a set of biological parameters (biomarkers), able to indicate the response to particular classes of chemicals (biomarkers of exposure) or the overall toxic effects of the pollutants accumulated in the organism (biomarker of stress), have been identified. This has been achieved largely in the framework of the Programme for the Assessment and Control of Pollution in the Mediterranean Region (MED POL), the Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic (OSPAR), and International Council for the Exploration of the Sea (ICES). A selection of the biomarkers that, in different organisms may be suitable to indicate a response to certain classes of chemicals, is today used in different international biomonitoring programmes to determine the biological sub-lethal effects of toxic chemicals or their mixtures. Therefore a starting point to determine the health status of organisms that represent the usual "seafood" may be the use of the biomarkers to understand, through some low-cost analysis, if the organisms reaching consumers are contaminated by toxic chemicals.

An example may better clarify this approach. Fish that are contaminated by organic aromatic xenobiotics should show, in empathic cells, high levels of cellular mixed-function oxygenase (MFO) activity. If the chemicals are genotoxic (capable of damaging the genetic information within a cell, potentially leading to mutations), it should be possible to point out DNA damage in the cells and increased micronuclei frequency. In the bile it should be possible to find fluorescent pigments with typical spectrofluorimetric spectra. In fish exposed to xenoestrogens, it should be possible to detect an abnormal presence of vitellogenin in the plasma of male fish. A decrease in acetylcholinesterase activity will indicate that the organism was exposed to pesticides. However, in the case of heavy metals, it is now clear that in fish, metallothionein (a protein, the concentration of which increases in an organism exposed to heavy metal) may increase also in response to organic chemicals able to induce oxidative stress. However, both the toxic effects of metals and of organic xenobiotics are clearly indicated by elevated levels of organic stress markers or by the presence of oxidative stress or by the genotoxic effects of the pollutants.

In this example, the health status of the fish is evaluated by the use of 4-5 simple biomarkers to analyse the liver and blood of the fish, together with a simple histological analysis of the organ. This may indicate whether the total accumulation of pollutants in the organism represents a risk to human health. Therefore, animals in which the response to specific classes of chemicals is known and in which toxic, genotoxic, and hormonal markers are not elevated over control level should represent safe food for the consumers.

More recently toxicogenomics, proteomics and metabolomics have started to give a more in-depth comprehension of the biological responses to the toxic effects of many different chemicals. However DNA microarrays, a classical tool in toxicogenomics, have been developed and used only on a certain number of fish and mollusc species. A generalized use of these methods to evaluate the effects of bioavailable contaminants on "seafood" is not yet established.

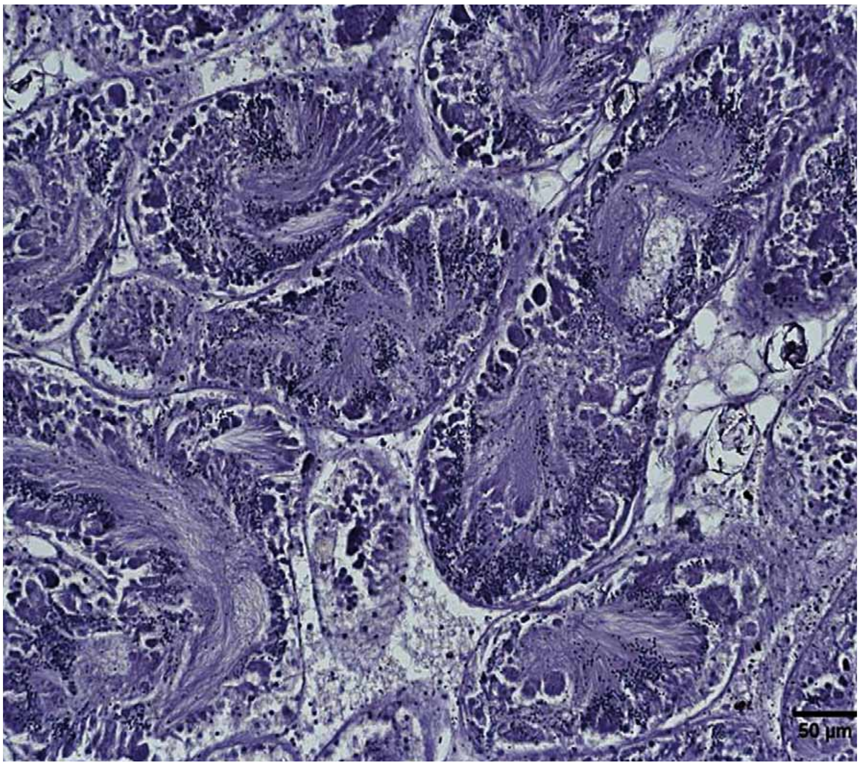


FIGURE 3.4.
Histological analysis is often used to look for cellular responses to organic xenobiotic pollutants. Credit: Veronica French

The use of qRT-PCR allows the precise detection of the change in the amount of specific mRNA. This approach is simpler and of lower cost than the use of a DNA microarray, but its general use as a method for the detection and quantification of specific mRNA in different organisms belonging to different phyla has yet to be proven. However, as mentioned above, the mRNAs to be investigated should be those coding for highly-conserved proteins such as benzo(a)pyrene hydroxylase, metallothionein, antioxidant enzymes, oxidative damage markers, heat shock proteins and proteins involved in DNA repair.

The use of proteomics is at a starting point; although very promising, this technology does not seem ready, today, for a large application in the evaluation of "seafood" quality. In fact, proteomic analyses are expensive (reagents and equipment) and time-consuming. The quantification of protein changes in the sample analysed by 2D electrophoreses needs 5-10 replicating experiments and the use of isotopic labelling is also currently very expensive. In addition, a Maldi TOF approach is usually not sufficient to identify the protein from an organism whose DNA is not fully sequenced. The protein identification needs the "novo" amino acid sequencing, requiring instruments such as an MSMS/TOF or TOF TOF which are expensive and complex to operate.

The data concerning metabolomics analysis seems to represent a possible future application in the field of food quality. However the use of equipment such as the NMR 500 triple quadrupole or TOF-TOF is highly expensive and, as for proteomics and genomics, the analysis of the results is complex. Therefore, system toxicology represents an area of secure development in the field of ecotoxicology and probably, in the coming years, will contribute considerably to the development of food quality/ toxicology analysis with the development of low-cost tools for simple and fast utilisation, capable of describing major characteristics of seafood in terms of both quality and security.

3.4 Warning signals from the marine environment: clinical-type tests on sentinel organisms

Harmful biological effects indices of environmental impact should be considered as potential early indicators of adverse interactions with human health. These indices can include molecular and cellular biomarkers for pathology, as well as higher level patho-physiological effects, which are determined either by biomonitoring or laboratory-based toxicological testing. A broad approach to the complex problem of assessing the "health of ecosystems" will facilitate the validation and further the essential new development of robust and rapid tools for assessment that will provide indicators for public health risk (Bowen & Depledge, 2006; Brander, 2007; Depledge *et al*., 1993; Ferson & Long, 1996; Galloway, 2006; Jha *et al*., 2000; Moore *et al*., 2004; Owen *et al*., 2008; Rice, 2003). Future efforts should focus on an integrated approach to the validation of biomarkers that are prognostic for ecological endpoints and that also have implications for human health, such as food safety (Bowen & Depledge, 2006; Depledge *et al*., 1993; Galloway, 2006; Todd, 2006; Moore *et al*., 2004; Owen *et al*., 2008). As with bioavailability and uptake, exposure to pollutant mixtures must also be considered with the possibility of complex synergistic interactions resulting in emergent and novel toxicities and pathologies (Howard, 1997; Kortenkamp & Altenburger, 1998; Warne & Hawker, 1995).

Coastal marine ecosystems are sensitive to exposure to toxic contaminants. Pollutants either individually, or in combination, may have sub-lethal effects at the cellular, organ and individual level, (e.g. causing changes in genetic, behavioural and reproductive activity). Particular species have been identified as indicators of this sensitivity, including the edible mussel, periwinkles, crabs and several species of fish (Altieri *et al*., 2007; Bayne *et al*., 1988; Stebbing *et al*., 1992). Biomarker responses for such sub-lethal effects include a variety of measures of specific molecular, cellular and physiological reactions of these species to contaminant exposure. A biomarker reaction is generally indicative of either contaminant exposure or poor health. The challenge is to integrate individual biomarker reactions into a set of tools and indices capable of detecting and monitoring the degradation in health of a particular organism.

Cellular and molecular biomarkers in fish and molluscs, coupled with histopathology provide a powerful set of "health status-related" assessment tools (Allen & Moore, 2004). Adverse molecular and cellular functional reactions, are often good indicators of cell injury and animal health status. In a situation where exposure to environmental stressors is likely to be sustained, biomarkers can be used to predict that further pathological changes will occur. Biomarkers for functional lysosomal and autophagic perturbations also appear to have potential as a measure of damage to ecological health (Moore *et al*., 2006).

Environmental Prognostics has previously been proposed as a branch of systems biology that is specific to the reactions of organisms to both natural and anthropogenic stress (Allen & Moore, 2004). Although biologists have been reducing life to its constituent parts for over 50 years, the new challenge is to reassemble these data to determine how complex systems, from subcellular processes to organisms, work. Systems biology attempts to reconstruct biological systems by developing and evolving series of overlapping conceptual, numerical and statistical models (Hunter, 2003), a process involving the interaction of experiment and simulation in an ongoing iterative process. Cell-based simulation models have also been successfully developed for molluscan hepatopancreas or liver analogue (McVeigh *et al*., 2006).

The use of coupled empirical measurements of biomarker reactions and modelling is proposed as a practical approach to the development of an operational toolbox for predicting the health of the environment and this has been manifested in the form of a decision support or "expert system" that can be used to categorise harmful environmental impact. This decision support system can be used to categorise environmental risk in populations of sentinel animals (Dagnino et al., 2007).

The current evolving ecosystem approach to marine environmental management requires that the cumulative effects of all conceivably relevant impacting human activities are considered. Work by Defra in the UK has shown that, although *performance indicators* play an important and essential role in environmental protection, these indicators do not allow us to say with confidence that, for example, the coastal seas are in a healthy state. Consequently, Defra have identified the requirement for a further category of indicators that can demonstrate that ecosystems are healthy (Altieri *et al*., 2007). These are known as *indicators of state* (Defra, 2005).

3.5 Epidemiological modelling of the health of coastal human communities

Increasing numbers of people worldwide have moved to live, work and play along coastal areas around the world's oceans. As discussed previously, coastal living is associated with both risks (e.g. natural events and extreme weather, sea level rise with climate change, microbial and chemical pollution, and HABs) and benefits (eg. access to jobs and commerce, to food supplies, and to the natural environment) for these human populations (Dewailly, 2002; Fleming, 2006; Knap *et al*., 2002).

The epidemiology (i.e. the study of the risks and health effects) of coastal human communities is in its infancy (Backer & Fleming, 2008; Kite-Powell *et al*., 2008). In developed countries, there are good data about the numbers and types of people living in coastal communities. However, there has been very little exploration of the short- and long-term exposures, health effects, and other consequences of living near the oceans for these coastal communities. In developing nations, there are little to no data on even the demographics (i.e. population numbers and characteristics) of their rapidly expanding coastal populations. Hence, in these countries, there are not even established baselines to monitor change in the exposures and health of expanding coastal populations.

Furthermore, only limited research has been done to identify those vulnerable populations at particular risk, either due to their innate vulnerabilities (e.g. the extremes of age, socio-economic factors, or underlying ill health), or their residence in higher-risk environments (e.g. coastal communities), or a combination of vulnerabilities. With increasing impacts of climate change and other oceans and human health challenges, these populations must be identified as being particularly vulnerable worldwide, and targeted for adaptation and mitigation interventions (Backer *et al*., 2008). However, while more could be done to consider what populations may be most vulnerable, even more important is the lack of surveillance and epidemiology research concerning these vulnerable populations.

There has been some epidemiologic work looking at the effects of specific chemical pollutants (e.g. methyl mercury and persistent organic pollutants in fish), microbial pollution (particularly of recreational marine waters), specific HAB exposures (e.g. brevetoxins and ciguatera fish poisoning), and coastal disasters (Fleming, 2006). However, there has been no epidemiologic research evaluating this rich mixture of exposures that coastal populations experience. Furthermore, even in developed nations, there are very limited surveillance mechanisms in place to monitor possible changes in exposures and health in coastal populations. In addition, although integrated ocean observing systems are being established globally to monitor oceanographic events using satellite, ship, and buoy technology, there has been relatively little communication between the oceanographic and public health (including epidemiologic) communities to explore possible interactions and collaborations of separate observing systems around coastal populations beyond specific examples of early warning systems for tsunamis and hurricanes (Kite-Powell, 2008). Therefore, as the world's coastal areas are increasingly impacted by human populations, it will be difficult to evaluate the impact this will have on the health and wellbeing of coastal populations as well as coastal ecosystems.

FIGURE 3.5.
Increasing numbers of people worldwide have moved to live, work and play along coastal areas around the world's oceans.

3.6 Knowledge management, communication and maximizing the science policy interface

There is a broad consensus that, as a society in Europe, we must change unsustainable domestic and industrial practices that may have been acceptable in the past but will not be acceptable in the future (see ICS-UNIDO[22]). These changes will occasionally be dramatic and at other times will be slow and less overt. Changes will occur in the choices that we make as individuals, in the technologies and solutions to problems that we demand from industry and government, and in the role that communities, in the broadest sense, play in decision-making.

Rapid economic and population growth are putting increasing pressures on natural resources, and human activities are causing unprecedented environmental changes. At the same time, science is responding to these challenges and knowledge of the interactions between natural environment and human health is continually growing. With the development of new technologies, we are entering an exciting and unprecedented era of biomedical and environmental science. Scientific knowledge can make an important contribution to the economy and improving people's wellbeing. However, if this knowledge remains largely inaccessible or unavailable it will not be used for the benefit of society. The effective management, communication and targeted translation of knowledge will, therefore, be critical to ensure that scientific advances are used to address important and emerging societal challenges.

Engaging with policy formulators and public health decision makers

The last 50 years has witnessed the steady growth of risk-based regulation as a key policy strategy for protecting the marine environment. Arguably, it was Rachel Carson's book Silent Spring in 1963 that propelled appreciation of the widespread impacts of chemical pollution into the public consciousness, catalysing President Richard Nixon to establish the US Environmental Protection Agency nearly a decade later. Since the 1960s and 1970s an increasing amount of legislation has been developed in the environment and health arena. Some of this has been specifically designed for protection of the marine environment (e.g. OSPAR for the North Sea) and various Directives applied across the EU for particular stressors (e.g. the Bathing Water Directive for water quality in the context of pathogens). Other pieces of legislation are not particularly focused on the marine environment but are still highly relevant (e.g. the REACH legislation and the Stockholm Convention on Persistent Organic Pollutants, UNEP – POPs).

REACH illustrates one of two features of policy and regulatory development over the last few decades. Regulation has taken an increasingly precautionary approach and indeed, in the EU, policy is underpinned by an explicit commitment to the precautionary principle (European Community, Lisbon Treaty, Art. 191) and enacted through mechanisms such as 'data before market' legislation enshrined in REACH and other Directives (e.g. those covering pharmaceutical products). The precautionary principle is both defined and applied in different ways (Wiener & Rogers, 2002). A commonly cited version is that defined within the UN Rio 1992 Declaration: 'where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'.

The precautionary principle has been broadened under the ecosystem approach of the OSPAR Commission to encompass all human activities: "By virtue of the precautionary principle, preventive measures are to be taken when there are reason-

[22] www.UNIDO.org

able grounds for concern that human activities may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship. A lack of full scientific evidence must not postpone action to protect the marine environment. The principle anticipates that delaying action would, in the longer term, prove more costly to society and nature and would compromise the needs of future generations."

FIGURE 3.6.
The EU Bathing Waters Directive requires Member States to monitor popular bathing places for indicators of microbiological pollution and other substances

FIGURE 3.7.
Rapid economic and population growth puts increasing pressures on natural resources.

The second feature is best illustrated by perhaps the most important piece of environmental regulation covering the aquatic and near-shore environment to emerge in recent decades, the EU Water Framework Directive (WFD - 2000/60/EC; EU Water Framework Directive, 2000). The WFD is underpinned by an integrated risk assessment and management approach, whereby there is consideration of both chemical and ecological status in defining water quality, with 'ecological status' incorporating biological, physico-chemical and hydro-morphological elements (Vincent *et al*., 2002). Water bodies (including rivers, lakes, estuaries, coastal waters and groundwaters) are periodically assessed and assigned to a classification system that grades their deviation (high, good, moderate, poor and bad) from a comparable site having no or very minor disturbance from human activity (Environment Agency, 2002). Programmes of measures (e.g. risk management) are put in place to facilitate meeting the WFD's overarching environmental objective for all water bodies to achieve "good ecological status" by 2015. This illustrates a move towards more holistic, integrated risk assessment and risk management approaches, in which ecological goals and assessment methods play a more prominent or even a central role. This integrated approach recognises the complex multifactorial nature of environmental risks and the need to apportion these to specific pressures such as diffuse agricultural pollution and point source discharges from industrial complexes or sewage treatment works.

Within the coastal zone, this integrated approach has been expanded further through the concept of Integrated Coastal Zone Management (ICZM), supporting regional transboundary-level programmes for inter-governmental bodies (Brander, 2007; McGlade, 2001; Moore & Csizer, 2001). This essentially "systems approach" assesses the changing states of coastal ecosystems using science-based information, linked to socio-economic benefits for countries sharing or bordering on large estuaries and deltas. The methods can be used in an integrated interdisciplinary way in order to address the consequences of ecosystem change and the ensuing implications for sustainable use and development of food resources, as well as the needs of industry and the impact on human health.

FIGURE 3.8.
Point source discharges from sewage treatment works are incorporated into the integrated risk assessment and management approach of the EU Water Framework Directive. Credit: Veronica French

ICZM holistically assesses the changing states of coastal ecosystems based on information obtained from five operational modules: (i) Ecosystem productivity; (ii) Fish and fisheries (sustainability & seafood safety); (iii) Pollution and health (both ecosystem & human); (iv) Socioeconomic conditions (poverty alleviation and public health improvement through development, education & investment); and (v) Governance protocols. These modules link science-based information to socioeconomic benefits for countries sharing coastlines or bordering on large estuaries and deltas. The methods can be used in an integrated interdisciplinary way in order to address the consequences of ecosystem change and the ensuing implications for sustainable exploitation and development of food resources, as well as the needs of industry and the impact on human health. It is essential in the use of these methods to always strive to address the needs and welfare issues of regional populations, as well as the requirements of industry, fisheries and agriculture for sustainable economic development (European Commission Coastal Policy, ICZM[23]; World Bank, 1995; Cassar, 2001).

The development of such approaches and tools to support management decisions concerning the marine environment has been an important policy priority over the last 50 years and will continue to be important in the future (e.g. current areas of interest include the development and use of health impact assessment, health damage valuation, human biomonitoring and cost-benefits methodologies as supporting tools).

Further policy priorities in the EU in the general area of environment and health policy have been articulated within the EU Action Plan on Environment and Health (Hester and Harrison, 2011), which covered the period between 2000 and 2010. The

[23] http://ec.europa.eu/environment/iczm/pdf/evaluation_iczm_report.pdf

marine environment is given special consideration within the Action Plan, but it is possible to identify key priorities as these relate to the marine environments that are covered by it. These priorities include better understanding of the links between environmental quality and human health (particularly for vulnerable groups such as the young children and the very old), the development of tools to better characterize causal links (e.g. environmental health indicators, biomonitoring approaches) and the need for integrated monitoring approaches for the environment (including food), to allow the determination of relevant human exposure. Endocrine disruption and the effects of chemical mixtures in the environment are specific areas where more information is needed (Howard, 1997; Kortenkamp & Altenberger, 1998).

Recently, a survey conducted by one of the authors as part of the EU Environment and Health ERANET (a European Research Area Network of environmental agencies, research funders and Government departments across Europe) confirmed that these remain priorities at an EU level (see Information Box 3.1), in addition to other priorities such as better understanding of the risks of emerging technologies (such as nanotechnology), improved understanding of the health impacts and consequences of climate change, and risk management of priority (toxic) substances such as mercury, PAHs, benzene, chlorinated solvents and Carcinogenic, Mutagenic and Reprotoxic (CMR) substances (Hylland, 2006; Jha *et al*., 2004; Kurelec, 1993).
In March 2010, the Fifth Ministerial Conference on Environment and Health, which convened under the auspices of the World Health Organisation in Parma, Italy, identified similar environment and health challenges for current societies around the world (see Information Box 3.1).

INFORMATION BOX 3.1.
Major environment and health policy challenges of our times as identified by European and international fora

Common policy priorities in the Environment and Health area across the EU identified by the EnvHealth ERANET*	Key environment and health challenges identified by the Fifth Ministerial Conference on Environment and Health (Parma, Italy, March 2010)
• Climate change: health impacts, health consequences; • Environment and health risks of (emerging) technologies: nanotechnology, environmental technologies, electromagnetic fields; • Tools and techniques: health impact assessment, biomonitoring, socio – economic approaches, cost – benefit (e.g. health damage evaluation); • Indoor air pollution: cardiovascular health, aeroallergens, particulates; • Vulnerable or susceptible groups, environmental health inequalities: children, prenatal, social unevenness, environmental justice; • Endocrine disruption.	• Health and environmental impacts of climate change; • Health risks to children and other vulnerable groups posed by poor environmental, working and living conditions (especially the lack of water and sanitation); • Socioeconomic and gender inequalities in the human environment and health; • Burden of non-communicable diseases, in particular to the extent that it can be reduced through adequate policies in areas such as urban development, transport, food safety and nutrition, and living and working environments; • Persistent, endocrine-disrupting and bio-accumulating harmful chemicals and (nano)particles.

***www.era-envhealth.eu, adapted from Moore et al. (2011)**

These policy priorities are very complementary and in some cases similar to the scientific challenges identified in Chapter 1, although from a policy perspective priorities remain predominantly focused within a risk assessment and risk management framework, with little consideration of some issues such as the marine environment as a health-promoting resource.

Engaging with the public

As noted above, a major challenge is to change the behavior of human populations affected by oceans and human health around their health and the health of the oceans. One way is to increase their involvement in oceans and human health research as "citizen scientists." Examples of citizen science initiatives include the Jellywatch programme[24], designed to collect information on the distribution of jellyfish species in the Mediterranean Sea and supported in ten countries. Other examples include beach clean ups, marine mammal stranding networks and bird sightings.

Another key requirement will be the improved communication with the general public of the close links between the oceans and human health. "Ocean literacy" is a term that has been coined to describe the capacity of people to:

- understand the essential principles and fundamental concepts about the functioning of the ocean;
- communicate about the ocean in a meaningful way; and
- make informed and responsible decisions regarding the ocean and its resources[25].

Ocean Literacy can be explored and promoted at all ages through the formal school curriculum and beyond. One example is a high school student and teacher targeted curriculum called AMBIENT[26] which explores various science and literacy skills related to the environment and human health using a HAB-related foodborne illness as a case study[27]. The establishment of the European Marine Science Educators' Association[28] in 2012 represents a major step forward in the development of Ocean Literacy in Europe. Since then, two European conferences on Ocean Literacy have been held, the first in Bruges, Belgium in October 2012 and the second in Plymouth, UK in September 2013. Thanks to these efforts, the European Commission is beginning to recognize the key role of ocean literacy in supporting its broader goals of a thriving blue economy and good environmental status of European seas.

FIGURE 3.9.
One way to raise awareness of the link between human health and the health of the oceans is to increase the general public's involvement in oceans and human health research as "citizen scientists." An example is the recording of marine mammal sightings and strandings. Credit: Neil Collier

Targeted research around the knowledge and decision making of human communities affected by oceans and human health issues is also needed. For example, Kuhar *et al.* (2009) and Nierenberg *et al.* (2009) investigated the public perception and consequent reactions to Florida red tides among persons living and visiting coastal areas regularly affected by the HABs. The results indicated that coastal residents and tourists may not have been effectively informed about Florida red tides and their impacts because of inconsistent public outreach. Preferred information sources included internet (80% of tourists and 53% of residents) as well as a local science organization (66%), while toll free numbers were rarely (14%) used by tourists.

This type of evaluative research has led to targeted outreach and education which has evolved from basic print material (flyers and posters) to an interactive website, to the use of video and social networking technologies, such as Facebook and Twitter (Nierenberg *et al.*, 2011, Figure 3.10 and Figure 3.12). In addition, there has been an increase in the use of various sources and methods of information delivery on oceans and human health issues. To take another example from the US, the Beach Conditions Reporting System[29] is a network which has been set up to collect and

[24] www.focus.it/meduse
[25] http://www.cosee.net/about/oceanliteracy/
[26] http://yyy.rsmas.miami.edu/groups/niehs/ambient
[27] http://yyy.rsmas.miami.edu/groups/niehs/ambient/teacher/food/Tfood.html
[28] http://www.emsea.eu
[29] http://coolgate.mote.org/beachconditions/; tel: 1-941-BEACHES

report real time data from life guards and beach managers on a range of beach-related issues (including respiratory irritation and dead fish from HABs, and oil from oil spills) to the public throughout the Gulf of Mexico. The information is accessible through phone or internet (Kirkpatrick 2009, Nierenberg *et al*. Fleming *et al*., 2011 Figure 3.11).

The Florida Poison Information Center has created and formally evaluated a 24/7 toll free number on aquatic toxins which allows the caller to access information on a range of aquatic toxin issues including Florida red tide in English and Spanish, as well as to speak directly with a trained Florida Poison Information Specialist (Fleming, 2007). Monitoring information for the Florida red tide organism has become more available through the Florida Fish and Wildlife Commission[30], and through the NOAA Gulf of Mexico HAB Bulletin[31] (Stumpf *et al*., 2009) (Figure 3.12). Finally, "grassroots" community groups (e.g. Solutions to Avoid Red Tide [START[32]]) health educators, public health managers, and researchers have developed targeted materials to educate various groups about exposure to and health effects from Florida red tide toxins, including: coastal residents and tourists, healthcare providers, and beach managers.

Horizon scanning for emerging hazards, risks and benefits

It will become increasingly important to develop a permanent surveillance for emerging problems affecting human health related to the coastal and oceanic environment. Many of these are readily apparent and can be predicted with varying degrees of confidence as outlined in this paper. However, as has been the case with many health problems, these can emerge from unexpected quarters and overwhelm unsuspecting public health organizations.

[30] http://research.myfwc.com/features/view_article.asp?id=9670
[31] http://tidesandcurrents.noaa.gov/hab/bulletins.html
[32] http://www.start1.com

FIGURE 3.10.
Florida Red Tide Beach Signage (Courtesy Florida Dept of Health, START, Mote Marine, University of Miami Oceans & Human Health Center, Florida Poison Information Center, and Ms Wendy Stephan MPH)

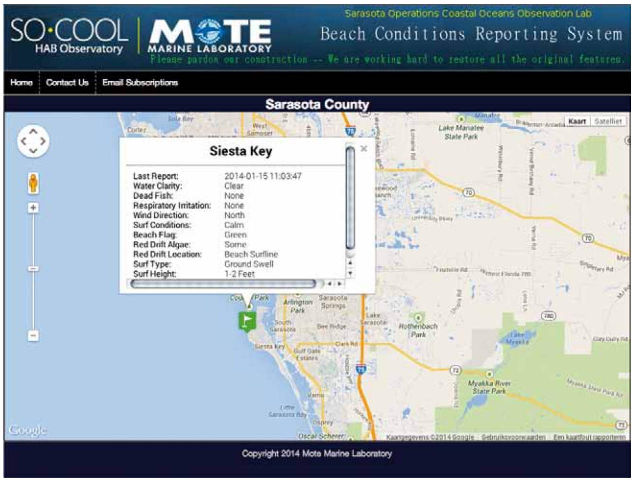


FIGURE 3.11.
Beach Conditions Reporting of the Gulf of Mexico Beach by Mote Marine Laboratory and Collaborators (http://coolgate.mote.org/beachconditions).

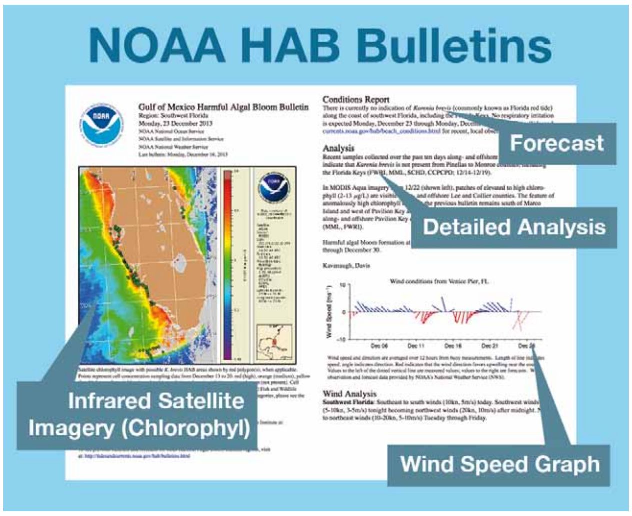


FIGURE 3.12.
National Oceanographic and Atmospheric Administration (NOAA) Harmful Algal Bloom (HAB) Bulletin (http://tidesandcurrents.noaa.gov/hab/bulletins.html)

4
A European Research Strategy for Oceans and Human Health

The marine environment contributes significantly to public health and well-being through the provision and quality of air we breathe, the food we eat, the water we drink and in offering health-enhancing economic and recreational opportunities. At the same time, the marine environment is threatened by human activities such as transport, industrial processes, agricultural and waste management practices. Although we remain dependent upon marine ecosystems, humans have altered, and will continue to alter, the marine environment. Evaluation and management of the resultant impacts, on both marine ecosystems themselves, and on human health, have largely been undertaken as separate activities, under the auspices of different disciplines with no obvious interaction. Hence, many of our perceptions of the relationships between the marine environment and human health are limited and still relatively unexplored, leaving critical knowledge gaps for those seeking to develop effective policies for sustainable use of marine resources and environmental and human health protection.

Research in Oceans and Human Health must be directed at elucidating key environmental processes, and providing a predictive capability for both biotic and abiotic environmental influences on human disease and well-being. The way forward requires the mobilization of interdisciplinary competencies around Europe and ensuring that the necessary scientific and technical capabilities are available. The key recommendation of this position paper is that a coordinated European programme of research in the area of Oceans and Human Health should be developed and supported to ensure the scale of investment and collaboration necessary to address the major challenges of understanding and dealing with the immense complexity of marine environment and human health interactions. The support for, and establishment of, such a programme will ultimately allow us to:

- better understand the potential health benefits from marine and coastal ecosystems;
- reduce the burden of human disease linked with marine environmental causes; and
- anticipate new threats to public health before they become serious.

A European Oceans and Human Health programme could also provide a platform for collaboration with other Oceans and Human Health initiatives (e.g. NIH/NSF and NOAA programmes in the USA) which will facilitate synergies and added value. This is an opportunity for the EU to build on existing and developing research platforms and opportunities for the benefit of not only EU citizens, but the global coastal community (particularly in developing nations).

Key Elements of an Oceans and Human Health Research Programme

If society is to have a practical capability to forecast how changes in the marine and other environments impact on linkages between natural systems, social systems and human health, we must develop a better understanding of the functioning of the biosphere and our connections with it (Allen, 2011). The complex and causal interconnections between marine environment and human health requires a systems approach addressing all levels of organization from genes to ecosystems. Such an integrated systems approach must be interdisciplinary drawing on the skills and expertise of many scientific disciplines as well as the social and economic sciences (see Figure 4.1).

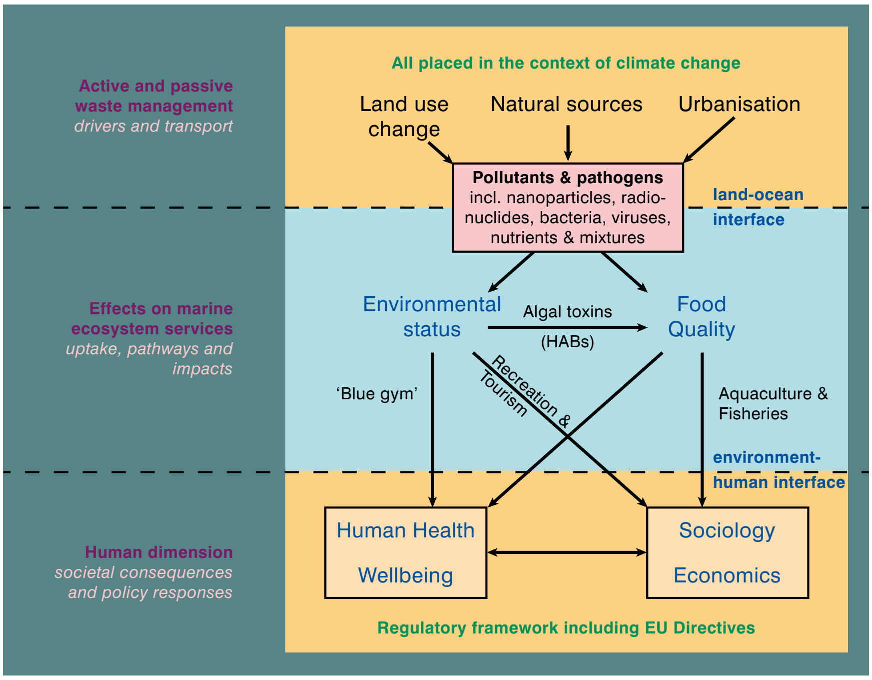


FIGURE 4.1.
Schematic diagram of a systems approach to marine environment and human health illustrating the interfaces between the land and the ocean and between the natural environment and medical and social sciences (Allen, 2011)

Living systems are strongly interdependent, often in ways that continue to surprise us, and environmental impacts - by both natural events and man-made interventions - are a fact of life. Among these impacts are harmful environmental pollutants and potentially pathogenic organisms to which people are exposed through a variety of complex transport and exposure pathways, e.g. through air (including marine aerosols), sediment, water and from chemical and microbiological residues in food. Many of these issues relate to complex problems such as the environmental biology and geochemistry of estuarine and marine sediments, and how these influence the transport, accessibility and bioavailability of chemical pollutants and infectivity of pathogens. The dispersion of harmful particles in the oceans is another area of major concern, including how environmental factors may govern their toxicity to marine organisms and human consumers of seafood. How exposed populations respond to these stressors in both the short and long-term will depend on both the degree of exposure and on individual factors (such as socio-economic and nutritional status, age, genes, gender and behavioural aspects) that influence avoidance or risk-accepting attitudes.

Developing the capacity to predict and minimise impacts of potential risks (and their harmful consequences for biological resources, ecosystems and human health) is a daunting task for legislators and regulators. Evaluating environmental risk requires dealing with complex issues such as the effects of the physico-chemical interactions on the speciation and uptake of pollutant chemicals; inherent inter-individual and inter-species differences in vulnerability to toxicity; the emergent toxicity of complex chemical mixtures; and knowledge of reservoirs of microbial pathogens as well as factors governing infectious viability (Allen, 2011; Moore *et al*., 2011). It is, therefore, not surprising that these are areas of growing public and government interest, which are reflected in various national and international priorities; for example, in the NSF/NIH Oceans and Human Health Programme (USA), the EU, the World Health Organisation (Millennium Ecosystem Assessment, 2005), and International Year of Planet Earth 2006 (Earth and Health theme).

While such predictive capability must remain a major long-term scientific goal, the scope of an Oceans and Human Health Programme should have an initial focus on exploratory research (e.g., “proof-of-concept”) and on building the interdisciplinary community required for the longer-term task. A particular emphasis in an Oceans and Human Health programme must be to bring the research community together with policy makers and decision makers in order to foster the process of policy formulation through improved knowledge transfer and exchange.

A significant aspect of an OHH Programme should be the inclusion of broader socio-economic issues addressing people-oriented, environmental health-related problems. Particular emphasis needs to be placed on the integration of public health within an ecosystem-based approach to management, as described in Chapter 1. Unfortunately, there remains a relative dearth of substantial epidemiological and public health data that would permit a comprehensive understanding of possible causal links between human and ecosystem health (see Millennium Ecosystem Assessment, 2005[33] and the World Health Organization[34]). However, by effectively identifying and interconnecting the interdisciplinary elements, we are beginning to see the emergence of new ways of solving problems in what are, at present, areas of research that have traditionally had little connection with one another (Di Giulio & Benson, 2002).

Effective communication of risk and risk assessment is an area that is still challenging. We need to conduct monitoring more effectively and improve risk communication practices, especially in relation to epidemiologic data. Questions arise as to whether we need alternatives to standard risk assessment; whether current risk assessment approaches and existing legislation are sufficient; and whether more efficient approaches are available or to be developed?

More effective public health outcomes may be delivered through the creation of science output that can be beneficial to public health through knowledge exchange. Other new actions such as adding a component of environmental monitoring to existing Public Health observatories and creating public awareness should also be explored and expanded. For example, in the USA there are initiatives making use of public/tourists in coastal areas to increase observation capacity via the distribution of hand microscopes and reporting on smartphones, of beach conditions including HABs and oil spills. The Eye on Earth initiative[35], including a ‘watch’ on EU bathing water quality and a forthcoming ‘watch’ application on marine litter represent good examples of initiatives that raise awareness through involvement in observation activities.

Improved **integration, communication and training** will be essential in order to create a European Oceans and Human Health research community. This will be complemented by the provision of a best practice guide for public health authorities. This guide would complement the RASFF (Rapid Alert System on Food and Feed) and inform in order to guide local decision makers.

Strategic research priorities and enabling actions

Taking into account all relevant environmental compartments in the coastal zone, the Oceans and Human Health Working Group has identified a number of **key research targets** to build the necessary Oceans and Human Health research capability in Europe (see Information Box 4.1). These targets should therefore constitute the main objectives of the envisaged European Oceans and Human Health Programme.

[33] www.millenniumassessment.org /en/index.aspx
[34] http://www.who.int/topics/environmental_health/en/
[35] http://www.eea.europa.eu/about-us/what/information-sharing-1/eye-on-earth

INFORMATION BOX 4.1.
Recommended strategic research targets of an envisaged European Oceans and Human Health Research Programme

1. Innovative monitoring and surveillance techniques in place which allow a much greater provision of relevant and accurate data (e.g. remote observation systems for coastal and marine ecosystems, detection of chemical and material pollutants, biogenic and microbial toxins and human pathogens, and improved testing for seafood and water safety.

2. Improved understanding of the physical, chemical and biological processes involved in the transport and transmission of toxic chemicals and pathogenic organisms through the marine environment to humans.

3. Improved understanding of the direct and indirect causal relationships between degradation of the marine environment and the incidence of diseases and adverse and beneficial effects on the well-being of the human population.

4. Improved environmental models to determine the extent of natural dispersion of sewage, agricultural effluents and industrial waste.

5. Expert systems to link existing models with our experience and knowledge of the connectivity between the marine environment and human health

6. Appropriate indicators to show the effectiveness of moving towards sustainable development where environmental, social and economic measures are linked.

7. Methods and mechanisms which demonstrate the value (economic, cultural, aesthetic etc.) to human well-being of marine environments at local, regional and global scale.

To successfully realise the objectives of a large interdisciplinary European research effort on Oceans and Human Health, it will be necessary to develop and/or improve a range of research support functions and capacities. Capacity-building is considered to be crucial in order to increase European competence in this area and is urgently required to overcome the fragmented nature of current research effort in Europe. Initial investments at European level should aim to fast-track the development of these structural elements, which will be crucial to the long-term capacity of Europe to support a major research programme linking marine environment and human health. Key areas for attention will include research infrastructures (including observation and monitoring platforms), building of interdisciplinary networking and partnerships, improved training programmes (PhDs and early stage researchers), knowledge management protocols and science-policy interfaces to ensure rapid uptake of policy-relevant knowledge.

Implementation of a European Oceans and Human Health Research Programme

Considering the research targets to build the Oceans and Human Health research capability in Europe (Information Box 4.1), it is important to recognize that much has already been done to address these targets, both at the scientific and policy level, although often from a topical or sectoral perspective, respectively. For example, the indicators mentioned in research target 6 (see Information Box 4.1) exist to a certain extent or are being developed under the MSFD. Methods to demonstrate value mentioned in research target 7 (see Information Box 4.1) also exist to a certain extent or are being developed in the context of the implementation of Target 2/Action 5 of the EU 2020 Biodiversity Strategy, and/or by Member States carrying out MSFD initial assessments. Hence, when developing the European research capability in OHH, there is a need to build on, support and complement past and current efforts and existing frameworks that share the same research targets.

INFORMATION BOX 4.2.
Cross-cutting enabling actions and capacities required to maximize the efficiency and impact of a European Oceans and Human Health research programme

- Provide adequate support for interdisciplinary research and training of young investigators to build capacity and improve our knowledge base on the marine environment and human health which is currently fragmented both in Europe and globally. A particular focus should be on developing modelling capacities (e.g. to design early warning systems) and linking experts in fields as diverse as oceanography, marine ecology, ecotoxicology, epidemiology and public health. Where relevant and possible, collaborative links should be developed with the private sector, for example by establishing co-funded PhDs and Research Fellowships;
- Increase knowledge management and horizon scanning for emerging problems, benefits and technologies in relation to the marine environment which may impact on human health and well-being;
- Build bridges between relevant stakeholders, for example by involving stakeholders at the outset of project formulation;
- Develop specific networking actions to overcome the fragmented research capability in Europe;
- Stimulate creative thinking and develop opportunities to explore alternatives to standard risk assessment procedures;
- Improve communication between research community and authorities in charge of environmental protection, food safety and human health;
- Improve communication to, and participation by, the wider public to raise public awareness about the complex relationship between oceans and human health. This includes supporting activities to promote Ocean Literacy which entails outreach to the public to improve the understanding of the importance of the oceans and, more specifically, about risks and benefits of human interactions with the marine environment (e.g. through citizen science-public participation, beach watches, etc.).

In spite of progress in the last decades, there remains an important need to consider and address the long and diverse set of policies and regulations relevant for OHH in a more integrated way than hitherto achieved. One of the first steps should therefore be to perform a thorough analysis of the various policies and legislations which have a bearing on the complex relationship between our marine environment and human health, to identify weaknesses, gaps and overlaps, and consider mechanisms to strengthen their interactions to improve effectiveness.

When implementing the OHH Research Programme, it will be essential to move towards a joined-up flexible research effort; not just multi-disciplinary, but a truly integrated and interdisciplinary effort that links to policy considerations and risk management in a whole ecosystem context. A dedicated programme will therefore require a holistic and interdisciplinary approach and must be of sufficient scale to allow a coordinated, multi-national collaboration. Particular emphasis should be put on ecosystems as providers of environmental goods and services and their sustainability as well as identifying the potential threats to these goods and services.

While it is necessary to increase our understanding of fundamental processes and complex interactions, Oceans and Human Health research should put considerable focus on finding tangible solutions (including capacity building) for known and emerging problems, and supporting current and future policy requirements. To ensure effective knowledge exchange between researchers, policy formulators and other stakeholders (e.g. NGOs and industry), an effective knowledge management system will be essential.

From an EU perspective, a key policy framework for developing a coordinated and science-based approach to the link between oceans and human health is the Marine Strategy Framework Directive[37]. The recommendations of this paper will also have relevance to the management of catchments, groundwater, estuarine and coastal marine environments under the EU Water Framework Directive[38], as well as the developing EU Coastal Zone Policy. Key European programmes which have the capacity to support an Oceans and Human Health initiative include Horizon 2020, the EU's next programme for research and technology development (2014-2020), and the newly emerging European Joint Programming Initiatives. However, national research programmes should also provide support for the rapid development of research programmes and capacities in the area of Oceans and Human Health.

A European Oceans and Human Health Programme should also encourage international collaboration with other Oceans and Human Health initiatives (e.g. NIH/NSF and NOAA programmes in the USA) as this will facilitate synergies and added value. This is an opportunity for the EU to build on existing and developing research platforms and opportunities for the benefit not only of EU citizens, but a global coastal-dwelling community (particularly in developing nations).

The research community required to address Oceans and Human Health challenges in Europe is currently very fragmented and recognition by policy makers of some of the problems is probably limited. Nevertheless, relevant policy issues for governments worldwide include the reduction of the burden of disease (including the early detection of emerging pathogens) and improving the quality of the global environment. Failure to effectively address these issues will impact adversely on efforts to alleviate poverty, sustain the availability of environmental goods and services, and improve health and social and economic stability.

[37] See http://ec.europa.eu/environment/water/marine/directive_en.htm
[38] See http://ec.europa.eu/environment/water/water-framework/

Credit: Neil Collier

References

Allen J.I. (2011). Marine Environment and Human health: an Overview. Hester R., Harrison R. (Eds.). Issues in Environmental Science & Technology 34:1-24. Royal Society of Chemistry, London.

Allen J.I., Moore M.N. (2004). Environmental prognostics: is the current use of biomarkers appropriate for environmental risk evaluation. Mar. Environ. Res. 58:227-232.

Altieri A.H., Silliman B.R., Bertness M.D. (2007). Hierarchical organization via a facilitation cascade in intertidal cordgrass bed communities. The American Naturalist 169:195–206.

Amorim A., Vasconcelos V.M. (1999). Dynamics of microcystins in the mussel *Mytilus galloprovincialis*. Toxicon 37:1041-1052.

Anderson J.L.R., Chapman S.K. (2005). Ligand probes for heme proteins. Dalton Transactions 13–24.

Anderson T.R. (2005). Planktonfunctional type modelling:running before we can walk? J. Plankton Res. 27(11):1073–1081.

Anon. (2004). Corrigendum to Regulation (EC) No 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific rules for the organization of official controls on products of animal origin intended for human consumption. Official Journal of the European Union L226:83–127.

Anon. (2006). Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC. OJ L 64, 4.3.2006, p. 37–51

Anon. (2009). Viruses in Food: Scientific Advice to Support Risk Management Activities. Meeting Report Microbiological Risk Assessment Series13. http://apps.who.int/bookorders/anglais/detart1.jsp?sesslan=1&codlan=1&codcol=15&codcch=751

Ashbullby K.J., White M.P., Pahl S., Depledge M. (2011). The psychological benefits of visiting different natural environments: Differential effects of coast, countryside and urban open space on wellbeing. Conference Proceedings. http://abstracts.bps.org.uk/index.cfm?&ResultsType=Abstracts&ResultSet_ID=7861&FormDisplayMode=view&frmShowSelected=true&localAction=details

Azzarello M.Y., Van-Vleet E.S. (1987). Marine birds and plastic pollution. Marine Ecology Progress Series 37:295-303.

Backer L.C, Fleming L.E., Rowan A., Baden D. (2003). Epidemiology and Public Health of Human Illnesses Associated with Harmful Marine Phytoplankton. In: UNESCO Manual on Harmful Marine Algae. Hallegraeff G.M., Anderson D.M., Cembella A.D. (Eds). Geneva, Switzerland: UNESCO/WHO, 725-750.

Backer L.C., Fleming L.E. (2008). Epidemiologic Tools to Investigate Oceans and Public Health. In: Walsh P.J., Smith S.L., Fleming L.E., Solo-Gabriele H., Gerwick W.H. (Eds.). Oceans and Human Health: Risks and Remedies from the Sea, Elsevier Science Publishers, New York, 201-218.

Backer L.C., Kish J.K., Solo Gabriele H.M., Fleming L.E. (2010). Naturally Occurring Water Pollutants. In: Water and Sanitation-Related Diseases and the Environment: Challenges, Interventions and Preventive Measures. Selendy J. (Ed). New Haven: Horizon International, Yale University.

Backer L.C., Schurz Rogers H., Fleming L.E., Kirkpatrick B., Benson J. (2005). Phycotoxins in Marine Seafood. In: Chemical and Functional Properties of Food Components: Toxins in Food. Dabrowski W. (Ed.). Boca Raton, F.L: CRC Press, 155-190.

Baker-Austin C., Stockley L., Rangdale R., and Martinez-Urtaza J. (2010). Environmental occurrence and clinical impact of Vibrio vulnificus and Vibrio parahaemolyticus: a European perspective. Environ Micro Rep 2:7–18.

Banack S.A., Johnson H.E., Cheng R., Cox P.A. (2007). Production of the neurotoxin BMAA by a marine cyanobacterium. Mar. Drugs 5:180-196.

Baptista M.S., Cianca R.C.C., Almeida M.R., Vasconcelos V.M. (2011). Determination of the non protein amino acid -N-methylamino-L-alanine in estuarine cyanobacteria by capillary electrophoresis. Toxicon 58:410-414.

Barton J., Pretty. J. (2010) What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis. Environmental Science and Technology 44(10):3947–3955.

Bayne B.L., Addison R.F., Capuzzo J.M., Clarke K.R., Gray J.S., Moore M.N., Warwick R.M. (1988). An overview of the GEEP workshop. Marine Ecology Progress Series 46:235-243.

Belda-Ferre P., Cabrera-Rubio R., Moya A., Mira A. (2011). Mining Virulence Genes Using Metagenomics. PLOS one 6,10.10.1371/journal.pone.0024975

Ben-Shoshan M., Turnbull E., Clarke A. (2012). Food Allergy: Temporal Trends and Determinants. Curr Allergy Asthma Rep 12:346–372.

Berntssen M.H.G., Julshamn K., Lundebye A.-K. (2010). Chemical contaminants in aquafeeds and Atlantic salmon (*Salmo salar*) following the use of traditional- versus alternative feed ingredients. Chemosphere 78(6):637-646.

Berry H.I., Bowen K., Kjellstrom T. (2010). Climate change and mental health: causal pathways framework. Internat. J. Public Health 55:123-132.

Bosch A. (1995). The survival of enteric viruses in the water environment. Microbiologia 11:393-396.

Bossart G. (2006). Case Study: Marine Mammals as sentinel species for oceans and human health. Oceanography 19(2):134-137.

Bowen R.E., Depledge M.H. (2006). The oceans and human health. Mar. Pollut. Bull. 53:541-544.

Boxall A.B.A., Hardy A., Beulke S., Boucard T., Burgin L., Falloon P.D., Haygarth P.M., Hutchinson T., Kovats R.S., Leonardi G., Levy L.S., Nichols G., Parsons S.A., Potts L., Stone D., Topp E., Turley D.B., Walsh K., Wellington E.M.H., Williams R.J. (2009). Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. Environ Health Perspect. 117:508-514.

Brander K.M. (2007). Global fish production and climate change. PNAS 104:19709–19714.

Browne M.A, Dissanayake A., Galloway T.S., Lowe D.M., Thompson R.C. (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis*. Environmental Science & Technology 42:5026-5031.

Bryant D., Rodenburg E., Cox T., Nielsen D. (1995). Coastlines at risk: An index of potential development-related threats to coastal ecosystems. WRI Indicator Brief. Washington, D.C., World Resources Institute.

Bunyavanich S., Landrigan C.P., McMichael A.J., Epstein P.R. (2003). The impact of climate change on child health. Ambul Pediatr 3(1):44-52.

Burke L., Kura Y., Kassem K., Spalding M., Evenga C. (2000). Pilot analysis of global ecosystems: Coastal ecosystems technical report. Washington, D.C., World Resources Institute.

Butt A.A., Aldridge K.E., Sanders C.V. (2004). Infections related to the ingestion of seafood Part I: Viral and bacterial infections. Lancet Infect Dis. 4(4):201-12.

Bystrzejewska-Piotrowska G., Golimowski J., Urban P.L. (2009). Nanoparticles: Their potential toxicity, waste and environmental management. Waste Management 29:2587–2595.

Camps M., Briand J.F., Guentas-Dombrowsky L., Culioli G., Bazire A., Blache Y. (2011). Antifouling activity of commercial biocides vs. natural and natural-derived products assessed by marine bacteria adhesion bioassay. Mar Pollut Bull. 62(5):1032-40.

Carpenter E.J., Anderson S.J., Harvey G.R., Miklas H.P., Peck B.B., (1972). Polystyrene spherules in coastal waters. Science 178:749-750.

CAS (2011). Specialized Substance Collections Count: CHEMLIST®. Chemical Abstracts Service, American Chemical Society. Available at: http://www.cas.org/content/regulated-chemicals [accessed 24 October 2011].

Cassar L. (Ed.) (2001). Integrated Coastal Area Management. United Nations Industrial Development Organization, Vienna, 443p.

Cato, J.C. (1998). Economic values associated with seafood safety and implementation of seafood. Hazard Analysis Critical Control Point (HACCP) programmes. FAO Fisheries Technical Paper. No. 381. Rome, FAO. 1998. 70p.

Chapman P.M. (2007). Determining when contamination is pollution - Weight of evidence determinations for sediments and effluents. Environment International 33:492-501.

Charlier R.H., Chaineux M-C.P. (2009). The Healing Sea: A Sustainable Coastal Ocean Resource: Thalassotherapy. Journal of Coastal Research 25(4):838-846.

Chen S. and Ge B. (2010) Development of a toxR-based loop-mediated isothermal amplification assay for detecting Vibrio parahaemolyticus. BMC Microbiology 10: 41

Cianca R.C.C., Baptista M.S., Lopes V.R., Vasconcelos V.M. (2012). The non-protein amino acid b-N-methylamino-L-alanine in novel Portuguese cyanobacterial isolates from Minho, Douro and Vouga Rivers. Amino Acids 42(6):2473-2479

Ciminiello P., Dell'Aversano C., Fattorusso E., Forino M., Tartaglione L., Grillo C., Melchiorre N. (2008). Putative palytoxin and its new analogue, ovatoxin-a, in Ostreopsisovata collected along the Ligurian coasts during the 2006 toxic outbreak. J Am Soc Mass Spectrom 19:111–120.

Claessens M., Van Cauwenberghe L., Vandegehuchte M., Janssen, C. (2013). New techniques for the detection of microplastics in sediments and field collected organisms. Marine Pollution Bulletin 70(1-2):227-233

Coleman F.C., Wehle D.H.S. (1984). Plastic pollution: a worldwide problem. Parks 9:9-12.

Connors P.G., Smith K.G. (1982). Oceanic plastic particle pollution: suspected effect on fat deposition in red phalaropes. Marine Pollution Bulletin 13:18-20.

Costanza R., d'Arge R., de Groot R., Farber S., Grasso M, Hannon B., Limburg K., Naeem S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton P., van den Belt M. (1997).The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Cracknell D.L., White, M.P., Corcoran, A., Pahl., S., Claydon, S., Cox, P., Depledge, M.H. (2011). The Restorative Potential of Subaquatic Biodiversity. Poster presented at the 9th Biennial Conference on Environmental Psychology, Sept. 2011, Eindhoven.

Cracknell D.L., White, M.P., Pahl S., Nicholls W.J., Depledge M.H. (2013). Sub-aquatic biodiversity and psycho-physiological well-being: A preliminary examination of dose-response effects in an aquarium setting. Manuscript submitting for publication.

Dagnino A., Allen, J.I., Moore M., Canesi L., Viarengo A. (2007). Integration of biomarker data into an organism health index: development of an expert system and its validation with field and laboratory data in mussels. Biomarkers 12:155-172.

Daohui L., Baoshan X. (2007). Phytotoxicity of nanoparticles: Inhibition of seed germination and root growth. Environmental Pollution, 243–250.

Deeds J.R., Schwartz M.D. (2009). Human risk associated with palytoxin exposure. Toxicon 56 (2):150–162.

Defra (2004). Diffuse water pollution from agriculture. R&D Newsletter Agriculture & the Environment, 12:8.

Defra (2005). Charting progress; an integrated assessment of the state of the UK Seas. Defra, London, 119p.

Depledge, M.H., Harvey, A.J., Brownlee, C., Frost, M., Moore, M.N., Fleming, L.E. (2013). Changing Views of the Interconnections Between the Oceans and Human Health in Europe. Microbial Ecology, 65(4), 852-859.

Depledge M.H. (2000). Rapid assessment of marine pollution (RAMP). In: Proceedings of the Vietnam-UK Joint Workshop on Marine Pollution Assessment. – Hanoi, June 8, 2000. Publi.National Centre for Natural Science and Technology of Vietnam, Hanoi, Vietnam, pp.5-16.

Depledge M.H., Amaral-Mendes J.J., Daniel B., Halbrook R.S., Kloepper-Sams P., Moore M.N., Peakall D.P. (1993). In: Biomarkers - research and application in the assessment of environmental health. Peakall, D.G., Shugart L.R. (Eds). Springer, Berlin, Heidelberg, 15.

Depledge M.H., Bird W.J. (2009). The Blue Gym: Health and wellbeing from our coasts. Mar. Pollut. Bull., 58:947-948.

Depledge M.H., Harvey A.J., Brownlee C., Frost M., Moore M.N., Fleming L.E. (2012). Changing views of the interconnections between the Oceans and Human Health in Europe. Microbial Ecol 65:852-9

Di Giulio R.T., Benson W.B. (Eds.)(2002). Interconnections between Human Health and Ecological Integrity.Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida, 110p.

Dwight R.H., Baker D.B., Semenza J.C., Olson B.H. (2004). Health effects associated with recreational coastal water use: urban versus rural California. Am J Public Health 94(4):565-7.

EC (2008). DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

EC (2008). Directive 2008/56/EC of the European parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

EFSA (2008a). Marine biotoxins in shellfish – Okadaic Acid and analogues, Scientific Opinion of the Panel on Contaminants in the Food chain, adopted on 27 November 2007. European Food Safety Authority. EFSA Journal 589:1-62

EFSA (2008b). Marine biotoxins in shellfish – Azaspiracid group, Scientific Opinion of the Panel on Contaminants in the Food chain, adopted on 9 June 2008. European Food Safety Authority. EFSA Journal 723:1-52.

EFSA (2009b). Influence of processing on the levels of lipophilic marine biotoxins in bivalve molluscs, Statement of the Panel on Contaminants in the Food Chain (Question No EFSA-Q-2009-00203), Adopted on 25 March 2009. European Food Safety Authority. EFSA Journal 1016:1-10.

EFSA (2009d).Marine biotoxins in shellfish – Pectenotoxin group, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 27 May 2009. European Food Safety Authority. EFSA Journal 1109:1-47.

EFSA (2009e). Marine biotoxins in shellfish – Domoic acid group, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 2 July 2009. European Food Safety Authority. European Food Safety Authority. EFSA Journal 1181:1-61.

EFSA (2009f). Marine biotoxins in shellfish – Summary Opinion, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 13 August 2009. European Food Safety Authority. EFSA Journal 1306:1-23.

EFSA (2009g). Marine biotoxins in shellfish – Palytoxin Group, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 13 August 2009. European Food Safety Authority. EFSA Journal 7(12) 1393:1-38.

EFSA (2010). The Community Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and food-borne outbreaks in the European Union in 2008, EFSA Journal 8(1):1496.

EFSA (2010a). Marine biotoxins in shellfish – Emerging Toxins: Ciguatoxin-group, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 18 May 2010. European Food Safety Authority. EFSA Journal 8(6)1627:1-38.

EFSA (2010b). Marine biotoxins in shellfish – Emerging Toxins: Brevetoxin-group, Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 5 July 2010. European Food Safety Authority. EFSA Journal 8(7)1677:1-29.

EFSA (2010c). Marine biotoxins in shellfish – Cyclic Imines (spirolides, gymnodimines, pinnatoxins and pteriatoxins), Scientific Opinion of the Panel on Contaminants in the Food chain; adopted on 5 July 2010. European Food Safety Authority. EFSA Journal 8(6)1628:1-39.

EFSA (2010d). Statement on further elaboration on consumption figure of 400g shellfish meat on the basis of new consumption data, EFSA Panel on contaminants in the food chain.; adopted on 31 July 2010. European Food Safety Authority. EFSA Journal 8(8)1706:1-20.

EFSA (2010e). Guidance on human health risk-benefit assessment of foods. European Food Safety Authority Scientific opinion. EFSA Journal 8(7).

EFSA (2012). Scientific Opinion on Norovirus (NoV) in oysters: methods, limits and control options. European Food Safety Authority Panel on Biological Hazards (BIOHAZ). EFSA Journal 10(1):2500.

EFSA(2009a). Marine biotoxins in shellfish – Yessotoxin group, Scientific Opinion of the Panel on Contaminants in the Food chain, adopted on the 2 December 2008. European Food Safety Authority. EFSA Journal 907:1-62.

EFSA(2009c). Marine biotoxins in shellfish – Saxitoxin group; Scientific Opinion of the Panel on Contaminants in the Food Chain, Adopted on 25 March 2009. European Food Safety Authority. EFSA Journal 1019:1-76.

Eggleton J., Thomas K.V. (2004). A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. Environment International 30:973-980.

Elmir S.M, Hower S., Jackson C.R., Barrett J.B., Cleary T., Davidson M., Davis J.A., Mukherjee S., Fleming L.E., Solo Gabriele H.M. (2013). Human-associated methicillin-resistant Staphylococcus aureus from a subtropical recreational marine beach Microbiology Ecology 65(2). DOI 10.1007/s00248-013-0216-1

EPA (2012). http://water.epa.gov/scitech/methods/cwa/bioindicators/biological_index.cfm#rapid. Accessed January 14th 2013.

EU (2000). Directive 2000/60.EC of the European Parliament and of the Council for the Community action in the field of water policy (Water Framework Directive). http://ec.europa.eu/environment/water/water-framework.

EU (2000). White paper on food safety. Commission of the European Communities: Brussels. p. 1-52.

EU (2004). Regulation (EC) No 853/2004 of the European Parliament and of the Council and for the organization of official controls under Regulation (EC) No 854/2004. Official Journal L 226, 25/06/2004 P. 0022–0082.

EU (2005). Commission Regulation (EC) No 2074/2005 of 5 December 2005 laying down implementing measures for certain products under Regulation (EC) No 853/2004 of the European Parliament and of the Council and for the organization of official controls under Regulation (EC) No 854/2004 of the European Parliament and of the Council and Regulation (EC) No 882/2004 of the European Parliament and of the Council, derogating from Regulation (EC) No 852/2004 of the European Parliament and of the Council and amending Regulations (EC) No 853/2004 and (EC) No 854/2004. Official Journal L338, 22/12/2005 P. 0027–0059.

EU (2010). Marine Strategy Framework Directive: Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) (2010/477/EU). Official Journal L232, 2/9/2010 P. 14 – 24.

EU (2011). Commission Regulation (EU) No 15/2011 of 10 January 2011 amending Regulation (EC) No 2074/2005 as regards recognised testing methods for detecting marine biotoxins in live bivalve molluscs. Official Journal L6, 11/1/2011, pp. 3–6.

European Commission (2002) Radiation protection 128, Assessment of the radiological impact on the population of the European Union from EuropeanUnion nuclear sites between 1987 and 1996, ISBN 92-894-0445-0. http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/128.pdf

European Commission (2010). Radiation Protection 164, Radioactive effluents from nuclear power stations and nuclear fuel reprocessing sites in the European Union, 2004-08.

FAO (1999). The state of world fisheries and aquaculture 1998. Food and Agriculture Organization of the United Nations FAO, Rome, 112 p.

FAO (2009). Food and Agriculture Organization of the United Nations: The State of Food Insecurity in the World 2009. Food and Agriculture Organization of the United Nations FAO, Rome.

FAO (2009). The State Of World Fisheries and Aquaculture 2008. FAO fisheries and Aquaculture Department, Food and Agriculture Organization of The United Nations, Rome 2009. ISBN 978-92-5-106029-2

FAO (2010). The state of world fisheries and aquaculture 2010.FAO Fisheries and Aquaculture Department. Food and agriculture organization of the United Nations, Rome.

Feldhusen F. (2000). The role of seafood in bacterial foodborne diseases. Microbes Infect. 2:1651-1660.

Fenical W. (2006). Marine pharmaceuticals: past, future, present. Oceanography 19(2):110-119.

Ferson S., Long T.F. (1995). In: Environmental Toxicology & Risk Assessment. Hughes J.S. et al. (Eds.). ASTM, Philadelphia 97.

Fleming L.E., Bean J.A., Katz D., Hammond R. (2001). The Epidemiology of Seafood Poisoning. In: Hui, Kits, Stanfield, eds. Seafood and Environmental Toxins. Marcel Dekker, pg. 287-310.

Fleming L.E., Broad K., Clement A., Dewailly E., Elmir S., Knap A., Pomponi S.A., Smith S., Solo Gabriele H., Walsh P. (2006). Oceans and human health: Emerging public health risks in the marine environment. Mar. Pollut. Bull. 53:545-560.

Fleming L.E., Kirkpatrick B., Backer L.C., Walsh C.J., Nierenberg K., Clark J., Reich A., Hollenbeck J., Benson J., Cheng Y.S., Naar J., Pierce R., Bourdelais A.J., Abraham W.M., Kirkpatrick G., Zaias J., Wanner A., Mendes E., Shalat S., Hoagland P., Stephan W., Bean J., Watkins S., Clarke T., Byrne M., Baden D.G. (2011). Review of Florida Red Tide and Human Health Effects. Harmful Algae 20:224–233.

Fleming L.E., Laws E. (2006). The Overview of Oceans and Human Health. Oceanography 19(2):18-23.

Fleming LE, Morris G, Beck S, Hurley F, Reis S, Depledge M, White M, Taylor T, Higgins T, Austen M, et al. (2013). Ecosystems services and mDPSEEA: A new sat nav for uncharted territory in environmental public health. ENVR 2013 (elsevier. conference-services), http://elsevier.conference-services.net/resources/247/3306/pdf/ENVR2013_0074.pdf

Fox F.R., Lloyd W.B. (1938). Convalescence on the coast. The Lancet 232:37-39.

Fortner J.D., Lyon D.Y., Sayes C.M., Boyd A.M., Falkner J.C., Hotze E.M., Alemany L.B., Tao Y.J., Guo W., Ausman K.D., Colvin V.L., Hughes J.B. (2005). C60 in water: nanocrystal formation and microbial response. Environ. Sci. Technol. 39:4307–4316.

Friedman M.A., Fleming L.E., Fernandez M., Bienfang P., Schrank K., Dickey R., Bottein M.Y., Backer L., Ayyar R., Weisman R., Watkins S., Granade R., Reich A. (2008). Ciguatera Fish poisoning: treatment, prevention and management. Marine Drugs, Special Issue on Marine Toxins, 6(3):456-479.

Fukuda S., Takao S., Kuwayama M., *et al.* (2006). Rapid detection of Norovirus from fecal specimens by real-time reverse transcription-loop-mediated isothermal amplification assay. Journal of Clinical Microbiology 44(4):1376-1381.

Galeano E, Rojas J.J., Martínez A. (2011). Pharmacological developments obtained from marine natural products and current pipeline perspective. Nat Prod Commun. 6(2):287-300.

Galgani F., Fleet D., Van Franeker J., Katsanevakis S., Maes J.M., Ouat J., Oosterbaan L., Poitou I., Hanke G., Thompson R., Amato E., Birkun, Janssen C. (2010). Marine Strategy Framework Directive Task group 10 report Marine litter. JRC. ISSN 1018-5593. ISBN 978-92-79-15653-3.

Galloway T.S. (2006). Biomarkers in environmental and human health risk assessment. Mar. Pollut. Bull. 53:606-613.

Gentien P., Lunven M., Lazure P., Youenou A., Crassous M.P. (2007). Motility and autotoxicity in *Karenia mikimotoi (Dinophyceae)*. Philos. Trans. Roy. Soc. B-Biological Sciences 362:1937-1946.

Gerwick W. (2008). Marine Remedies. In: Walsh P.J., Smith S.L., Fleming L.E., Solo-Gabriele H., Gerwick W.H. (Eds.). Oceans and Human Health: Risks and Remedies from the Sea. Elsevier Science Publishers, New York, p425-429.

Given S., Pendleton L.H., Boehm A.B. (2006). Regional public health cost estimates of contaminated coastal waters: a case study of gastroenteritis at southern California beaches. Environ Sci Technol 40(16):4851-4858.

Goldberg E.D. (1994). Diamonds and plastics are forever? Marine Pollution Bulletin 28:466.

Gómez-Couso, H., Freire-Santos, F., Amar, C.F.L., Grant, K.A., Williamson, K., Ares-Mazás, M.E., McLauchlin, J. (2004). Detection of Cryptosporidium and Giardia in molluscan shellfish by multiplexed nested-PCR. Internat. J. Food Microbiol., 91:279– 288.

Gomiero A., Dagnino A., Sforzini S., Negri A., Viarengo A., (2012). Heat stress effects on toxicity of copper and oxytetracycline on the marine protozoa Euplotes crassus in a climate change perspective. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, Volume 163: S4.

Grad Y.H., Lipsitch M., Feldgarden M., Arachchi H.M., Cerqueira G.C., et al. (2012). Genomic epidemiology of the Escherichia coli O104:H4 outbreaks in Europe, 2011. Proc Natl Acad Sci USA 109:3065–3070.

Gramentz D. (1988). Involvement of loggerhead turtle with the plastic, metal and hydrocarbon pollution in the Central Mediterranean. Marine Pollution Bulletin 19:11-13

Grosell M., Walsh P. (2006). Sentinel Species and Animal Models of Human Health. Oceanography 200619(2):126-133.

Guillois-Bécel *et al.* (2009). An oyster-associated hepatitis A outbreak in France in 2007. Euro Surveill. 14(10):19144.

Haines A, Patz J. (2004). Health Effects of Climate Change. JAMA 291(1):99-103.

Haines A., McMichael A.J., Smith K.R., Roberts I., Woodcock J., Markandya A., *et al.* (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. Lancet 374:2104-14

Hajeb P., Selamat J.A. (2012). Contemporary review of seafood allergy. Clin Rev Allergy Immunol. 42(3):365-85.

Hall A.J. (2012). Norovirus: the perfect pathogen? J Infect Dis. 205 (11):1622-1624.

Han F., Ge B. (2008). Evaluation of a loop-mediated isothermal amplification assay for detecting *Vibrio vulnificus* in raw oysters. Foodborne Pathog. Dis. 5:311–320.

Handy R.D., Crane M., Valsami-Jones E. (2008). The ecotoxicology of nanoparticles and nanomaterials: current status, knowledge gaps, challenges, and future needs. Ecotoxicology 17:315–325.

Hardman-Mountford N., McGlade, J.M. (2002). Variability of physical environmental processes in the Gulf of Guinea and implications for fisheries recruitment. An Investigation Using Remotely Sensed SST. pp49-66. In: McGlade J.M. *et al.* (Eds). The Gulf of Guinea Ecosystem. Elsevier, Amsterdam.

Heilaan M. *et al.* (2008). Toxicity of nanosized and bulk ZnO, CuO and TiO to bacteria *Vibrio fischeri* and crustaceans Daphnia magna and *Thamnocephalus platyurus*. Chemosphere 71:1308–1316.

Hess P. (2011). Phytoplankton and biotoxin monitoring programmes for the safe exploitation of shellfish in Europe. In: New Trends in Marine and Freshwater Toxins: Food Safety Concerns (e-book), Cabado A.G., Vieites J.M. (Eds.). Advances in Food Safety and Food Microbiology Series. NovaPublishers; ISBN: 978-1-61470-398-3.

Hess P., Nicolau E. (2010). Recent developments in the detection of phycotoxins. Advances and new technologies in toxinology, Meeting on Toxinology, SFET Editions 35–41. Free on-line access on the website :http://www.sfet.asso.fr

Hester R.E. and Harrison R.M. (eds.) (2011) Marine Pollution and Human Health. In Volume 33 of Issues in environmental science and technology, Royal Society of Chemistry, Cambridge.

Hevrøy E.M., Waagbø R., Torstensen B.E., Takle H., Stubhaug I., Jørgensen S.M., Torgersen T., Tvenning L., Susort S., Breck O., Hansen T. (2012).; Ghrelin is involved in voluntary anorexia in Atlantic salmon raised at elevated sea temperatures. Gen Comp Endocrinol 175:118-134;

Howard C.V. (1997). Synergistic effects of chemical mixtures: can we rely on traditional toxicology? The Ecologist 27:192-195.

Hughes C.C., Fenical W. (2010). Antibacterials from the sea. Chemistry 8;16(42):12512-25.

Hunt G.J., Leonard D.R.P., Fry F. (1989). High-rate seafood consumers near Sellafield: comparison of conventional assessments of caesium-137 intakes with the results of whole-body monitoring. Rad. Prot. Dosim. 27(1):35-41.

Hunt G.J., Leonard K.S., Gitzinger C., Janssens A., Godeanu–Metz, Henrich E. (2007). Article – 35 of the Euratom Treaty: Overview of national radioactive discharge and environmental monitoring requirements in the European Union, IAEA–CN-145-091P

Huss, H.H., Ababouch, L., Gram, L. (2004). Assessment and management of seafood quality and safety. FAO Fisheries Technical Paper, No. 444. Food and Agriculture Organization of the United Nations, Rome, 240p.

IOC (2012). Intergovernmental Oceanographic Commission of UNESCO. Website on harmful and toxic algae: http://www.marinespecies.org/hab/aphia.php?p=taxlist

Irish K.E., Norse E.A. (1996). Scant emphasis on marine biodiversity. Conservation Biology 10:680.

Islam M.S., Tanaka M. (2004). Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Marine Pollution Bulletin 48:624–649.

Iwamoto M., Ayers T., Mahon B.E., Swerdlow D.L. (2010). Epidemiology of seafood-associated infections in the United States. Clin Microbiol Rev. 23(2):399-411.

IWGCCH (2010). The Interagency Working Group on Climate Change and Health(IWGCCH). A Human Health Perspective on Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change. Published by Environmental Health Perspectives and the National Institute of Environmental Health Sciences, 2010. http://www.cdc.gov/climatechange/pubs/HHCC_Final_508.pdf

Jackson R. (1990). Waters and spas in the classical world. Med Hist Suppl.10:1–13.

Jeebhay M.F., Robins T.G., Lehrer S.B., Lopata A.L. (2001). Occupational seafood allergy: a review. Occup Environ Med. 58(9):553-562

Jha A.N., Cheung V.V., Foulkes M.E., Hill H.J., Depledge M.H. (2000). Detection of genotoxins in in the marine environment : adoption and evaluation of an integrated approach using the larval stages of the marine mussel, *Mytilus edulis*. Mutat. Res. 464:213-228.

Jiang L., Gao L., Sun J. (2003). Production of aqueous colloidal dispersions of carbon nanotubes. J. Colloid Interface Sci. 260:89–94.

Jingyuan L. (2007). Toxicity and bioaccumulation of nanomaterial in aquatic species. Journal of the U.S. SJWP 1-16.

Jonasson S., Eriksson J., Berntzon L., Spácil Z., Ilag L.L., Ronnevi L-O., Rasmussen U., Bergman B. (2010). Transfer of a cyanobacterial neurotoxin within a temperate aquatic ecosystem suggests pathways for human exposure. P. Natl. Acad. Sci. USA 107:9252-9257.

Joner E., Hartnik T., Amundsen C.A. (2007). Environmental fate and ecotoxicity of engineered. Norwegian Pollution Control Authority BIOFORSK. TA/2304/2007.

Jones A.C., Gu L., Sorrels C.M., Sherman D.H., Gerwick W.H. (2009). New tricks from ancient algae: natural products biosynthesis in marine cyanobacteria. Curr Opin Chem Biol. 13(2):216-23.

Jones K.A., *et al.* (2002). Guidance on the assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions, 115 pp, ISBN 0859 0 5185 http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947348591

Jonker M.J., Svendsen C., Bedaux J.J.M., Bongers M., Kammenga J.E. (2005). Significance testing of synergistic/antagonistic, dose level-dependent, or dose ratio-dependent effects in mixture dose-response analysis. Environmental Toxicology and Chemistry 24:2701-2713.

Jonker M.T.O., Brils, J.M., Sinke, A.J.C., Murk, A. J., Koelmans, A.A. (2006). Weathering and toxicity of marine sediments contaminated with oils and polycyclic aromatic hydrocarbons. Environmental Toxicology And Chemistry 25:1345-1353.

Kite-Powell H.L., Fleming L.E., Backer L.C., Faustman E.M., Hoagland P., Tsuchiya A., Younglove L.R., Wilcox B.A., Gast R.J. (2008). Linking the oceans to public health: current efforts and future directions. Environ Health. 7 Suppl 2:S6:1-12.

Kitts D.D, Yu C.W.Y, Aoyama R.G., Burt H.M., McErlane K.M., (1992). Oxytetracycline degradation in thermally processed farmed salmon. J Agric Food Chem 40,(10):1977–1981.

Knap A., Dewailly E., Furgal C., Galvin J., Baden D., Bowen B., Depledge M., Duguy L., Fleming L.E., Ford T., Moser F., Owen R., Suk W., Unluata U. (2002). Indicators of Ocean Health and Human Health: A Research Framework. Environmental Health Perspect 110:839-845.

Kortenkamp A., Altenburger R. (1998). Synergisms with mixtures of xenoestrogens: a reevaluation using the method of isoboles. Sci. Total Environ. 221:59-73.

Köser C.U., Ellington M.J., Cartwright E.J.P., Gillespie S.H., Brown N.M., Farrington M., Holden M.T.G., Dougan G., Bentley S.D., Parkhill J. (2012). Routine use of microbial whole genome sequencing in diagnostic and public health microbiology. PLoS Pathog. 8:e1002824

Kozlovski V., Brusov V., Sulimenkov I., Pikhtelev A., Dodonov A. (2004). Novel experimental arrangement developed for direct fullerene analysis by electrospray time-of-flight mass spectrometry. Rapid Commun. Mass Spectrom. 18:780–786.

Kris-Etherton P.M., Harris W.S., Appel, L.J. (2002). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease.Circulation, 106:2747-2757.

Kuhar S., Nierenberg K., Kirkpatrick B., Tobin G. (2009). Public Perceptions of Florida Red Tide Risks. Risk Analysis 29:7.

Kurelec B. (1993). The genotoxic disease syndrome. Mar. Environ. Res. 35:341-348.

Laist D.W. (1997). Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe J.M., Rogers D.B. Verlag, New York, p99-139.

Lartigues S.B, Grarrigues P.P., (1995). Degradation Kinetics of Organiphosphorus and Organonitrogen Pesticides in Different Waters under Various Environmental Conditions. Environ Sci Technol 29, 1246-1254

Lassus P., Fremw J., Ledoux M., Bardouil M., Bohec M. (1989). Patterns of experimental contamination by *Protogonyaulax-tamarensis* in some French commercial shellfish. Toxicon 27(12):1313–1321.

Lawton J.H., Depledge M.H. *et al*. (2011). Demographic change and the Environment. Royal Commission on Environmental Pollution, TSO, London. 128p.

Le Guyader F.S., Parnaudeau S., Schaeffer J., Bosch A., Loisy F., Pommepuy M., Atmar R.L. (2009). Detection and quantification of Norovirus in shellfish. Appl. Environ. Microbiol. 75:618-624.

Lees D and CEN-WG6-TAG4 (2010). International Standardisation of a Method for Detection of Human Pathogenic Viruses in Molluscan Shellfish. Food Environ Virol 2:146–155.

Lees D., CEN-WG6-TAG4 Working Grasp. (2010). International standardization of a method for detection of human pathogenic viruses in molluscan shellfish. *Food Environ. Virol. 2:146–155.*

Lees D.N. (2000). Viruses and bivalve shellfish. InternationalJournal of Food Microbiology 59:81–116.

Leonard D.R.P. (2012). Radiological assessments of the public: the challenge of assessing changes to the 'Critical Group' at Sellafield, IRPA13, Glasgow In Press

Leonard D.R.P., Hunt G.J. (1985). A study of fish and shellfish consumers near Sellafield: Assessment of the critical groups including consideration of children. J. Soc. Radiol. Prot. 5(3):129-138.

Leonard D.R.P. (2012) Radiological assessments of the public: the challenge of assessing changes to the 'Critical Group' at Sellafield, IRPA13, Glasgow 2012, P01.88 page 399, http://www.irpa13glasgow.com/2012/05/abstract-book/

Lopata L., O'Hehir R.E., Lehrer S.B. (2010). Shellfish allergy. Clinical Experimental Allergy. 40:850–858.

Lopman B.A. *et al.* (2004). Epidemiology and Cost of Nosocomial Gastroenteritis, Avon, England, 2002–2003. Emerging Infectious Diseases 10:1827-1834.

Loprinzi C.L., Levitt R., Barton D.L., Sloan J.A., Atherton P. J., Smith D.J., Dakhil, S.R., Moore, D.F., Krook, J.E., Rowland, K.M., Mazurczak, M.A., Berg, A.R., Kim G.P. (2005). Evaluation of shark cartilage in patients with advanced cancer. Cancer 104:176–182.

Lowther J.A., Avant J.M., Gizynski K., Rangdale R.E., Lees D.N. (2010). Comparison between quantitative realtime reverse transcription PCR results for Norovirus in oysters and self-reported gastroenteric illness in restaurant customers. J. Food Protect. 73:305-311.

Lucy, F.E., Graczyk, T.K., Tamang, L., Miraflor, A., Minchin, D. (2008). Biomonitoring of surface and coastal water for Cryptosporidium, Giardia, and human-virulent microsporidia using molluscan shellfish. Parasitol. Res., 103(6):1369-75 DOI 10.1007/s00436-008-1143-9.

Lyons B.P., Thain J.E., Stentiford G.D., Hylland K., Davies I. M., Vethaak A. D. (2010). Using biological effects tools to define Good Environmental Status under the European Union Marine Strategy Framework Directive. Marine Pollution Bulletin 60:1647-1651.

Maas J., Verheij R., de Vries S., Spreeuwenberg P., Schellevis F., Groenewegen P. (2009). Morbidity is related to a green living environment. Journal of Epidemiology and Community Health 63(12):967-973.

MacDonald D.D. Carr R.S., Calder F.D., Long E.R., Ingersoll C.G. (1996). Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology 5(4):253-278.

MacKintosh C., MacKintosh R.W. (1994). The inhibition of protein phosphatases by toxins: implications for health and an extremely sensitive and rapid bioassay for toxin detection. In: Codd G.A., Jeferies T.M., Keevil C.W., Potter E. (Eds.). Detection Methods for Cyanobacterial Toxins. The Royal Society of Chemistry, Cambridge, p90-99.

Marine Board of the European Science Foundation. Position Paper 15: Marine Biotechnology: A New Vision and Strategy for Europe. September 2010 http://www.marineboard.eu/images/publications/Marine%20Biotechnology-37.pdf

Martinez-Urtaza, J., Simental L, Velasco D, DePaola A, Ishibashi M, Nakaguchi Y, Nishibuchi M, Carrera-Flores D, Rey-Alvarez C, Pousa A. Pandemic Vibrio parahaemolyticus O3:K6, Europe (2005). Emerg Infect Dis. 11:1319-1320.

Martins A., Vasconcelos V. (2011). Use of qPCR for the study of hepatotoxic cyanobacteria population dynamics. Arch. Microbiology 193:615-627(1.754).

Maso M., Garces E. (2006). Harmful microalgae blooms (HAB); problematic and conditionsthat induce them. Mar. Pollut. Bull. 53:620-630.

Mattiucci, S., Fazii, P., De Rosa, A., Paoletti, M., Salomone Megna, A., Glielmo, A., De Angelis, M., Costa, A., Meucci, C., Calvaruso, V., Sorrentini, I., Palma, G., Bruschi, F., Nascetti, G. (2013). Human cases of gastric anisakiasis caused by the Anisakiasis and gastroallergic reactions associated with Anisakis pegreffi infection, Italy. Emerging Infect. Diseases, 19:996-999.

Mayer A.M., Glaser K.B., Cuevas C., Jacobs R.S., Kem W., Little R.D., McIntosh J.M., Newman D.J., Shuster B.C., Shuster D.E. (2010). The odyssey of marine pharmaceuticals: a current pipeline perspective. Trends Pharmacol Sci. 31:255-256.

McGinn A.P. (1999). Safeguarding the health of the oceans. Worldwatch Paper No. 145, 87p.

McGlade J.M. (2001). Governance of fisheries. In: von Bodungen B., Turner R.K. (Eds.). Science & Integrated Coastal Zone Management. Dahlem Conference 86, Dahlem University Press. pp 349-261.

McMichael A.J., Lindgren E. (2011). Climate change: present and future risks to health - and necessary responses. J Intern Med. 270: 401–413. doi: 10.1111/j.1365-2796.2011.02415.x.

McVeigh A., Moore M.N., Allen J.I., Dyke P. (2006). Lysosomal responses to nutritional and contaminant stress in mussel hepatopancreatic digestive cells: a modelling study. Marine Environmental Research 62(1):S433-S438.

Mee L. (1992). The Black Sea in crisis: A need for concerted international action. Ambio 21(4): 278-286.

Mellmann A., Harmsen D., Cummings C.A., Zentz E.B., Leopold S.R., *et al.* (2011). Prospective genomic characterization of the German enterohemorrhagic *Escherichia coli* O104:H4 outbreak by rapid next generation sequencing technology. PloS One 6: e22751 doi:10.1371/journal.pone.0022751.

Millennium Ecosystem Assessment (2005a). Millennium Ecosystem Assessment : synthesis report. Washington, D.C., Island Press.

Millennium Ecosystem Assessment (2005b). Ecosystems and Human Well-being : Biodiversity Synthesis. World Resources Institute, Washington, D.C.

Millennium Ecosystem Assessment (2005c). Drivers of change of change in ecosystems and their services.in : Ecosystems and Human Well-Being : A framework for assessment. Chapter 4. World Resources Institute, Washington, D.C.

Millennium Ecosystem Assessment (2005d). Ecosystems and Human Well-being: General Synthesis. Island Press, Washington, D.C., 137 p.

Miller M.A., Kudela R.M., Mekebri A., Crane D., Oates S.C., *et al.* (2010). Evidence for a Novel Marine Harmful Algal Bloom: Cyanotoxin (Microcystin) Transfer from Land to Sea Otters. PLoS ONE 5(9): e12576. doi:10.1371/journal.pone.0012576.

Mitchell R., Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. The Lancet 372(9650):1655-1660.

Moore C.J. (2008). Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environmental research 108:131-139.

Moore M.N. Kempton P.D. (2009). A synopsis of the Joint Environment and Human Health Programme in the UK.*Environ. Health*, 8 (1):S1 doi:10.1186/1476-069X-8-S1-S1.

Moore M.N., Allen J.I., Somerfield P.J. (2006). Autophagy: role in surviving environmental stress. Marine Environmental Research 62(1):S420-S425.

Moore M.N., Csizer Z. (2001). Integrated coastal zone management as a toolbox for environmentally sustainable industrial development in coastal areas. In: Integrated Coastal Area Management. Cassar L.F. (Ed.) pp. 161-166. UNIDO, Vienna.

Moore M.N., Depledge M.H., Readman J.W., Leonard, P. (2004). An integrated biomarker-based strategy for ecotoxicological evaluation of risk in environmental management. Mutation Res. 552:247-268.

Moore M.N., Owen R., Depledge, M.H. (2011). Scientific challenges and policy needs. In: Marine Environment & Human Health, Eds. R. Hester & R. Harrison, Issues in Environmental Science & Technology 34:128-163. Royal Society of Chemistry, London.

Moore MN (2006). Do nanoparticles present ecotoxicological risks for the health of the aquatic environment? Environ Int 32:967–976.

Moore S.K., Trainer V.L., Mantau N.J., Parker M.S., Laws E.A., Backer L.C., Fleming L.E. (2008). Center for Oceans and Human Health: Climate variability, climate change and harmful algal blooms. Mini-Monograph: Research in Oceans and Human Health. Environmental Health 7(2):S4:1-12

Moore, M.N., Depledge, M.H., Fleming, L., Hess, P., Lees, D., Leonard, P., Madsen, L., Owen, R., Pirlet, H., Seys, J., Vasconcelos, V., Viarengo, A. (2013). Oceans and human health (OHH): a European perspective from the Marine Board of the European Science Foundation (Marine Board-ESF). Microbial Ecol., 65(4):889-900. DOI 10.1007/s00248-013-0204-5

Morais J., Augusto M., Carvalho A.P., Vale M., Vasconcelos V.M. (2008). Microcystins - cyanobacteria hepatotoxins- bioavailability in contaminated mussels exposed to different environmental conditions. European Food Research & Technology 227:949-952.

Moreno Ancillo A., Caballero M.T., Cabanas R., et al. (1997). Allergic reactions to Anasakis simplex parasitizing seafood. Ann. Allergy Asthma Immunol.79:246-250.

Morris G.P., Beck, S.A., Hanlon P., Robertson, R. (2006). Getting strategic about the environment and health. Public Health 120:889–907.

Moser M.L., Lee D.S. (1992). A fourteen-year survey of plastic ingestion by western North Atlantic seabirds. Colonial Waterbirds 15:83-94.

Mudit M., Khanfar M., Shah G.V., Sayed K.A. (2011). Methods for evaluation of structural and biological properties of anti-invasive natural products. Methods Mol Biol. 716:55-71.

Mutreja A., Kim, D.W., Thomson, N.R., Connor, T.R. Lee, J.H. Kariuki, S. Croucher, N.J. Choi, S.Y. Harris, S.R. Lebens M. et al. (2011). Evidence for several waves of global transmission in the seventh cholera pandemic. Nature 477:462–465.

Nagamine K., Hase T., Notomi T. (2002). Accelerated reaction by loop-mediated isothermal amplification using loop primers. Mol Cell Probes 16:223-229.

Negri A, Oliveri C, Sforzini S, Mignone F, Viarengo A, Banni M. Transcriptional response of the mussel Mytilus galloprovincialis (Lam.) following exposure to heat stress and copper. PLOS One, DOI: 10.1371/journal.pone.0066802.

Nierenberg K., Byrne M., Fleming L.E., Stephan W., Reich A., Backer L.C., Tanga E., Dalpra D., Kirkpatrick B. (2010). Florida Red Tide Perception: Residents versus Tourists. Harmful Algae 9(6):600-606.

Nierenberg K., Hollenbeck J., Fleming L.E., Stephan W., Reich A., Backer L.C., Currier R., Kirkpatrick B. (2011). Frontiers in Outreach and Education: The Florida Red Tide Experience. Harmful Algae 10:374–380.

Nierenberg K., Reich A., Currier R., Kirkpatrick B., Backer L., Stumpf R., Fleming L., Kirkpatrick G. (2009). Beaches and HABs: Successful Expansion of the Florida Red Tide Reporting System for Protection of Public Health through Community Education and Outreach, Florida Journal of Environmental Health 203, 18-24.

Notomi T., Okayama H., Masubuchi H., Yonekawa T., Watanabe K., Amino N., Hase T. (2000). Loop-mediated isothermal amplification of DNA. Nucleic Acids Res. 28:E63.

Novack B., Bucheli T.D. (2007). Occurrence, behaviour and effects of nanoparticles in the environment. Environmental Pollution 150:5–22.

Okamoto K., Fleming L.E. (2005). *Algae*. In: Encyclopedia of Toxicology (2nd edition). Wexler P, editor. Oxford, England: Oxford University Press, 2005, Volume 1, pgs 68-76.

Orr J.C. *et al.* (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681–686.

Osswald J., Rellan S., Gago A., Vasconcelos V.M. (2008). Uptake and depuration of anatoxin-a by *Mytillus galloprovincialis* under laboratory conditions. Chemosphere 72:1235-1241.

Otero P., Pérez S., Alfonso A., Vale C., Rodriguéz P., Gouveia N.N., Gouveia N., Delgado J., Vale P., Hirama M., Ishihara Y., Molgó J., Botana L. (2010). First toxin profile of ciguatericfsih in Madeira arquipelago. Analytical Chemistry 82:6032-6039.

Ottaviani, D., F. Leoni, E. Rocchegiani, C. Canonico, S. Potenziani, S. Santarelli, L. Masini, S. Scuota, A. Carraturo. (2010). Vibrio parahaemolyticus-associated gastroenteritis in Italy: persistent occurrence of O3:K6 pandemic clone and emergence of O1:KUT serotype. Diagn. Microbiol. Infect. Dis. ;66:452–455.

Owen R., Depledge M.H., Hagger J.A., Jones M.B., Galloway T.S. (2008) Biomarkers and environmental risk assessment: guiding principles from the human health field. Marine Pollution Bulletin 56:613-619.

Pahl-Wostl C. (2007). The implications of complexity for integrated resource management. Environmental Modelling and Software 22:561-569.

Pandey P.K. (2009). Endangered medicinal species of the Indian Ocean: radical need for conservation. Chem Biodivers. 6(7):990-1001.

Pearce F. (1998). Muddy waters - Pollution inspectors miss poisons hidden in sediment. New Scientist 158:22-22.

Pempkowiak J., Sikora A., Biernacka E. (1999). Speciation of heavy metals in marine sediments vs their bioaccumulation by mussels. Chemosphere 39:313-321.

Perkins R, Morgan S. (2004) Poisoning, envenomation, and trauma from marine creatures. Am Fam Physician 69 (4): 885–90.

Pintó R.M. et al. (2009). A Risk assessment in shellfish-borne outbreaks of hepatitis A. Appl Environ Microbiol 75:7350–5.

Plano, L.R.W., T. Shibata, A.C. Garza, J. Kish, J.M. Fleisher, C.D. Sinigalliano, M.L. Gidley, K. Withum, S.M. Elmir, S. Hower, C.R. Jackson, J.B. Barrett, T. Cleary, M. Davidson, J. Davis, S. Mukherjee, L.E. Fleming, and H.M. Solo-Gabriele (2013) Human-associated methicillin-resistant Staphylococcus aureus from a subtropical recreational marine beach. Microbial Ecology, 65(4):1039-1051 (doi:10.1007/s00248-013-0216-1).

Pokhrel S. *et al.* (2009). Comparison of the mechanism of toxicity of binary and mixed binary metal oxide nanoparticles based on dissolution and oxidative stress proprieties. Chemie Ingenieur Technik 81(8):1167.

Population Reports (2000). Population and the environment: the global challenge volume 28(m15).Johns Hopkins School of Public Health, Baltimore. http://www.k4health.org/sites/default/files/M%2015.pdf

Priiss A. (1998). Review of epidemiological studies on health effects from exposure to recreational water. International Journal of Epidemiology 27:1-9.

Pulskamp K., Diabaté S., Krug H.F. (2006). Carbon nanotubes show no sign of acute toxicity but induce intracellular reactive oxygen species in dependence on contaminants. Elsevier Toxicology letters 168:58–74.

Quarrie J. (Ed.)(1992). Earth Summit '92. Regency Press, London, 240p.

Readman J.W., Mantoura R.F.C., Rhead M.M. (1984). Transfer processes in cohesive sediment systems In: Distribution, composition and sources of polycyclic aromatic hydrocarbons in sediments of the Tamar catchment and estuary. Parker W.R., Kinsman D.J.J. (Eds), Plenum Press, 155-170.

Reis S, Steinle S, Morris GM, Fleming LE, Cowie H, Hurley F, Dick J, Smith RI, Austen M, White M (2013). Developing an integrated conceptual model for health and environmental impact assessment. Conference Paper of the 2012 Berlin

Conference of the Human Dimensions of Global Environmental Change on “Evidence for Sustainable Development”, 5-6 October 2012, Berlin, Germany, http://www.berlinconference.org/2012/wp-content/uploads/2013/01/Reis-Developing_an_integrated_conceptual_model-205.pdf

Rice J. (2003). Environmental health indicators. Ocean Coastal Man. 46:235-259.

RIFE (2011). Radioactivity in Food and the Environment. Food Standards Agency. SEPA, 248 pp, ISSN 1365–6414.

Roberts, J., Cumberland, P., Sockett, P. et al. (2003). The study of infectious intestinal disease in England: socio-economic impact. Epidemiol Infect., 130: 1-11.

Rodriguez P., Alfonso A., Otero P., Katikou P., Georgantelis D., Botana L.M. (2012). Liquid chromatography-mass spectometry method to detect Tetrodotoxin and Its analogues in puffer fish Lagocephalus sceleratus (Gmelin, 1789) from European waters. Food Chem 132:1103-1111.

Rodriguez P., Alfonso A., Vale C., Alfonso C., Vale P., Tellez A., Botana L.M. (2008). First toxicity report of tetrodotoxin and 5,6,11-trideoxyTTX in the trumpet shell Charonia lampas lampas in Europe. Anal Chem 80(14):5622-9.

Rogowska J., Namieśnik J. (2010). Environmental implications of oil spills from shipping accidents. Rev Environ Contam Toxicol. 206:95-114.

Roodman D.M. (1998). The natural wealth of nations: Harnessing the market for the environment. The Worldwatch Environmental Alert Series. W.W. Norton & Co., 1998. 303 p.

Roose P., Albaigés J., Bebianno M.J.,Camphuysen C., Cronin M., de Leeuw J., Gabrielsen G., Hutchinson T., Hylland K., Jansson B., Jenssen B.M., Schulz-Bull D., Szefer P., Webster L., Bakke T., Janssen C. (2011). Chemical Pollution in Europe’s Seas: Programmes, Practices and Priorities for Research, Marine Board Position Paper 16. Calewaert, J.B., McDonough N. (Eds.). Marine Board-ESF, Ostend, Belgium.

Rose J., Thill A. and Brant J. (2007). Methods for structural and chemical characterization of nanomaterials. In: Environmental Nanotechnology. Applications and Impacts of Nanomaterials. Wiesner M.R., Bottero J Y. (Eds):105-154. McGraw Hill, New York.

Rossini G.P., Hess P. (2010). Phycotoxins: chemistry, mechanism of action and shellfish poisoning. In: Clinical Toxicology, Vol. 2, Chapter 2.3, p65-122. Luch A. (Ed.). Experientia Supplementa (EXS) book series, Birkhäuser Publishing, Basel.

Roth E. and Rosenthal H. (2006) Fisheries and aquaculture industries involvement to control product health and quality safety to satisfy consumer-driven objectives on retail markets in Europe. Marine Pollution Bulletin 53(10-12):599 – 605

Russell R. (1760). A Dissertation on the Use of Sea Water in the Diseases of the Glands particularly the Scurvy, Jaundice, King’s-Evil, Leprosy and the Glandular Consumption. English Translation (from Latin), fourth Edition. London: W Owen.

Ryan P.G. (1987). The incidence and characteristics of plastic particles ingested by seabirds. Marine Environment Research 23:175-206.

Ryan P.G., Connel A.D., Gardner B.D. (1988). Plastic ingestion and PBCs in seabirds; is there a relationship?. Marine Pollution Bulletin 19:174-176

Rzezutka A., Cook N. (2004). Survival of human enteric viruses in the environment and food.FEMS Microbiol. Rev. 28:441-453.

Saker M.L., Metcalf J.S., Codd G.A., Vasconcelos V.M. (2004). Accumulation and depuration of the cyanobacterial toxin cylindrospermopsin in the freshwater mussel *Anodonta cygnea*. Toxicon 43:185-194.

Sandifer PA, Collier TK, Trtanj JM (2013). Linking ocean, organism, and human health for sustainable management of coastal ecosystems. In: Grimes J (ed) Encyclopedia of Sustainability Science and Technology, Springer (in press)

Scallan E. *et al*. (2011). Foodborne illness acquired in the United States--major pathogens. Emerg Infect Dis. 17(1):7-15.

SCENIHR (2005). Opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies. Scientific Committee on Emerging and Newly Identified Health Risks, European Commission SCENIHR/002/05.

Scharff R.L. (2010). Health related costs from foodborne illness in the US The Produce Safety Project at Georgetown University. www.producesafetyproject.org.

Schrey E., Vauk G.J.M. (1987). Records of entagled gannets (*Sula bassana*) at Helgoland, German Bight. Marine Pollution Bulletin 18:350-352.

Secchi E., Zarzur S. (1999). Plastic debris ingested by a Blainville's beaked whale, Mesoplodon densirostris, washed ashore in Brasil. Aquatic Mammals 25:21-24.

Seitz S.R. *et al*. (2011). Norovirus Infectivity in Humans and Persistence in Water. Appl. Environ. Microbiol. 77:6884-6888.

Shuval H. (2003). Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment. J Water Health 1(2):53-64.

Silva M., Azevedo, J., Rodriguez P., Alfonso A., Botana L.M., Vasconcelos V. (2013). New Gastropod Vectors and Tetrodotoxin Potential Expansion in Temperate Waters of the Atlantic Ocean. Marine Drugs 11:1936-1960.

Singh S. *et al*. (2010). Unveiling the mechanism of uptake and sub-cellular distribution of cerium oxide nanoparticles. Molecular BioSystems 6:1813–1820.

Skropeta D. (2008). Deep-sea natural products. Nat Prod Rep. 25(6):1131-66.

Smith A.J., *et al*. (2011). A large foodborne outbreak of Norovirus in diners at a restaurant in England between January and February 2009. Epidemiol Infect. 1:1-7.

Soenen S. J. *et al*. (2010). Intracellular iron oxide nanoparticle coating stability determines nanoparticle usability and cell functionality. Drug Discovery Today 15:23-24.

Spear L.B., Aineley D.G., Ribic C.A. (1995). Incidence of plastic in seabirds from the Tropical Pacific, 1984-91: relation with distribution of species, sex age, season, year and body weight. Marine Environmental Research 40:123-146.

Stebbing A.R.D., Dethlefsen V., Addison R.F., Carr M., Chapman P.M., Cofino W.P., Heip C., Karbe L., Moore M.N., Vethaak A.D. (1992). Overall summary and some conclusions from the Bremerhaven workshop. Marine Ecology Progress Series (91):323-329.

Stegeman J.J., Moore M.N., Hahn M.E. (1993). Special issue - responses of marine organisms to pollutants. Marine environmental research 35. (1-2):iii-iv

Stewart I., Carmichael W.W., Backer L.C., Fleming L.E., Shaw G.R. (2011). Recreational Exposure to Cyanobacteria. In: Encyclopedia of Environmental Health. Burlington VT: Elsevier Science Publishers, 4:776-788.

Stewart J.R., Fleming L.E., Fleisher J.M., Abdelzaher A.M., Maille Lyons M. (2011). Waterborne Pathogens. In: The Marine Environment and Human Health. Hester R., Harrison R. (Eds). Issues in Environmental Science and Technology, Royal Society of Chemistry (RSC) Publishing, London, UK, volume 33.

Stratton MR, Campbell PJ, Futreal PA (2009). The cancer genome. Nature 458, 719-724.

Stumpf R., Tomlinson M., Calkins J., Kirkpatrick B., Fisher K., Nierenberg K., Currier R., Wynne T. (2009). Skill Assessment for an Operational Algal Bloom Forecast System. Journal of Marine Systems 76: 151-161.

Su L.F., Kidd B.A., Han A., Kotzin J.J., Davis M.M. (2013). Virus-specific CD4 memory-phenotype T cells are abundant in unexposed adults. Immunity. 38(2):373-383 http://dx.doi.org/10.1016/j.immuni.2012.10.021

Symes S.J. *et al.* (2007). Norovirus mixed infection in an oyster-associated outbreak: an opportunity for recombination. Arch Virol. 152(6):1075-86.

Tacon A.G.J., Hasan M.R., *et al.* (2006). Use of fishery resources as feed inputs for aquaculture development: trends and policy implications. FAO Fish.Circ. 1018:99.

Tacon A.G.J., Metian M. (2008). Global Overview on the Use of Fish Meal and Fish Oil in Industrially Compounded Aquafeeds: Trends and Future Prospects. Aquaculture 285:146-158.

Tam C.C., *et al.* (2011). Longitudinal study of infectious intestinal disease in the UK (IID2 study): incidence in the community and presenting to general practice. Gut doi:10.1136/gut.2011.238386

Thompson Coon J., Boddy K., Stein K., Whear R., Barton J. and Depledge M.H. (2011). Does participating in physical activity in outdoor naturalenvironments have a greater effect on physical and mental wellbeingthan physical activity indoors? Environmental Science & Technology 45(5):1761-1772.

Thompson F.L. (2006). The biology of Vibrios. F. L. Thompson, B. Austin, and J. Swings (Eds.). ASM Press, Washington, DC., 423 p.

Thornburg C.C., Zabriskie T.M., McPhail K.L. (2010). Deep-sea hydrothermal vents: potential hot spots for natural products discovery? J Nat Prod. 26;73(3):489-99.

Tibballs J., Yanagihara A.A., Turner H.C., Winkel K. (2011) Immunological and toxinological responses to jellyfish stings. Inflamm Allergy Drug Targets. 10(5):438-46.

Tibbetts J. (2004). The State of the Oceans, Part 1: Eating Away at a Global Food Source. Environ Health Perspect 112:a282-a291.

Todd E.C.D. (2006). Challenges to global surveillance of disease patterns. Mar. Pollut. Bull. 53:569-578.

Torres A.M., Monteiro C.A. (2002). Towards an ecology minded public health. J. Epidemiol. Community Health 56:82.

Torstensen B.E., Espe M., Sandem M., Stubhaug I., Waagbø R., Hemre G.I., Fontanillas R., Nordgarden U., Hevrøy E.M., Olsvik P., Berntssen M.H.G. (2008). Novel Production of Atlantic Salmon (*Salmo Salar*) Protein Based on Combined Replacement of Fish Meal and Fish Oil with Plant Meal and Vegetable Oil Blends. Aquaculture 285:193-200.

United Nations Environment Program (1991). Change and challenge: An introduction to the West and Central African Action Plan. Nairobi, UNEP, 1991. 23 p.

United Nations Environment Program (UNEP) (1988). State of the marine environment in the South-East Pacific region. Bogota, UNEP, 1988.

United Nations Population Division (1999). World Urbanization Prospects: The 1999 revision. New York, UN, 128 p.

Valero, A., del Mar López-Cuello, M., Benítez, R., Adroher F.J. (2006). Anisakis spp. in European hake, *Merluccius merluccius* (L.) from the Atlantic off north-west Africa and the Mediterranean off southern Spain. Acta Parasitologica, 2006, 51(3), 209–212.

Van den Berg A., Maas J., Verheij R., Groenewegen P. (2010). Green space as a buffer between stressful life events and health. Social Science and Medicine70(8):1203-1210.

van Pelt, W., de Wit, M. A., Wannet, W. J. et al. (2003). Laboratory surveillance of bacterial gastroenteric pathogens in the Netherlands, 1991-2001. Epidemiology and Infection 130 (3): 431-441.

Vasconcelos G.J, Swarmz R.G. (1976). Survival of Bacteria in Seawater Using a Diffusion Chamber. Appl Environ Microbiol 31:913-920.

Vincent C., Heinrich H., Edwards A., Nygaard K., Haythornthwaite K. (2002). Guidance on typology, reference conditions and classification systems for transitional and coastal waters.CIS Working Group 2.4 (COAST), Common Implementation Strategy of the Water Framework Directive, European Commission, 119pp.

Volker S., Kistemann T. (2011) The impact of blue space on human health and well-being – Salutogenic health effects of inland surface waters: A review. International Journal of Hygiene and Environment Health. 214(6):449-60.

Walsh P, Hogstrand C. (2008). Aquatic Animal Models of Human Health. In: Walsh P.J., Smith S.L., Fleming L.E., Solo-Gabriele H., Gerwick W.H. (Eds.). Oceans and Human Health: Risks and Remedies from the Sea, Elsevier Science Publishers, New York, 527-531.

Walsh P.J., Smith S.L., Fleming L.E., Solo-Gabrielle H.M., Gerwick W.H. (Eds) (2008). Oceans and Human Health. Risks and Remedies from the Seas. Elsevier. 644p.

Wang X.J., Yu R.C., Luo X., Zhou M.J., Lin X.T. (2008). Toxin-screening and identification of bacteria isolated from highly toxic marine gastropod Nassarius semiplicatus. Toxicon 52(1):55-61.

Warne M.St.J., Hawker D.W. (1995). The number of components in a mixture determines whether synergistic and antagonistic or additive toxicity predominate: the funnel hypothesis. Ecotox. Environ. Safety 31:23-28.

Watkins S.M., Reich A., Fleming L.E., Hammond R. (2008). Neurotoxic Shellfish Poisoning. Marine Drugs (Special Issue on Marine Toxins) 6:431-455.

Wells, P.G. (1999). Biomonitoring the health of coastal marine ecosystems - The roles and challenges of microscale toxicity tests. Marine Pollution Bulletin 39:39-47.

Westra L., Bosselmann K., Westra R. (Eds) (2008). Reconciling Human Existence with Ecological Integrity - Science, Ethics, Economics and Law. Earthscan, London, p384.

Wheeler B., White M.P., Stahl-Timmins W., Depledge M.H. (2012). Does living by the coast improve health and wellbeing? Health & Place 18:1198-1201.

White M.P., Alcock I., Wheeler B.W., Depledge M.H. (2013). Coastal proximity and health: A fixed effects analysis of longitudinal panel data. Health & Place, 23:97-108

White, M.P., Alcock, I., Wheeler, B.W. & Depledge, M.H. (2013). Would you be happier living in a greener urban area? A fixed effects analysis of panel data. Psychological Science 24:920-928 DOI: 10.1177/0956797612464659

White M., Smith A., Humphryes K., Snelling D., Depledge M. (2010). Blue space: the importance of water for preference, affect, and restorativeness ratings of natural and built scenes. J. Environ. Psychol. 30:482-493.

White M.P., Cracknell D., Corcoran A., Jenkinson G., Depledge M.H. (2013). Do preferences for waterscapes persist in inclement weather conditions and extend to sub-aquatic scenes? *Landscape Research*. DOI:10.1080/01426397.2012.759919.

White M.P., Hignett A., Pahl, S. (2012). Surf to Success Outcomes: Can Learning to Surf Promote Individual and Environmental Well-Being? Project Report for Ecominds.

White M.P., Pahl S., Ashbullby K.J., Herbert S., Depledge M.H. (2013). Feelings of restoration from recent nature visits. Journal of Environmental Psychology 35:40-51.

White M.P., Pahl S., Lefroy M., Smith A., Coley S. (2011). Surf for Success?Evaluation of a surfing intervention for teenagers at risk from exclusion. European Centre for Environment and Human Health, Working Paper.

WHO - World Health Organization (2010). Poverty, social exclusion and health systems in the WHO European Region. Copenhagen, WHO Regional Office for Europe. 40p.

WHO (1999). Joint FAO/NACA/WHO Study Group on food safety issues associated with products from aquaculture. World Health Organization (WHO) Technical Report Series No. 883. World Health Organization, Geneva, Switzerland.

WHO (2008). World Health Organization 2008-2013 Action Plan for the global Strategy for the Prevention and Control of Noncommunicable Diseases.

WHO (2010). Poverty, social exclusion and health systems in the WHO European Region. Copenhagen, WHO Regional Office for Europe. 40p.

Wiener J.B., Rogers M.D. (2002) Comparing precaution in the United States and Europe. Journal of Risk Research 5:317–349.

Wilson and Schwarzman, 2009 Wilson MP, Schwarzman MR (2009). Toward a New U.S. Chemicals Policy: Rebuilding the Foundation to Advance New Science, Green Chemistry, and Environmental Health. Environ Health Perspect 117:1202-1209. http://dx.doi.org/10.1289/ehp.0800404

Windom H.L. (1992).Contamination of the marine environment from land-based sources. Mar. Pollut. Bull., 25:32-36.

Woo C.K., Bahna SL. (2011). Not all shellfish "allergy" is allergy! Clinical and Translational Allergy 1:3.

World Bank (1995). Africa: a framework for integrated coastal zone management. Washington, DC, World Bank.

World Bank (2010). Theories of behavior change. Communication for Governance and Accountability Program (CommGAP). Washington, DC: World Bank. http://documents.worldbank.org/curated/en/2010/01/11629704/theories-behavior-change

World Wildlife (WWF). Strategies for Change http://www.wwf.org.uk/what_we_do/strategies_for_change22.cfm. Accessed September 26, 2011.

Xue X.X., Ruan W.D., Yang L.B., Ji W., Xie Y.F, Chen L., Song W., Zhao B., Lombardi J.R. (2012). Surface-enhanced Raman scattering of molecule adsorbed on Co-doped ZnO nanoparticles. Journal of Raman spectroscopy 43:61–64.

Yamazaki W., Seto K., Taguchi M., Ishibashi M., Inoue K. (2008). Sensitive and rapid detection of cholera toxin-producing *Vibrio cholerae* using a loop-mediated isothermal amplification BMC. Microbiology 8:94.

Zaias J., Backer L.C., Fleming L.E. (2010). Harmful Algal Blooms (HABs). In: Human-Animal Medicine: A clinical guide to toxins, zoonoses, and other shared health risks. Rabinowitz P., Conti L/ (Eds). Elsevier Science Publishers, New York, 91-104.

Zhou J.L., Fileman T.W., Evans S., Donkin P., Llewellyn C.A., Readman J.W., Mantoura R.F.C. Rowland S.J. (1998). Fluoranthene and pyrene in the suspended particulate matter and surface sediments of the Humber estuary, UK. Mar. Poll. Bull. 36:597-597.

Zhou J.L., Fileman T.W., Evans S., Donkin P., Readman J.W., Mantoura R.F.C., Rowland S. (1999). The partition of flouranthene and pyrene between suspended particles and dissolved phase in the Humber Estuary: a study of the controlling factors. Sci. Total Environ. 244:305-321.

Zinn C., Lopata A., Visser M., Potter P.C. (1997). The spectrum of allergy to South African bony fish (Teleosti). S. African Med. J. 87(2):146-151.

Zoumis T., Schmidt A., Grigorova L., Calmano W. (2001). Contaminants in sediments: remobilisation and demobilisation. Science of the total environment 266:195-202.

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