

The background of the book cover is a composite image. The top half features a large, textured blue sphere, resembling a globe or a celestial body, with a map of the world's oceans overlaid. The bottom half shows a beach scene with people walking along the shore under a cloudy sky. A large, semi-transparent sphere is overlaid on the left side, containing a detailed image of a rocky coastline with waves crashing against the shore.

OCEANS AND HUMAN HEALTH

Implications for Society and Well-Being

Edited by

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Foreword

The seas across this planet and their effects on human society and its destiny are a fascinating subject for analysis and insights derived from intellectual inquiry. This diverse and complex subject necessarily requires a blending of knowledge from different disciplines, which the authors of this volume have achieved with remarkable success.

Human well-being as it relates to the condition of the seas spread across the globe and its nexus with societal issues is very much part of the history of the human race. Very basic and simple concerns relate to food and nutrition that are derived on a large scale from ocean resources. Additionally, the history of the world has itself been shaped essentially by the ability of human beings to master transportation across the seas and the ability to access and utilize a range of resources from marine structures, including hydrocarbons, minerals, and a wealth of other resources, which in a variety of ways have become a part of daily human existence. Not only has the power structure of global relationships been directly influenced by the ability of societies and nations to travel far and wide, often extending their military prowess and weaponry to other lands, but also in today's world the ability, for instance, to carry out deep sea drilling for oil and gas provides large economic benefits to those who possess technologies and skills in these areas.

Unfortunately, in today's world human beings are also altering, at an unprecedented rate, the relatively stable relationship that we have lived with in relation to the Earth's oceans and seas. As a result of the rapid increase in emissions of carbon dioxide since the beginning of industrialization and its absorption by the oceans, their

acidification is threatening marine life of various forms. The melting of ice across the Arctic is likely to change maritime activities significantly, with the possible emergence of new routes linking east to west. There could also be changes in ocean currents on account of changes in the salinity gradient of some seas where such melting is occurring at a significant level. The impact of climate change has resulted in sea-level rise, which is not only affecting human habitat in several parts of the world where settlements have flourished over thousands of years, but also communities are now facing an increased threat of coastal flooding and storm surges as a consequence. At the same time, with sea-level rise, the intrusion of salinity in areas far away from the coast is becoming a reality. This would undoubtedly affect the quality and availability of groundwater resources to the detriment of people at a distance from the sea, who historically have been immune to these conditions.

The impacts of climate change on coastal ecosystems could have serious consequences not only for those directly affected but also as a result of the emergence of a large number of climate refugees, who with the threat of sea-level rise experienced in the past and anticipated in the future could decide to move away from locations where civilizations and cultures have been able to thrive for thousands of years. Indeed, such a trend could affect societies not only in the immediate vicinity of affected locations but also areas far away that would become attractive destinations for climate refugees threatened with sea-level rise.

Sea-level rise poses a serious threat for ecosystems, with health implications for human beings and all living species in coastal areas and beyond. Species likely to be affected would not only include plant life but other life forms as well. For instance, the low-lying areas of West Bengal and

the region that is now Bangladesh form part of the traditional habitat of the Bengal tiger. Indeed, the Sunderban islands still have a small population of Bengal tigers, which with the projections of sea-level rise could become extinct and consigned to history. There also could be increases in the nature and extent of vector-borne diseases in some of these areas, and, of course, once such a trend were to set in, its impact could extend geographically to other areas far from the shore. Serious threats to all forms of life also have been imposed by other human actions that have led to serious problems of pollution. A tragic example of this was the prolonged discharge of methyl mercury in Japan into the Minamata Bay and Shiranui Sea that notoriously has become associated with Minamata disease, which has afflicted thousands of human beings and innumerable numbers of fish and other marine species and animals that consumed contaminated marine food. This serious problem continued for 36 years before effective action was taken to put an end to it. Oil spills also cause incalculable damage to an unknown range of living species. The most recent case of a serious oil spill was that created by the Deepwater Horizon project of BP, where a devastating oil spill stretched far and wide across the Gulf of Mexico.

The following pages in this volume are written in a lucid and very readable style, and provide a wealth of knowledge and insightful analysis, which is a rare amalgam of multidisciplinary perspectives and unique lines of intellectual inquiry. This volume is of great value, and it will appeal as much to a nonspecialist reader as it would to specialists in the diverse but interconnected subjects covered by this volume.

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About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/bowen/oceanshumanhealth

The website includes:

- Powerpoints of all figures from the book for downloading
- PDFs of all tables from the book for downloading

Section One

Coastal Seas, Human Health, and Well-Being: Setting the Stage

Chapter 1

Influences of the Oceans on Human Health and Well-Being

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1.1 Introduction

Oceans have attracted humans to their shores since ancient times. Over thousands of years, they have served as a source of food, provided livelihoods, and generated commerce, as well as being a means of disseminating people, and later, connecting civilizations, near and far. Their importance is reflected in many cultural practices, and is manifest in inspirational art.

Inevitably, the oceans influence our health and well-being. Damaged marine ecosystems arising from natural disasters or as a result of human exploitation, lead to negative consequences for human health and well-being [1–10].

“Health” in this context is usually defined as physical and physiologic health, which is lost or damaged following the emergence of disease or after injury. The impact of the oceans on health is typically assessed in relation to changes in the incidence of acute and chronic diseases. For instance, acute poisonings and infections associated with the consumption of seafood containing harmful algal bloom

(HAB) toxins and microbial organisms result in acute disease episodes, while chronic diseases such as diabetes and cancer may occur after long-term exposure to persistent organic pollutants consumed in contaminated seafood. Drowning is, of course, also a well-recognized health threat associated with activities in or on our seas.

Unlike human health, the term “human well-being” is not one with a consensus definition. It is a concept used in a broad-ranging set of literatures without a precise, consensus definition. Rather, the term “well-being” is a concept or abstraction used to refer to whatever is assessed in an evaluation of a person's “life situation” or “being [11].” Within the pages of this book, the term is used in the following ways:

- economic vitality built upon the foundations of ecosystem service value and sustainable development practices;
- social and cultural integrity;
- psychological stability and strength; and/or
- human happiness.

The decline of well-being associated with some of the negative effects on physical and physiologic health noted earlier, is now widely accepted. There is also recognition of the negative impacts on mental health arising from ocean events, ranging from the aftermath of extreme weather events and tsunamis to the loss of ocean-derived livelihoods and cultural activities in coastal communities resulting from degradation of marine ecosystems, especially in relation to the collapse of fisheries.

The best known benefits to human health and well-being arising from interactions with the oceans are related to the consumption of seafood, rich in alpha omega fatty acids

and nonterrestrial animal proteins and amino acids. Indirect benefits to health also arise from marine-derived pharmaceuticals and vitamins. However, alongside the promotion of physical health, there is increasing recognition of the value of coastal seas in promoting better mental health. Individual benefits include decreased vulnerability to depression and the fostering of broader societal “health” benefits related to employment, commerce, and even cultural and artistic activities. The importance of mental health and well-being was captured within the World Health Organization (WHO)'s definition of health, namely “a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity” [12]. Mental health and well-being also emerge as important outcomes in models of ecosystem services. The Millenium Ecosystem Assessment (2005), for instance, identifies “good social relations” and “freedom of choice and action” as key well-being outcomes [13]. Other ecosystem service approaches include similar psychological constructs in their definitions of well-being; for example “positive emotions” [14] and a “sense of place” [15]. These broader positive impacts of the oceans on human well-being, physical health, and coastal communities have only recently begun to be explored as part of a growing research effort exploring the significance of our interactions with the natural environment [16].

In this chapter, we review the growing body of evidence regarding the influence of interactions between humans and the oceans on health and well-being. Past research that has focused on risks and harms is discussed, but we especially focus on the explorations of the benefits of the oceans to both human health and well-being.

1.2 Interactions and routes of exposure

Human interactions with the oceans can be both direct (i.e., fishing or bathing) and indirect (i.e., human use of antibiotics resulting in the emergence of antibiotic-resistant organisms in coastal waters, seafood, and marine mammals; and the burning of fossil fuels leading to global climate change and sea-level rise). Although varying in terms of latency of exposure and effect (i.e., the time between exposure and observable impacts), almost all our interactions with the oceans have the potential to come back to help or hurt humans and other animals in unexpected ways, both now and in the future.

Many researchers suggest that for there to be effects of oceans on health and well-being, there must be exposure [15–18]. In general this is true, but it does overlook the fact that sometimes false perceptions or perceived threats that in reality do not exist can exert powerful influences on well-being, and ultimately health. For example, the belief that seafood might contain toxins, even when it does not, can still lead to anxiety, the avoidance of seafood consumption, and ultimately adverse health impacts.

In general, however, exposure is key, and may range from the visual and aural experiences of seeing and hearing the oceans to the direct physical contact with marine waters (e.g., through swimming and other water sports), the consumption of seafood from all levels of the marine food chain, and the inhalation of marine aerosols both in coastal areas and further inland. These exposures can be acute, sub-acute, and/or chronic (e.g., direct skin contact with an oil spill, inhalation of a HAB toxin during a bloom lasting days to months, and the daily consumption over many years of low levels of mercury-contaminated seafood,

respectively). The nature of the timing and extent of exposures can lead to a wide range of acute and chronic diseases on the one hand, but paradoxically, potentially short and/or long term health and well-being benefits on the other. Finally, exposures and their subsequent health and well-being consequences also vary in relation to the underlying susceptibilities of individuals (e.g., increased vulnerabilities of the elderly, children, immunosuppressed, etc), and by the population density of people living on or near the coasts, particularly in low and middle income nations.

1.3 Risks

Many of the most important influences of the oceans on human health and well-being are increasingly driven by global environmental change (e.g., the frequency of occurrence of algal blooms; and human demographic change and associated discharges of pharmaceuticals and other pollutants). Of interest, climate change may be especially important in this regard (as is discussed later and in other chapters), often to the increasing detriment of human health and well-being. The most obvious effects of climate change include increased risks of drowning and physical trauma after coastal inundation associated with extreme weather events (e.g., hurricanes or cyclones); and in the longer term, increases in exposure to infectious diseases (e.g., cholera) and harmful algal blooms (e.g., red tides), reduced food security, and adverse mental health impacts [4]; all these are associated with sea-level and sea-temperature rise, and with more severe and frequent extreme weather and flooding events.

More indirect effects of global climate change that have yet to be fully explored, include ocean acidification (secondary to increasing carbon dioxide levels in the atmosphere),

which adds to pressures on fisheries that are already stressed, and may result in increased risks of malnutrition and starvation as well as mental health impacts in fishing- and seafood-dependent communities [19]. Rising temperatures are already associated with geographic changes in the distribution, and possibly increasing frequencies of occurrence, of pathogenic microbes (e.g., bacteria living in the marine environment such as *Vibrio cholera*, which can cause illnesses [cholera] in humans) and harmful algal blooms (e.g., exuberant growth of algae which can produce potent natural toxins) [20]. The distribution and bioavailability of chemical pollutants are also changing as the climate changes. These effects are likely to be associated with the increasing degradation of coastal resources and infrastructure, prompting massive population migration of “climate-change refugees” and increasing conflict locally and internationally [21]. With regards to climate-driven migration, however, some researchers remain sceptical [22]. Migrants often tend to move within their own country or region, rather than embarking on migrations further afield. What is of interest here is that those forced to relocate over both short and long distances may be more at risk from mental and physical illnesses, while those relocated actively as part of an adaptation processes may, in some cases, derive health benefits.

Historically and currently, marine ecosystems have been a major source of employment. The open-ocean and coastal wild-capture seafood industry, has been and continues to be one of the most dangerous for workers from drowning, trauma, and mental-health impacts. Other ocean and coastal extractive activities, such as aquaculture (e.g., intensive farming of fish and other seafood in ponds, coastal or even deeper ocean water) and working within the oil and gas industry, also have their own adverse

consequences for physical health and well-being [23, 34]; merchant marine, cargo, and even cruise shipping can also provide dangerous occupations [25, 26]. New marine and maritime activities have been added over the past two centuries around recreational use, particularly of the coastal seas. Although usually associated with beneficial health and well-being effects (discussed later), these occupations and activities are not without their own (primarily) physical health risks to workers and participants [27].

Humans have created a wealth of new synthetic materials over the past 150 years, often purposefully designed to last and used in an enormous range of products. During manufacture and following use and disposal, many persistent organic chemicals end up in the oceans, joining other emerging contaminants (e.g., plastics, radionuclides [predominantly anthropogenic and natural radioactive substances put to many industrial uses], and nanoparticles [predominantly anthropogenic ultrafine particles between 1 and 100 nm increasingly used in a wide range of products ranging from sun screens to fuel additives]). They accumulate both in food chains and in components of marine ecosystems more widely. When specific adverse biological effects can be linked to the presence of contaminants in ecosystems, they are redesignated as “pollutants” [28]. Other toxicological impacts owe their origins to marine mining and the release of inorganic chemicals (e.g., metals such as mercury) and organic chemicals associated especially with the oil and gas industry (e.g., petroleum oils). The terrestrial use of fertilizers (e.g., phosphorus, nitrogen and urea) and pesticides may also be detrimental as they are washed into the sea by rain [29–32]. Finally, pharmaceutically active products ranging from estrogens from female birth control to antibiotics used in medicine and veterinary medicine,

and even excreted cancer chemotherapy agents found in animal and human fecal waste, are increasingly delivered to marine ecosystems by rivers, with direct and indirect damaging effects [33, 34].

Persistent organic pollutants (e.g., the pesticide DDT, and PCBs used in transformers) and heavy metals can directly affect the health of humans and marine mammals where toxicity is manifest as immune-suppression, the developmental and neurologic diseases, and possibly the emergence of cancer, particularly in native coastal human populations [18, 35]. Increasing concentrations of nutrients (e.g., fertilizers and fecal waste from humans and animals) in marine waters are often associated with increasing microbe populations, including pathogenic microbes and toxin-producing harmful algal blooms [36]. Antibiotic-resistant organisms (e.g., the bacteria methicillin-resistant *Staphylococcus aureus* [MRSA]) have already been found in coastal environments, notably on beaches, and may give rise to virtually untreatable infections [37]. The long-term effects of micro-plastics (very fine pieces of plastic generated by ocean waves and other processes on larger plastic waste), nanoparticles, and other novel compounds are just beginning to be explored. Within aging populations, and with the obesity epidemic, increasing body burdens of persistent chemicals are being identified, leading potentially to heightened risks of cancers, possibly dementia, and other chronic diseases [38].

As noted earlier, general human farming activities (including coastal aquaculture), coupled with increasing nutrient use and rising ocean temperatures, appear to be expanding the ranges and numbers of potentially pathogenic microbes (viruses and parasites as well as bacteria) living in coastal environments [36]. These can give rise to acute and chronic infectious diseases (including acute gastrointestinal disease from Norwalk virus in

contaminated shellfish; skin infections with MRSA bacteria; and potentially chronic liver disease, and even death, from *Vibrio parahaemolyticus* bacteria). Particularly vulnerable populations include young children and immune-suppressed individuals (such as persons undergoing chemotherapy or with AIDS) [39–42]. These illnesses can affect not only consumers of contaminated seafood, but also seafood-harvesting workers.

Harmful algal blooms appear to be increasing in frequency worldwide in all aquatic systems, and their geographic ranges are also changing due to climate change and human activities (e.g., carried globally in ballast water, and in some cases triggered by increasing nutrients) [43]. Some of these phytoplankton species, so important in underpinning the marine food web, produce potent natural toxins which in humans cause acute and chronic neurologic illness and possibly cancer after seafood ingestion, as well as acute and subacute respiratory illness through exposure to toxin-contaminated marine aerosols [44, 45]. At the same time, overuse of, and environmental contamination with, antibiotics may have major negative impacts on one large and important group of algae, the cyanobacteria (blue-green algae), which could have significant implications for fisheries that are already stressed [46].

Many of the world's fisheries (both coastal and deep ocean) are dwindling due to exploitation, habitat degradation, and anthropogenic pollution following the expansion of human populations along the coastal margins. Therefore, large numbers of people and livestock animals dependent on food derived from the sea are likely to be confronted with malnutrition and starvation (as well as the loss of the potential health benefits). Coastal communities in developing nations are especially at risk [10].

Although an ancient agricultural practice, aquaculture is rapidly expanding in all aquatic environments, tripling in the past 15 years. It already provides seafood for many countries locally, and as an exported commodity it is predicted to account for 39% of total global seafood production by weight [47–49]. In the future, aquaculture may also be used increasingly for diverse purposes such as biofuel production, carbon sequestration, and as a source of medical products [50]. There is growing evidence of the negative ecosystem impacts in all aquatic environments of intensive and increasingly large-scale aquaculture, particularly its microbial, chemical, and nutrient generation. The impact of the growing implementation of aquaculture on wild seafood populations is still being explored [51]. Furthermore, relatively little is known about the long-term health effects of aquaculture on workers or consumers, particularly the high use of antibiotics and the genetic manipulation of marine species by aquaculture [23, 52].

1.4 Benefits

As noted earlier, the benefits to health and well-being from the oceans have typically focused on physical health, as well as societal “health,” benefits. The Fisheries and Agricultural Organization (FAO) estimates that for over one billion people worldwide, particularly in developing countries, seafood is the primary source of animal protein [53, 54]. Furthermore, fish and shellfish are the most highly traded foods internationally, providing local jobs and national export earnings (over US\$51 billion/year) through both traditional coastal/ocean seafood harvesting and the growing reliance on aquaculture in all aquatic environments [53, 55]. A stable and consistent source of seafood is essential therefore for the nutritional health,

prosperity, and security of a large segment of the world's population [54].

As well as its utility as a basic source of protein low in polyunsaturated fats and high in micronutrients, increasing evidence links seafood with a range of human health benefits. These include the effects of the long-chain polyunsaturated omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) present in high amounts in some seafood, which are linked to the prevention of stroke and cardiovascular mortality, and some level of protection against depression, Alzheimers, and some cancers [18, 56–58]. Western medicinal practitioners now recommend increasing the amount of seafood in the diet as a preventive health measure [56].

The oceans also represent an important source of pharmaceutical products (including anticancer and pain medications). Other chemicals (e.g., extracted from kelp and algae) harvested from the oceans and along the coasts are used in a range of products with additional health benefits [59–62].

Among emerging uses of the oceans, under the rubric “blue carbon,” marine organisms such as algae are likely to be actively used in the future for producing biofuels and for carbon sequestration to mitigate global change [50].

Offshore-wind, tidal, and wave energy reduce the need for energy from traditional sources, which have significant health impacts through air pollution [63].

More associated with societal “health” benefits are issues such as the use in scientific research of marine models of humans and their diseases (e.g., *Aplysia* (the sea hare) as a developmental neurophysiology model) [64, 65]. Marine organisms, particularly marine mammals, also serve as sentinel species of the potential threats posed by interactions with the oceans: thus, sea lions have been

documented as suffering neurologic and other health effects from exposure through the food chain to a mixture of HAB toxins, persistent organic pollutants, and antibiotic-resistant bacteria [44, 66–69]. Identification of such cases can provide early warning of future human health impacts.

Finally, the most complex and elaborate forecasting systems (including the Integrated Ocean Observing System (IOOS)) have been developed for the monitoring and prediction of weather, extreme weather events (such as hurricanes), and global environmental change, as part of efforts to predict, mitigate, and prevent health threats to humans and societies [70–72]. Other more localized and collaborative efforts (including utilizing citizen science and stakeholder participation) have been developed to predict, mitigate, and manage the health impacts of harmful algal blooms (Box 1.1), microbial pollution, and chemical pollution [73–75].

Box 1.1 Red tide risk and benefit story

As discussed earlier, harmful algal blooms and their potent natural toxins have been viewed in general as an unalloyed risk rather than benefit to human health. For example, the Florida red tide organism, *Karenia brevis*, regularly blooms in the Gulf of Mexico and beyond; its potential natural toxins, brevetoxins, are associated with a range of impacts on human, societal, and animal health [45, 76]. During blooms, literally millions of fish, birds, and even marine mammals sicken and die due to the neurotoxic effects of brevetoxins. Humans who consume shellfish (and possibly fish) contaminated with brevetoxins develop an acute and potentially fatal neurologic illness, neurotoxic shellfish poisoning (NSP). Asthmatics and

other people develop acute and subacute respiratory disease (including asthma exacerbations, bronchitis, and pneumonia) associated with breathing marine aerosols contaminated with brevetoxins.

Yet at the same time, research into Florida red tides has led to a number of discoveries, some of the serendipitous, which have directly and indirectly benefited human health. The organism is a phytoplankton, an important component of the marine food chain as well as essential to ocean photosynthesis and potentially carbon sequestration. Brevetoxins are very specific toxins which have been used to explore the mechanisms of the sodium channels of nerve cells in neurophysiologic research, leading to a greater understanding of human physiology and more appropriate treatments for human diseases. Research into brevetoxins has identified a new compound, brevenal, also elaborated by the HAB organism. Brevenal is an antagonist to brevetoxins, and as such can be used as a specific treatment for brevetoxin-induced diseases and similar illnesses such as ciguatera fish poisoning; brevenal also has been shown to increase the mucocilliary blanket in the lung, which has led to it being patented for the treatment of the fatal inherited lung disease, cystic fibrosis. Finally, interdisciplinary and interagency groups working with communities and citizens around Florida red tide issues have developed early warning programs, outreach and educational materials, and exposure and disease reporting systems for affected communities and individuals, as well as policy changes around nutrient use to possibly prevent future algal blooms [73, 74].

Thus, research into and exploration of ocean issues such as HABs can have both positive and negative effects for human health and well-being, often unknown and unpredicted. Furthermore, it is the interactions between

humans and the oceans that make these exposures and effects possible.

1.4.1 Health and well-being from ocean and coastal ecosystems

As was alluded to earlier, some of the most exciting research into the well-being (and possibly physical health) benefits of the oceans have come from exploration into health and well-being from the natural environment.

From an ecosystem-services perspective, marine environments provide a range of positive benefits to health and well-being [13, 15, 77, 78]. Some, such as the provision of seafood, with its important nutrient and nutritional content, and pharmaceutical compounds derived from ocean-based organisms, are already well-documented, and their economic significance has been evaluated. Other health and well-being benefits, especially those arising from direct exposure to the sea (e.g., through immersion, ingestion, and observation) have received relatively little scientific attention, despite being documented by the Sumerians, Egyptians, Greeks, and Romans [79–81]. Broadly speaking, the issue is whether (and how) “thalassotherapy” (from the Greek word for sea, *thalassa*) works in the sense of aiding human health and well-being remains obscure and its economic significance has yet to be determined.

One of the earliest accounts (1750–1760) of the possible health benefits of seawater was provided by Richard Russell [82]. Reviewing an extensive number of case studies, Russell concluded that “Sea Water” may have a range of medicinal properties for “glandular” diseases such as scurvy, King's Evil (scrofula), jaundice, and tuberculosis. His main argument was based on seawater's mineral

content. Building on the widespread belief that the healing properties of terrestrial thermal springs depended on the minerals dissolved in the water (that could, it was believed, be both ingested and absorbed through the skin), he reasoned that since “it is certain, that salts contribute greatly to all Cures that are performed by Medicinal Waters... [and that since]... all these Qualities, and some others plainly appear in Sea Water... [it]... gives us great Hopes, that the Materia Medica may soon receive some extraordinary Addition from this Part of Nature.” (p. xii, 1760) [82].

Following the publication of his treatise, he established a practice at Brighton on the south coast of England where patients, including members of the royal family, engaged in sea bathing as a cure for all manner of ills. Several hospitals were subsequently established, including the Royal Seabathing Infirmary at Margate in 1791 specifically designed to treat scrofula [83]. Similar developments occurred across Europe with dozens of thalassotherapy resorts and treatment centers being established during the nineteenth century [80]. These therapies were often provided alongside other more established “spa” treatments such as: hydrotherapy (which uses only water), balneotherapy (which uses thermal mineral waters), and sea mud and algae treatments [80, 84].

The evidence in support of thalassotherapy was, however, largely anecdotal and often overplayed by commercial interests [80]. The pathways by which seawater were supposed to treat specific diseases were unclear; case studies, such as those reviewed by Russell, often featured a range of treatments, leaving it unclear whether or not seawater was the critical intervention. Perhaps unsurprisingly, therefore, the demand for thalassotherapy declined with the introduction of antibiotics in the middle of the twentieth century that demonstrably treated the

same diseases targeted by seawater treatments but through well understood biological pathways. Nevertheless, there is evidence of a recent reemergence of interest in thalassotherapy, especially among richer clients [80], and therein perhaps lies the most obvious benefits of the oceans to health and well-being.

For over 250 years, the main focus was on the physical mechanisms by which seawater could tackle disease, while the possibility that the oceans and seas could have their largest impact through mental health and well-being, perhaps through pain reduction [85], was for many years less well researched. There is now a large and extensive body of literature which shows that stress, anxiety, pain, and mental disorders can directly affect physical health by reducing immune functioning and increasing the risk of physical conditions (such as cardiovascular disease, type 2 diabetes, and premature mortality) [86–88]. It is therefore entirely conceivable that one of the main benefits of ocean and sea exposure may be in the way in which it calms the mind, rather than directly healing the body. Reviewing the evidence for “spa” treatments in general, for instance, Bender *et al.* concluded, “the placebo effect is considerable, and if it ‘pleases,’ and pain is reduced and the patient's general well-being improves, then arguably it is of value irrespective of trial results from randomized, controlled trials” (p. 222) [84].

So, given that all modern definitions of health (including those used by ecologists) include mental well-being, is there any evidence that the oceans and seas in particular, as opposed to more general water-based therapies, are good for mental health and well-being? The evidence comes from two separate strands of research, which broadly can be summarized as economic and psychological. The economic approach to measuring well-being is based on three key assumptions [89]. First, it is assumed that

individuals have different preferences, and thus objective circumstances are not necessarily good indicators of well-being, since different individuals will react to these circumstances differently. Second, it is assumed that people are often unwilling and/or unable to express their well-being verbally, rendering responses to surveys, etc., unreliable. Third, it is assumed, instead, that people reveal their preferences through their allocation of scarce resources, such as time and money. Thus, if individuals voluntarily choose to visit or live near the sea, relative to alternative locations, then it is assumed that the sea is good for their well-being, because they are acting on (and paying for) their personal preferences.

From this perspective, there is an enormous amount of evidence that people around the world are keen to spend time by the sea, either by choosing to live near the coast or to visit coastal locations, engage in sea cruises, or go diving for tourism and recreation purposes [13, 15, 77, 90–93]. Importantly, they are also willing to pay a price premium to do so, as evidenced using the revealed-preference technique of hedonic pricing [94]. For example, homes with coastal views tend to cost more than similar homes with noncoastal views [77, 95], and people are willing to pay more for tourist accommodation with coastal views [96]. This approach can also be used to examine the effect that degradation of the marine environment has on well-being by looking at the reduced willingness to visit degraded sites. For instance, “episodes of harmful (including toxic) algal blooms in coastal waters are increasing in frequency and intensity, harming other marine resources such as fisheries as well as human health. In a particularly severe outbreak in Italy in 1989, harmful algal blooms cost the coastal aquaculture industry \$10 million and the Italian tourism industry \$11.4 million” (p. 6) [13]. Other studies based around revealed preferences have employed the

travel-cost method and used the value of the cost of travel as a proxy for willingness to pay for use of the site. For example, Whitehead *et al.* (2008) employed this method in valuing beach access in North Carolina in the United States [97].

Where there is no obvious market for the expression of preferences (e.g., for the protection of marine environments or species), economists use “stated preference” methods, such as contingent valuation and choice experiments to estimate the value. These ask people to make trade-offs in order to establish how much value people attach to these nonmarket goods. The well-being these values express may include so-called “non-use” values such as the satisfaction one derives from helping preserve a species for future generations [93]. These methods can also be used to understand the (perceived) value of health of sea and coastal environments by asking people how much they would be willing to pay for improvements in the quality of the marine environment. Using this approach, for instance, Machado and Mourato (2002) estimated the amount people in Lisbon would be willing to pay to reduce their risk of gastroenteritis from bathing in local contaminated coastal waters [98]. Other studies have focused on the value of algal blooms [99]. Using these studies inferences can then be made about the well-being derived from improved marine environments.

The second main way of assessing the well-being associated with exposure to the seas and oceans is psychological, which is based on what people say about how they think and feel about their lives and experiences [100]. One strand of research asks people to quantify their well-being while exposed to different environments, either *in situ* or virtually (e.g., using photographs, videos, etc.). This line of research suggests that individuals report higher levels of positive emotions when exposed to aquatic