Marine Pollution in Context

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Contents

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Acronyms and Abbreviations

DDT	Dichloro-diphenyl-trichloroethane
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
MARPOL	International Convention for the Prevention of Pollution from Ships
PCBs	Polychlorinated biphenyls
PFOS	Perfluorooctanesulphonic acid
PFOA	Perfluorooctanoic acid
TBT	Tributyltin

1.1 Introduction

You have opened this book because you have an interest in the ocean and the impact of humans upon it. This is a serious issue that gains plenty of media attention, but prior to the early 1950s it was generally considered that oceans were so expansive that they could absorb waste inputs indefinitely. Early concerns were raised specifically in response to the dumping of radioactive wastesin the ocean. Other globally recognisable events, such as mercury poisoning in Minamata Bay—Japan, oil spill disasters from vessels such as the Torrey Canyon in Great Britain in 1967, and the Oceanic Grandeur in Torres Strait in 1970, further highlighted the vulnerability of oceans to pollution. The highly visual impacts of large oil spills provided the initial direction for marine pollution research, and publications in the decade between 1970 and 1980 were dominated by studies on oil pollution. The risk of oil spills still exists today and incidences such as the Exxon Valdez Spill in 1989 and *Deepwater Horizon* (British Petroleum) in 2010 have challenged even the best available oil spill response programs and strategies. Periods after both events saw a further proliferation of research publications on oil pollution, expanding our knowledge and challenging our management capabilities.

Pollution of the marine environment is caused by a wide range of activities, and it is commonly reported that as much as 80% of marine pollution is a result of land-based activities (◘ Figure 1.1). Fertiliser runoff from agricultural land has been highlighted as the cause of the **dead zone** in the Gulf of Mexico. The Northern Pacific Gyre Garbage Patch is an example of the consequences of poor solid waste management on a global scale. The Fukushima Daiichi nuclear accident in 2011, ocean acidification, ports and shipping, and multiple other land-based point and non-point source (also known as diffuse source) inputs highlight the challenges for minimising the threat of marine pollution. Contemporary research publications related to marine pollution not only cover the traditional focus on oil spills and radioactive waste dumping, but include a wide range of existing and emerging chemicals and substances of concern such as pesticides, pharmaceuticals, phthalates, metals, fire retardants, nano- and micro-particles, and mixtures of these. The growing body of knowledge has aided our understanding of how these substances behave in the marine environment and how organisms interact with them, helping to define the study of marine pollution.

Marine pollution is a challenging field of study requiring a **multidisciplinary approach** to assessment and management that incorporates social, environmental, economic, and political considerations (e.g. Ducrotoy and Elliott 2008). Importantly, we must also consider the impacts of pollution in combination with other stressors that affect the health of marine ecosystems, such as over-exploitation and harvesting of marine species, natural disasters, diseases, and exotic species.

Each chapter of this book has been touched upon in the above paragraphs, and the more pages you explore the more informed you will become about marine pollution. With 70% of the Earth's surface covered by oceans, marine pollution is unfortunately a large local and global issue and will be for many years to come. *Homo sapiens* have inhabited the Earth for around 150,000 years, and over this time our species has vastly influenced chemical, physical, and biological processes. However, the greatest anthropogenic impacts of pollution have occurred in the last 100 years. The fact that our population has more than quadrupled in this time, increasing from 1.9 billion in 1918 to over 8.0 billion today (2023) (Worldometer, 2023), highlights the scale of human influence. This human population expansion has no doubt contributed to the proposition of a new geological epoch, the **Anthropocene**, which represents the period in Earth's history dominated by humans, commencing around the start of the Industrial Revolution (Steffen et al. 2007).

Our consumption as individuals and communities has inevitably contributed to global-scale demands for raw materials, industrial chemicals, pharmaceuticals, and the associated waste production and pollution caused by the way we live in modern society. Indeed, our human footprint varies between different social and cultural circumstances across the globe. On a per capita basis, higher income countries are generally the greatest consumers of resources. At the same time, there is a large increase in consumerism in middle-income countries with the expansion of a middle-class population who have more money to spend on prod-

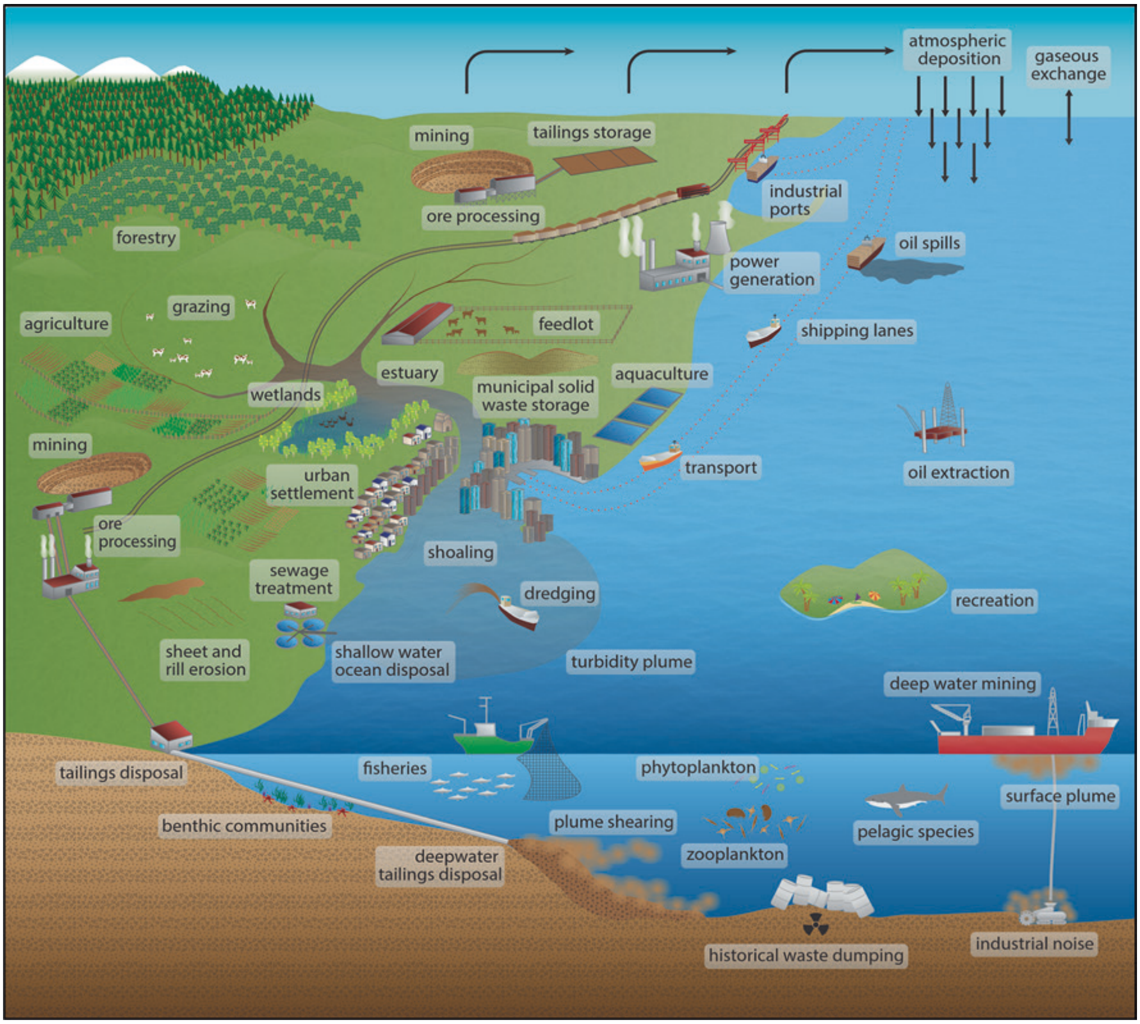


Figure 1.1 Consider the different causes of pollution and how they might be managed differently. *Image*: designed by A. Reichelt-Brushett created by K. Petersen

ucts and services (Balatsky et al. 2015). Low-income countries tend to have a per capita lower contribution to consumption, but also have fewer resources to manage the waste that is produced. Low-income countries also accept waste from high-income countries for payment and recycling, sometimes in working conditions that are harmful to human and environmental health (e.g. e-waste and plastics) (e.g. Makam 2018).

1.1.1 Intentional, Accidental, and Uncontrollable Pollution

Pollution is not always deliberate; a distinction can be made between intentional, accidental, and uncontrollable pollution (Figure 1.2). Furthermore, marine pollution may be slow and chronic or sudden and more acute (Figure 1.3). Sudden pollution events tend to be unintentional, and include accidents and natural disasters. Chronic pollution is often intentional and controlled, and may have a direct point source or non-point sources.

There may be many reasons for intentional pollution such as shipping practices (▶ Box 1.1), a lack of alternative options (such as the availability of waste collection services for litter in low- and middle-income countries), and simply a disregard for regulations. Intentional pollution can be addressed by creating an enabling environment for change and facilitating pollution reduction measures (e.g. Robinson 2012). Incentive and disincentive schemes (colloquially known as carrot and stick approaches) such as encouraging the development of pollution reduction technologies, creating local- to global-scale law, policy and penalties have been shown to reduce polluting behavior (Hawkins 1984).

Accidents are usually caused by factors or events that were unforeseen in risk assessment and/or are a result of inadequate risk minimisation strategies (Garrick 2008). This generally reflects a lack of knowledge and/or poor

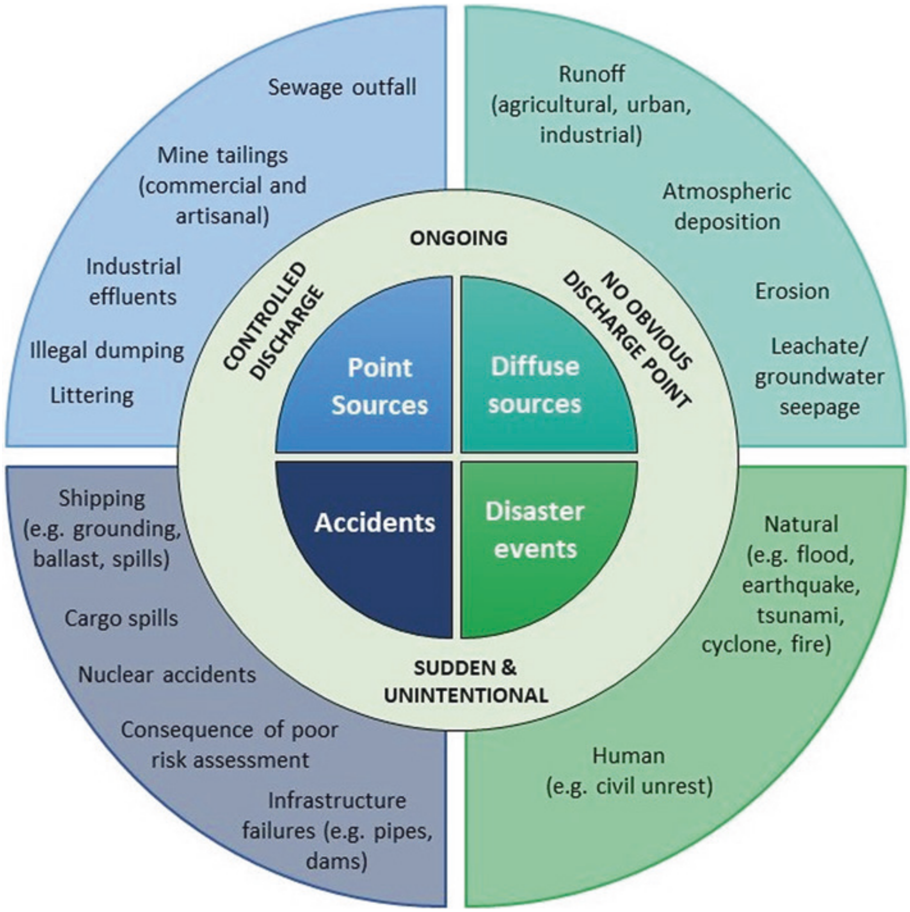


Figure 1.2 Summary of some of the primary sources of marine pollution. *Image*: designed by A. Reichelt-Brushett, created by K. Summer and A. Reichelt-Brushett

contingency provisions. Disaster events, such as cyclones/hurricanes/typhoons (e.g. Hurricane Irma, Cyclone Debbie, and Typhoon Hato all in 2017), floods (e.g. monsoon floods in India and Bangladesh in 2017, flooding and mudflows in California in 2018), and tsunamis (e.g. affecting Thailand and Indonesia in 2004, Japan in 2010, and Haiti in 2010) are largely uncontrollable, but can be major generators of pollution (Figure 1.3d). Extreme events such as these create large volumes of marine debris and cause the breakdown of urban infrastructure such as sewage systems, and waste disposal and storage facilities. Extensive flooding during these events transports polluting substances from activities on land into marine environments.

The environmental consequences of pollution do not distinguish between intentional and unintentional causes, but understanding the nature of the causes is important for minimising future risks and repeated incidences. While humans are the polluters, we also hold the key to solutions and this is where we can focus positive energy and create beneficial outcomes for marine ecosystems and the environment in general. For example, rather than just feeling disappointed about the number of plastic containers washed up on a beach, and rather than just picking up that plastic or doing surveys to measure the amount of debris washed up on beaches, we can develop and implement solutions to reduce the production of litter at the source.

Throughout the world, experts and non-experts alike have invested themselves in managing and understanding pollution. Some people's careers are dedicated to reducing the impacts of marine pollution, and the rise of citizen science and volunteer programs highlights the community interest in pollution reduction. The imagery of pollution such as Figure 1.4 (see also ▸ Box 1.2) evokes emotion and enhances public con-

Figure 1.3 **a** Intentional plastic discarded in Eastern Indonesia, an area of poorly developed waste management infrastructure and limited land resources (*Photo*: A. Reichelt-Brushett), **b** Clean-up following an oil spill in 2007, the Cosco Busan, a container ship, dumped 58,000 gallons of oil after striking the San Francisco Bay bridge in Calif (*Photo*: "Clean Up After a Big Oil Spill" by NOAA's National Ocean Service is licensed under CC BY 2.0), **c** Uncontrollable algae bloom from septic waste seepage into the ocean in Indonesia (*Photo*: A. Reichelt-Brushett), and **d** debris and damage from the 2004 Tsunami, Aceh, Indonesia (*Photo*: "Tsunami 2004: Aceh, Indonesia" by RNW.org is licensed under CC BY-ND 2.0)

cern, which in turn drives the demand for clean-up operations, prosecutions (where applicable), and legislative change. Popular science books such as *Toxic* Fish *and Sewer Surfing* (1989) by Sharon Beder and *Moby Duck* (2011) by Donovan Hohn have also contributed to raising awareness of marine pollution issues.

We are all part of the problem, but you are also an essential part of the solution. I hope this book provides you with guidance and enhances your passion to make a difference. An important place to start is to develop our understanding of the natural systems we are living and working in.

Box 1.1: Example of Intentional Contaminant Release

In 1973, 1.5 million tonnes of crude oil were intentionally released from the tanker *Zoe Colocotronis* when the ship ran aground just off the southwest coast of Puerto Rico. Along with the jettison of cargo, this oil release was ordered to help the ship get off the reef. Three years later, a cargo ship ran aground on the Nantucket Shoals, but this time jettison of cargo was suggested but rejected. This ship broke apart and all the cargo was lost to sea. The United States National Academy of Sciences developed a lengthy report, "Purposeful Jettison of Petroleum Cargo", in 1996, to provide clarification on when cargo jettison is appropriate and may prevent a larger incident. In the past, many vessels were required to slowly release oil. The lifeboats on board the Titanic were required to carry oil for "use in stormy weather", under the British Merchant Shipping Act 1894, and United States Coast Guard regulations also required "storm oil" to be carried on lifeboats. This is because the thin slick that oil forms on the water surface absorbs energy and dampens waves. The regulations requiring the carrying of "storm oil" were removed in 1983. For further details: ▶ https://response.restoration.noaa.gov/about/media/some-situations-ships-dump-oil-purpose.html.

Figure 1.4 Every year thousands of young albatrosses die a slow and painful death on the Midway Atoll, a small coral- and sand bank in the North Pacific. They are fed by their parents with plastic waste floating on the sea—3000 km from the nearest continent. In the end, they starve from too much plastic in their stomachs. Midway Atoll National Wildlife Refuge in Papahānaumokuākea Marine National Monument. *Photo*: "Raise your Voice (2010): Midway—Message from the Gyre (2009)/Chris Jordan" by Ars Electronica CC BY-NC-ND 2.0 ► https://creativecommons.org/licenses/by-nc-nd/2.0/legalcode

Box 1.2: Plastics, Microplastics, and Nanoplastics

For some of the most problematic contaminants, it is not possible to simplify the cause of the pollution. All drains lead to the sea, and littering and dumping of plastic waste have resulted in the increasing accumulation of plastic in the ocean, to the extent that rubbish islands have formed due to gyres in the ocean.

Plastics can cause toxicity to organisms upon exposure or ingestion, and contain additives which themselves can be toxic. Because plastic takes a long time to break down, and many types of plastic are less dense than water and hence are easily transported in currents, we have created a new vector for transporting not only contaminants but also pathogens and invasive species over long distances. A 2018 report of a supermarket plastic bag located in the Mariana Trench at a depth of 10,898 m highlights an emerging threat of plastic pollution in the ocean (Chiba et al. 2018). As you can imagine, organisms attached to such debris would not normally find themselves in such ecosystems, and the ecological consequences of such introductions are completely unknown.

We have been hearing about microplastics in the ocean for several years in mainstream media. There has been some effort to remove microplastics from some products. Nanoplastics are small microplastics, generally defined as between 1 and 100 nm. Ultimately, all plastic will eventually be broken down into nanoparticles, so the nanoplastic concentration in the ocean is only going to increase as the large amounts of plastic debris in the ocean disintegrate. Remediation of microplastic pollution is not currently possible; while nets can be adapted to remove large plastic debris, once plastic has broken into small pieces there is no practical way to remove them from the environment.

► Chapter 9 is specifically focused on plastics in the marine environment.

1.2 Properties of Seawater

Seawater makes up 97% of water on Earth. It supports around 20% of the currently known species but two-thirds of the predicted total of ~8.7 million species (Mora et al. 2011). Although estimates of unknown species vary between studies, the point is that we clearly lack in our understanding of the immense biodiversity of marine ecosystems. Nonetheless, we do have a good understanding of the general chemistry of the system that supports the abundance of marine life. There is much more to learn about biogeochemical variability throughout the world's oceans, how organisms adapt to local conditions, and how these conditions influence the behaviour, bioavailability, and toxicity of contaminants.

Among all molecules, water stands out for its diversity (i.e. it is found naturally in solid, liquid, and gaseous states), occurrence throughout the environment, vast variety of uses, and its role as a medium for life (Manahan 2009). Water is an important chemical transport medium and an excellent solvent; it has a high latent heat capacity, is transparent and penetrable by light, and is prone to pollution but totally recyclable. Central to the behaviour of water is **hydrogen bonding**. Hydrogen bonding is a weak electrostatic force that influences the orientation of individual water molecules as the hydrogen atoms of one water molecule are attracted to the oxygen atom of other water molecules close by. These bonds are about 10 times weaker than a covalent O–H bond but strong enough to be maintained during temperature change. Therefore, water can resist changes in temperature by absorbing energy that would otherwise increase the motion of H_2O molecules (► Box 1.3). All of the water molecules in solid ice have formed the maximum four hydrogen bonds with a heat capacity of 0.5 cal/g/°C compared to liquid water which has by definition a heat capacity of exactly 1 cal/g/°C (i.e. 1 g of water is increased by 1 °C for every calorie of added heat energy). This is extremely high compared to other liquids and solids (second only to liquid ammonia) and effectively causes fresh and seawater bodies to withstand great changes in temperature compared to atmospheric temperatures, enabling the large oceans to act as climate moderators where summer heat is stored and radiated back to the atmosphere in winter. Libes (2009) elaborates in several excellent chapters that explain the detailed physical chemistry of seawater and the biogeochemistry of marine systems.

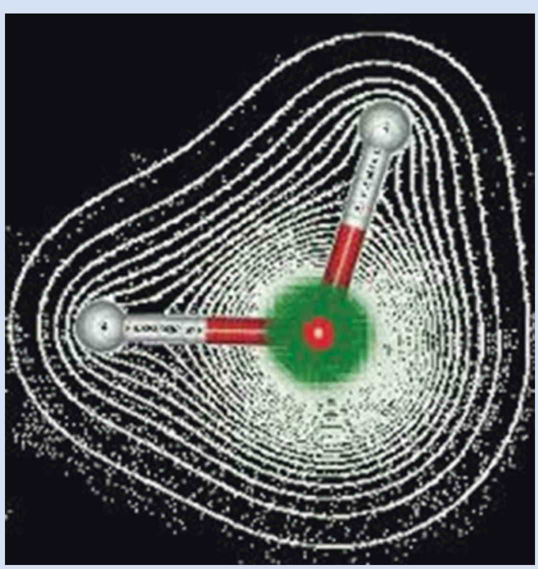
In general terms, the chemistry of seawater is quite stable and has some very similar properties to fresh water. You can consider it fresh water with increased quantities of specific dissolved ions which influence its properties (◘ Table 1.1 compares the composition of seawater to fresh water). For example, fresh water freezes at 0 °C whilst seawater freezes at around −2 °C, due to differences in surface density (seawater 1.02 g/cm^3 compared to fresh water 1.00 g/cm^3 at 25 °C [Libes, 2009]), which also slightly influences the solubility of gases and dissolved ions. **Salinity** is generally referred to as being 35 g/kg (or 35 parts per thousand) but ranges from 31 to 38 g/kg, being influenced by precipitation and evaporation.

Box 1.3: Water, Solvation, and Energy

Dr. Don Brushett, Chemist, Southern Cross University.
You may have heard the statement that "*water is life*". While that statement may be hyperbole, it is true that without water, there is no life.

The water molecule has a number of characteristics that ensures its important role on our planet. Firstly, let us investigate the Polarity **Polarity** of the water molecule. Polarity is a term used to describe the unequal sharing of electrons within a molecule. Atoms are imbued with a unique characteristic known as electronegativity; this can be described as the strength with which each atom attracts electrons. Oxygen is much more electronegative than hydrogen and therefore the electrons spend more time around the oxygen atom. ◘ Figure 1.5 shows that electron density, the regions where the electrons spend 90% of the time. We can think of this polarised molecule as somewhat like a bar magnet which can attract or repel other polar molecules or ions.

The innate Polarity of water is what makes it such a powerful solvent. The average salinity of seawater is approximately 35 (‰). That is to say that approximately 3.5% of seawater by mass of seawater is dissolved salts. This ability to



◘ **Figure 1.5** ► Box 1.3: The water molecule and electron cloud. Licenced under CC BY-NC-ND 2.0

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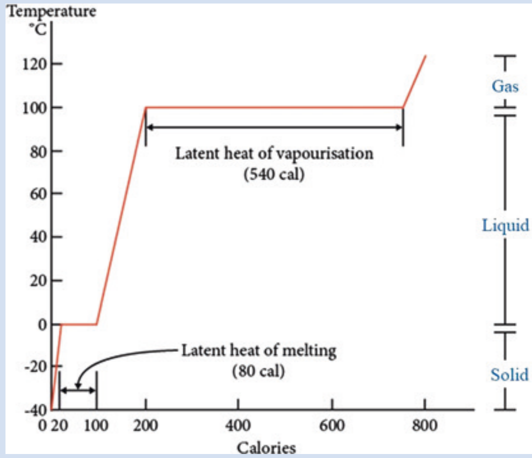

Figure 1.6 ► Box 1.3: The phase transitions of water that are caused by changing heat content. The slopes of the lines indicate heat capacity. Adapted from Libes (2009)

dissolved charged particles has important implications when we consider ionic pollutants. Water has the ability to dissolve large quantities of ions and to transport them over large distances. Conversely, water does not solve non-polar molecules. As they say, "*oil and water don't mix*". Although many organic pollutants are not soluble in water, the polar nature of water forces them to associate with other non-polar substances such as soils, clays, and organic material. In effect, this can concentrate the organic pollutants to the detriment of benthic and filter feeding organisms.

Directly associated with the polar nature of the water molecules is the phenomena called **hydrogen bonding**. Hydrogen bonds are transient and form between the oxygen of one molecule and the hydrogen of another molecule. These polar-polar interactions are about one-tenth as strong as a covalent. This is a significant force when you are vast numbers of molecules. Consider water (18amu) and carbon dioxide (44amu). Carbon dioxide is more than twice the mass of water, yet it only exists as a gas on Earth. Hydrogen bonding makes water **sticky** and allows the water molecule to exist as a solid, liquid and gas in the temperature present on our planet.

This stickiness, due to hydrogen bonding, has important implications for the physical properties of water. Water has a relatively large latent heat of fusion and latent heat of vaporation. The former is the amount of heat required to transform 1 g of ice into liquid water or the amount of heat that must be removed to transform 1 g of liquid water into ice (Libes 2009) (Figure 1.6). The latent heat of evaporation is comparable to the latent heat of fusion, but refers to the liquid–gas phase transition (Libes, 2009). These relatively high latent heat are another consequence of hydrogen bonding.

It takes nearly 4 times as much energy to raise the oceans 1 °C compared to the surrounding land. This moderates the temperature of coastal regions in both hot and cold climates. Water absorbs energy in hot regions which is transferred to cooler polar regions by ocean currents and warms them. Consider the Gulf Stream which makes the climate of Europe pleasant, compared to equivalent latitudes in Siberia. The **stickiness** associated with hydrogen bonding also endows water with large heat of phase change. This also influences global temperatures, for example, water in the tropics absorbs energy when it changes phase from a liquid to a gas. The gaseous water moves through the atmosphere and energy is released when water condenses and falls as rain or snow in cooler parts of the globe. These phenomena moderate the climate around the planet.

Compared to freshwater systems, the pH of seawater is generally fairly constant. However, there is evidence that the changing **carbon dioxide** concentration in the atmosphere is affecting the natural bicarbonate/carbonate buffer system of seawater. Carbon dioxide dissolution in the ocean acts to reduce available carbonate ions, impacting calcification rates of organisms, and releasing hydrogen ions that influence pH and calcium carbonate solubility (Doney et al. 2009). Even small coral reef islands have been shown to influence the local pH of seawater through the exchange of tidal waters seeping into and reacting with calcareous sands (Santos et al. 2011). Local temperatures may increase to extreme levels in rock pools cut off from the ocean during low tides and become hypersaline through evaporation, reaching salinity levels over

Table. 1.1 Comparison of the properties and major components of natural seawater and freshwater systems

Component	Examples/dominant forms	Seawater	Fresh water
Physicochemistry			
Density		1.02 (g/cm^3) Solutes contribute to increased mass; sits below fresh water at saltwater wedge in estuaries, etc.	1.00 (g/cm^3) (pure water)
Conductivity		53.0 (mS/cm) or 35 ppt Proportionate to ionic charge (i.e. salinity)	0.05–1.5 (mS/cm) (= 5–1500 µS/cm)
pH	[H^+] [OH^-]	pH 7.5–8.4 Bicarbonate buffer (alkalinity) resists overall pH changes	pH 5.5–7.5 Variable buffering capacity; more easily influenced (e.g. by organic acids and carbonic acid in rainfall)
Alkalinity	HCO_3^-, CO_3^{2-}, H_2CO_3	100–150 (mg/L, total)	5–500 (mg/L, total) Related to softness/hardness (i.e. Ca^{2+}, Mg^{2+}, which typically contribute carbonate [CO_3^{2-}])
Freezing point		-1.91 °C Salts between H_2O molecules reduce rate of ice crystal formation	0.00 °C (pure water)
Specific heat		3.898 (jg/°C) Intermolecular salts reduce number of H bonds and thus potential energy to be overcome	4.182 (jg/°C) All H bonds must be disrupted before heat can be raised
Overall stability		Expansive, deep, well-mixed, chemically and physically stable systems; less spatial and temporal variability	Smaller (often closed), shallower, less stable, and more variable catchment scale biogeochemical/anthropogenic influences
Elements/ions			
Major elements/ions	Na^+, Cl^-	~35,000 ppm total salts > 500 mM (~86% total salinity)	Highly variable depending on local geology; dominant elements/ions: HCO_3^-, (48% of total), Ca^{2+}, Mg^{2+}, K^+, SiO_2, Fe^{3+}
	Mg^{2+}, SO_4^{2-}, Ca^{2+}, K^+	10–50 mM (~13.8% total salinity)	
Minor elements/ions	Br^-, Sr^{2+}, F^-, B^{2+}, Ba^{2+}	0.1–100 mM (<0.2% total salinity)	
Trace elements	Fe, Mn, Cu^{2+}, Li^+, Ni, Zn , Cr, Al, Co, etc.	< 1–100 mM (<0.2% total salinity)	
Gases			
	N_2, O_2, Ar, CO_2, N_2O	nM to mM Surface waters in equilibrium with atmosphere; saturation changes with depth (pressure), temperature, sediment, oxygenation, and redox reactions	nM to mM Greater variation between locations; varies with physicochemistry as well as plant/microbial communities, local atmospheric deposition, etc

(continued)

Table. 1.1 (continued)

Component	Examples/dominant forms	Seawater	Fresh water
Nutrients			
	NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, K^+, SO_4^{2-}	µg/L to mg/L Oligotrophic—low (e.g. coral reefs), mesotrophic—moderate (e.g. coastal waters, upwelling), eutrophic—excessive	µg/L to mg/L Variable depending on land use, rainfall, hydro-dynamics, organisms and nutrient cycling, closed/open system
Dissolved organic compounds			
	Humic materials (humic and fulvic acids), tannins, amino acids, lipids, organometallic compounds	ng/L to µg/L Generally very low; different water solubilities among compounds—potentially affected by salts	ng/L to mg/L Variable between locations; can be naturally very low or high depending on vegetation, land use, seasonal differences
Particulate material			
	Inorganic (sand, clay, metal hydroxides); organic (hydrogen atoms biomass, faeces, moults, and dead tissue)	Concentration range µg/L–mg/L, increases with proximity to coastlines (related to river inputs, turbulence, depth), generally low in open water column; smaller particle sizes = slow settling velocity	Concentration range µg/L–g/L, variable between locations; influenced by hydrology, geology, topography, land use, trophic structure, turbulence, seasonal rainfall

Sources: Libes (1992); Pilson (1998); Riley and Chester (1971) and prepared by K. Summer

50 ppt. Marine organisms have adapted on an evolutionary timeline to cope with these locally dynamic conditions. ▸ Chapter 11 is dedicated to further understanding atmospheric carbon dioxide and changing ocean chemistry.

The natural composition of **coastal seawater** is more variable than the open ocean due to influences from activities on adjacent land and river systems draining into the oceans (◘ Figure 1.1). Water quality is affected by the array of associated catchment activities in river systems that drain into coastal waters. Globally, there are numerous examples of inputs of contaminants to the marine environment from catchment activities such as agriculture, deforestation, aquaculture, mining, manufacturing industries, shipping, urban settlements, landscape modification, and the like (e.g. Edinger et al. 1998; Brodie et al. 2012; Vikas and Dwarasish 2015). Point sources and non-point sources of pollution come from both land- and sea-based activities (◘ Figure 1.1). Point sources are far easier to manage and legislate compared to non-point sources.

1.3 Water in the Mixing Zone Between Rivers and the Ocean

The transition zones between freshwater **catchment** areas and saline oceans are known as **estuaries**. Here, the physicochemical conditions naturally vary both temporally and spatially. During flood events, rivers may flow with fresh water to their mouths, drastically reducing local ocean salinity. Drought conditions may see the influences of ocean salinity extend far upstream in low-lying river systems. Historically, estuaries were some of the earliest settled areas on many continents and are now among the most heavily exploited natural systems in the world; with that comes a legacy of the impacts of human activities (Barbier et al. 2011). Importantly, estuaries are highly productive systems and breeding grounds for many marine pelagic species (Meynecke et al. 2008; Pasquaud et al. 2015). Estuaries provide extensive ecosystem services and are valued for their raw materials, coastal protection, fisheriesFisheries, nutrient cycling, along with tourism, recreation, education, and research. However, the health of estuaries has been in decline for many years and this is recognised on a global scale. Water quality decline is one of the major threats to the health of estuaries throughout the world (e.g. Kennish 2002; Karydis and Kitsiou 2013).

The mixing between fresh and seawater is a complex zone of chemical interactions that have important influences on the behaviour of contaminants, particulates, and their potential toxicity. Competing ions in seawater influence adsorption and deposition of contaminants onto and off fine sediments. At the **saltwater wedge** (where seawater meets less dense fresh water in an estuary), flocculation occurs whereby suspended particles settle out of the water column along with associated bound contaminants, only to be later redistributed through the system in high rainfall events and periods of fast-flowing water. A detailed perspective of these interactions in estuaries can be found in Reichelt-Brushett et al. (2017).

1.4 A Brief Social History of Pollution

Defining **pollution** is not easy and the word has shifted its dominant meaning considerably over time. Nagle (2009) provides an interesting legal perspective on the "*Idea of Pollution*", and some background context from this helps set the scene for understanding marine pollution. The word pollution was used as early as 1611 in The King James translation of the Bible, and mostly referred to disgust related to a judgement with broad reference to effects or harm upon humans or human environments. In legal cases decided before 1800, English courts used the word pollution in the context of harm to family, church, government, or other human institutions. Pollution occurred in the context of sexual or spiritual harm, newspapers have been referred to as "*polluted vehicles that lacked truth*", and corrupt legal or political processes were considered polluted processes. In 1820, the act of slavery was described as the "*pollution of slavery*". In 1878, the Louisiana Supreme Court described money earned from the sale of slaves as "*polluted gold*". This human focus on the meaning of pollution still exists and is used in moral, ethical, and cultural contexts. Reference to environmental pollution is not really mentioned in political debates until the end of the nineteenth century. Nagle (2009) suggests that river pollution was a key to transforming the meaning and context of the word. Importantly, the **judgement** connotation was removed, and instead pollution was more descriptive and perhaps technical.

Sometimes, the meanings of words are defined for a very specific purpose. Indeed, the definition of pollution means different things under different legalisations, even within a single country, so the meaning of the word becomes relative to the context in which it is used. People have tried to create broad definitions of pollution, only to come to a realisation that activities such as children blowing bubbles would be deemed as pollution. Even though the concept of pollution eludes a precise definition, there is a strong argument in the environmental science literature that differentiates between contamination and pollution (e.g. Chapman 2007; Walker et al. 2012). As an ecotoxicologist, I value this differentiation and have found it useful when reporting and publishing research findings because it helps to focus attention on research needs, and sites and situations of high concern and risk. However, the distinction is limited by the current scientific understanding, exposure concentration, and defining what an adverse effect is (Walker et al. 2012). The following text provides some further insights into defining contamination and pollution.

1.4.1 Contamination and Pollution

When considering marine **contamination**, we make an immediate link to substances present in the marine environment that should not be there at all, or are present in excessive concentrations that are not natural or normal. Importantly, the natural background level of any given substance will vary between and within locations around the world. You should also recognise that there are no normal background levels for synthetic substances. With this in mind, we may work with the following definition:
"Marine contamination occurs when the input of a substance from human and human-related activities results in the concentration of that substance in the marine environment becoming elevated above the naturally occurring concentration of that substance in that location".

Missing from the definition of contamination is the fact that there is no clarity about how a contaminant affects organisms and what concentrations are harmful, and this is what differentiates contamination from pollution (Chapman 2007). We can measure a substance and find that it is elevated compared to background concetrations, but what does that mean for the health of different species, ecosystem function, and services that are exposed to it? At what concentrations and forms should different contaminants concern us? How do we assess situations where more than one type of contaminant is present? We also have to consider the impacts of these contaminants on receptors that are not distinctly marine but interact with the marine environment (i.e. those organisms that feed on marine biota including humans, birds, polar bears, and other wildlife). A weight of evidence approach (i.e. using a combination of information and independent sources to provide sufficient evidence to support decision-making) can be applied to gain a fuller understanding of when and how contamination causes pollution (Chapman 2007). Once we gain this understanding, it is possible to identify if a contaminant is actually detrimental and polluting. Chapman (2007) highlights that all pollutants are contaminants, but not all contaminants are pollutants. The distinction also infers that pollution is more serious and through this, it has become a more emotive word than contamination.

According to the joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP):

> *"Pollution is the addition by* human activity*, directly or indirectly, of substances or energy to the marine environment which results in detrimental effects, for example hazards to human health, hindrance to amenity use,* recreational *activities and* fishing*."*

Put simply, a contaminant is a substance present in the environment where it should not normally occur, or at concentrations above background levels, and a pollutant is a contaminant that causes adverse effects in the natural environment. Many subtle variations in these definitions exist in the literature. A key point to consider is that the word **pollution** should be used when a detrimental effect has been determined. Indeed, it may just be a matter of further research to prove a contaminant is a pollutant. Remember that pollution is socially constructed in all contexts, so there will always be grey areas, particularly when considering natural causes of pollution (e.g. do extreme weather events cause marine pollution even in natural landscapes? Should sedimentation from a landslide be deemed as pollution?).

1.5 Organism Exposure to Contamination

The definition of pollution by GESAMP uses broad examples of **detrimental impacts** that are largely human-focused. Importantly, these detrimental impacts are linked to changes in organism and ecosystem health after exposure to contaminants through biotic and abiotic factors. The degree to which marine species may be exposed depends on the chemical behaviour of contaminants (e.g. speciation, complexation) in different environmental conditions (e.g. physicochemistry), along with the physiology of a given species and how it interacts with the surrounding environment. Environmental interactions are dictated by the ecological niche of the species including the resources it uses and where it sits in the trophic structure. The species behaviour, mobility, metabolic processes, strategies of feeding and reproduction, and lifespan influence environmental interactions and the potential pathways of chemical uptake, storage, and elimination. Even organisms that are taxonomically similar may have vastly different exposure pathways. ◘ Table 1.2 highlights how differently some species of mollusc interact with their environment.

Sessile organisms do not move at all, whilst **sedentary** organisms tend to have very limited movement, and are thus both are favourable for biomonitoring and in situ studies. Albeit, we must keep in mind that the early life stages of many marine species may be free moving and transported extensive distances by winds, currents, tides, and wave action. By comparison, free-moving species have the potential to actively avoid unfavourable condi-

Table. 1.2 Various species of marine mollusc (Phylum: Mollusca) interact differently with the environment, despite being taxonomically similar

Genus/species name	Habitat	Morphology	Feeding habit and trophic status	Mobility and behaviour	Life cycle/other
Austrocochlea porcata (zebra top snail)	Wide range of habitats, exposed rocky shores, mid-high intertidal, sand, seagrass, mangroves	Rounded black and white-yellow striped shell, ~2.5 cm; diet and environmental conditions affect colouration and width of stripes	Herbivore; diatoms, and algae scraped from rock/substrate	Occurs in large aggregations	Dioecious; external fertilisation
Cabestana spengleri (triton; predatory whelk)	Sheltered moderately exposed reef to 20 m depth; among rocks and cunjevoi (*Pyura stolifera*) on exposed intertidal rocky shores	Medium-large (~15 cm), thick, brown trumpet-shaped shell with series of ribs	Preys almost exclusively on ascidians (*Pyura stolonifera*); locate by chemoreception of prey substances in water	Intermittent, relatively rapid foraging movements	Reproduction—egg fertilisation by mating, association in pairs, females remain on egg mass for one month
Conus anemone (cone shell)	Sheltered, moderately exposed reef, lagoons, 0–50 m depth	Conical-shaped shell 6–16 cm, harpoon-like radula connected to specialised venom sacs	Carnivore; uses venom to paralyse fish and invertebrates which are eaten live	Usually hidden under rocks/in sand during day, emerge at night to feed	Lays egg clusters on hard substrate; few offspring survive to adulthood
Donax deltoides (pipi/Goolwa cockle)	Exposed, high-energy sandy beaches, below intertidal sand surface	Triangular bivalve, shell ~5 cm with white-light pink exterior, purple interior	Filter feeder; water passed across gills where small particles are extracted; retract fully to avoid predation	Burrowing	Simultaneous hermaphrodites—serial broadcast spawning; 4–5 yr lifespan
Haliotis rubra (black lip abalone)	Crevices, caves, vertical rock surfaces; intertidal zone to 40 m depth	Large (up to 20 cm), oval foot and shell; rapid growth; respire by virtue of holes in shell through which water flows	Herbivore; graze on drift algae, kelp, and algae on rock surface	Move to more exposed locations as they grow to avoid predation; little movement	15 yr lifespan, broadcast spawning
Ischnochiton (chitons)	Attached to wave-swept intertidal rock surfaces and in crevices	Muscular foot; oval shell 3–9 cm with overlapping plates; lack eyes though have light sensitive organs in shell; respire by beating water under body with cilia	Omnivore; use radula teeth to rasp encrusting algae/animal material from rock	Move slowly after dusk to avoid predation	Dioecious; females deposit eggs on rock surfaces after males release sperm into water

(continued)

Table. 1.2 (continued)

Genus/species name	Habitat	Morphology	Feeding habit and trophic status	Mobility and behaviour	Life cycle/other
Morula marginalba (mulberry whelk)	Rock crevices in mid-intertidal zone	Off-white shell ~2 cm with raised black bumps; radula used to drill hole in shell of prey, assisted by production of sulphuric acid which helps dissolve calcium carbonate	Carnivore; important predator of barnacles and other invertebrates; feeds on oysters in estuaries where it is considered a pest	Often occur in clusters, little movement	Internal fertilisation; attaches eggs individually to substrate
Mytilus edulis (blue mussel)	Sheltered-moderately exposed reef, engineered structures; wide thermal tolerance	Bivalve, up to 12 cm; fibrous byssal threads attach to substrate; complex gill system	Filter feeder; bioaccumulate significant metal loads (commonly used as a biomonitor for this reason)	Permanently attached (sessile)	Broadcast spawning; range limited by drift of larval/juvenile stages; 18–24 yr lifespan—varies significantly with attachment location
Nautilus pompilius (chambered/pearly nautilus)	Depths up to 600 m—buoyancy controlled by changing shell chamber fluid volume/density	Well-known logarithmic spiral shell cross section; diameter up to 26 cm; primitive eye, ~90 cirri (tentacles)	Carnivore; feeds on suspended carrion/detritus, living shellfish; find prey by olfaction and chemotaxis; eat infrequently due to low energy expenditure	Freely swimming; propelled by drawing water in and pushing out of chamber; can also crawl or land on seafloor	Dioecious, annual mating; ~20 yr lifespan

Sources: Beesley et al. (1998), Edgar (2000). Table created by K. Summer tions. For this reason, they are poor **biomonitors** because we usually do not understand their history of exposure. Additionally, accumulation of contaminants in some species and magnification in higher organisms may be specifically of interest for human health reasons given that we are top-order consumers and rely on oceans for food (in some areas more so than others). There is more discussion in ▶ Chapter 3 along with other chapters about organism interactions with contaminants, measuring toxic effects, food chain transfer, etc.

1.6 Contaminant Behaviour

All contaminants, whether inorganic or organic (◘ Table 1.3), will ultimately be distributed through ecosystems and stored in various compartments (e.g. sediments and body tissues). The environmental fate of contaminants results from their chemical properties, and it is the fugacity (sometimes described as the potential to move between media) of a substance that determines its likely distribution after its release into the environment (e.g. water or lipid solubility, vapour pressure) as well as the hydrodynamic and physiological processes occurring in those ecosystems (e.g. winds, currents, flow rate, upwelling, and sedimentation). We tend to focus our sampling on the various compartments of water, biota, and sediment. Once compartmentalised, the duration of storage will depend on the stability of the conditions in that compartment. For example, when sediments are disturbed, stored contaminants can be remobilised back into the water column, or if an organism dies the contaminants that were taken up and stored in its body will become available to detritivores and through trophic levels thereafter.

Most organic compounds break down over time; metals, however, are elements and as with other elements they cannot be broken down further. For this reason, they tend to sequester in different environmental compartments. Plants and animals vary widely in their ability to regulate their metal content, and how organisms respond will depend on the type of metal, type of organism, and physicochemical conditions that define the metal species (complex). Ecotoxicological studies help us to understand how an organism interacts with a contaminant and identify measurable stress responses.

1.7 A Multidisciplinary Approach to Understanding Pollution and Polluting Activities

Consideration must be given to the various exposure pathways, distribution processes, contaminant behaviour, and organism interactions to effectively manage marine pollution. A combination of applied sciences including chemistry, biology, ecology, hydrodynamics, toxicology, statistics, and oceanography should be used in the monitoring, management, and mitigation of marine pollution. ◘ Figure 1.7 provides a conceptual approach that highlights the interacting factors associated with understanding marine pollution for research and management. Undesirable outcomes of past polluting activities highlight the need for social research to also be included in the multidisciplinary approach for decision-making.

Community expectations have changed over the years in many parts of the world, particularly for mining and other potentially polluting industries. Resource extraction projects and infrastructure developments both require community-engaged decision-making during planning, construction, and operation. In some countries, these industries are working with the concept of gaining a **social licence to operate** (e.g. Prno 2013; Kelly et al. 2017) to gain community endorsement. Interestingly, this reintroduces the judgement in the historical use of the word pollution (Nagle 2009). Such research helps to identify the social acceptability of biodiversity offsets and trade-offs as tools to protect marine environments (e.g. Richert et al. 2015), and helps define how a development or project may be accepted by a community.

1.8 Polluting Substances—Local and Global Considerations

When we consider polluting substances, there are distinctly different threats to coastal marine ecosystems compared to open ocean ecosystems. We have already noted that around 80% of marine pollution is from land-based sources. The extent to which these reach the open ocean generally decreases with distance from land (e.g. Vikas and Dwaraskish 2015), although floating pollutants such as plastics can travel 1000s of kilometres across the ocean. In the context of marine-based sources of polluting substances, Tornero and Hanke (2016) provide a detailed review of sources in European seas. They highlight shipping, mariculture, offshore gas exploration and production, seabed mining, dredging and dumping, and legacy sites as major sea-based activities that release contaminants (Tornero and Hanke, 2016). These activities are globally relevant as marine-based sources of polluting substances.

Ocean dumping of wastes have in the most part been addressed by international conventions and protocols (▶ Chapter 16), but legacy problems remain. The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, commonly known as the **London Convention**, is one of

Table. 1.3 Contaminants in the marine environment: types, common sources, and general factors influencing impacts and potential as pollutants and useful references/examples

Contaminant class	Examples	Examples of sources	General impacts and influencing factors	Reference
Trace elements ► Chapter 5	Arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), silver (Ag), zinc (Zn); rare earth metals of increasing concern, e.g. lithium (Li), caesium (Cs), and yttrium (Y)	Antifouling paints, batteries, electronics, fuels, building materials, mining wastes (small and large scale, terrestrial, deep sea; marine tailings disposal), agricultural and urban runoff, industrial effluents, landfill leachate, erosion, atmospheric deposition, shipping accidents, and operational ship discharges	Many essential at low concentrations, highly toxic at elevated levels; natural variation due to local geology; solubility and toxicity strongly influenced by water physicochemistry (i.e. pH, salinity, complexing capacity, and dissolved oxygen), competition with essential elements affects structure and function of biomolecules and physiological processes. Biological detoxification and depuration processes exist	Walker et al. (2012), Reichelt-Brushett (2012)
Organometallic compounds Chapters 4 and 7	Mono, di and tri-butyltin (TBT), methylmercury (CH_3Hg^+), and some pesticides	Agricultural runoff and waste, industrial effluents, mining wastes, and antifouling paints	Organic forms of some metals are more toxic than their inorganic counterparts; may be direct inputs or naturally formed after metal introduction—influenced by type and abundance of organic ligands, microbial communities (i.e. methylating bacteria), and oxygenation	Renzoni et al. (1998)
Agricultural chemicals Chapters 7 and 8	Insecticides, herbicides, fungicides, and other specific pesticides and disinfectants	Agricultural runoff and waste, aquaculture, and mariculture	Synthesised for biocidal properties (many non-specific) similar activity in receiving environment; continuing legacy of older formulations (e.g. DDT) that are extremely persistent compared to most modern formulations	Walker et al. (2012)
Nutrients ► Chapter 4	Nitrogen (N) and phosphorous (P)	Fertilisers, sewage, urban and agricultural runoff, aquaculture, and mariculture	Enrichment in plant nutrients increases primary productivity; eutrophication and associated changes to ecosystem structure and function (e.g. increased crown of thorns starfish outbreaks, algal blooms produce toxins and cause deoxygenation); influenced by water exchange, limiting nutrients, nutrient cycling, and type and resilience of ecosystem (e.g. reefs requiring oligotrophic conditions will be more significantly affected than a mesotrophic system)	Brodie et al. (2012)
Persistent organic and halogenated chemicals Chapters 7 and 8	Dioxin, fluorocarbons, organochlorines, organophosphates, organobromines, etc	By-products of fuel and waste combustion and industrial processes (e.g. paper and plastic manufacturing), flame retardants, fire-fighting foam, non-stick coatings, landfill leachates, agricultural runoff, and atmospheric deposition	Extremely Persistent chemical structures with many now banned in many countries. They are mostly lipophilic and bioaccumulate and biomagnify. There are limited biological detoxification and degradation pathways	Arpin-Pont et al. (2016)

(continued)

Table. 1.3 (continued)

Contaminant class	Examples	Examples of sources	General impacts and influencing factors	Reference
Hydrocarbons and dispersants ▸ Chapter 6	Oil, gas, and some petroleum products	Shipping operations and accidents and off-shore extraction and processing	Comprised of C and H with high molecular stability and lipophilicity and are physical and chemical toxicity. The extent of pollution depends on amount, type of hydrocarbon (i.e. volatility, viscosity) and the hydrodynamics of the spill area	Walker et al. (2012); Kujawinski et al. (2011)
	Dispersants	Oil spill remediation	Used to break oil into droplets which can be easily dispersed in water, and enhance biodegradation; toxic to pelagic/benthic organisms; should not be used in shallow or ecologically sensitive waters (e.g. reefs, fishing areas, and marine parks)	Kujawinski et al. (2011)
Dissolved gases ▸ Chapter 11	Carbon dioxide (CO_2)	Fossil fuel emissions, agriculture, and atmospheric equilibration	Ocean acidification depending on carbonate biogeochemistry (pH buffering capacity). May cause decreased carbonate saturation and thus reduce biogenic calcification	Anthony et al. (2008)
Pharmaceuticals Chapters 12 and 13	Antibiotics, antidepressants, blood pressure and diabetes medication, birth control, anti-bacterial agents, illicit drugs, and veterinary products	Sewage outfall (treated and untreated) and biosolids, agricultural runoff, wastewater discharges, aquaculture, and mariculture	Sewage treatment methods often ineffective. Concentrations in the environment reflect variable spatial and temporal usage trends. May cause endocrine disruption (e.g. feminisation of male organisms). The pollution potential depends on the mode of action, concentration, and stability of the compound as well as potential mixtures	Walker et al. (2012); Arpin-Pont et al. (2016)
Personal care and household products Chapters 12 and 13	Soaps; sunscreens; disinfectants; surfactants; nanoparticles (e.g. zinc and titanium dioxide)	Sewage; recreation; wastewater discharges; industrial cleaning; operational ship discharge	High inputs into coastal zones which are sensitive breeding/nursery grounds for many species (not significant in open ocean). Generally slow to degrade with potential photochemical reactions and toxic degradation products. Specific persistence and toxicity vary between compounds	Walker et al. (2012)
Pathogens ▸ Chapter 12	Parasites, viruses, protozoans, and bacteria	Untreated sewage, agricultural run-off, aquaculture, and mariculture	Introduction of new diseases, shifts in symbiotic microbial populations, and reduced resilience to existing diseases which can be exacerbated by deteriorating water quality	Lafferty et al. (2004)

(continued)

Table. 1.3 (continued)

Contaminant class	Examples	Examples of sources	General impacts and influencing factors	Reference
Plastics and debriss ► Chapter 9	Plastic bottles; packaging and general rubbish; microplastics; fishing nets and lines; timber; metal; other building materials	Dumping, litter, natural disasters, commercial fishing, aquaculture, and shipping accidents	Pollution potential depends on the size, shape, and buoyancy of the material. They are typically persistent impacting organisms by ingestion, entanglement, and release of toxicants (e.g. PCBs). May cause reduced air–water and sediment–water oxygen exchange and act as hosts for translocation and introduction of species attached to drifting plastics	Derraik (2002)
Sediment Chapters 5 and 7	Soil; clay; sand; fine sediment	Dredging, port construction, direct dumping of dredged sediment, catchment clearing, poor quality riparian vegetation, high rainfall, and erosion	Various particle sizes and settling rates. Causes high turbidity, smothering, and reduced light penetration. The impacts are related to the frequency, intensity, and duration of exposure and associated contaminant toxicity	Brodie et al. (2012); Erftemeijer et al. (2012)
Other Chapters 10 and 12	Radioactivity and explosives,	Conflict, accidents, weapons testing and use, and emissions from historical ocean dumping	May be non-ionising (low-energy photons) (e.g. light, radio waves) or ionising (high energy alpha, beta, gamma particles). Results in free radical production (e.g. OH^-) that is highly reactive. The impacts are influenced by radiation type and decay rate (half-life)	Livingston and Povinec (2000)
	Noise	Shipping, military operations, seismic surveys; deep sea mining	Impact on communication and navigation signals of marine species may also cause chronic stress. The density of water means that sound propagates much further and faster in water than in air	Williams et al. (2015)
	Thermal pollution	Heated industrial effluents; increasing sea surface temperature (global warming)	Heat causes oxygen depletion resulting in changes in species distribution and metabolism, possible breakdown of symbiosis (e.g. coral bleaching). Heat may also increase the toxicity of chemical contaminants noting that tropical species tend to live closer to their upper temperature thresholds than temperate species but some species adapt	Baker et al. (2008)

Table preparation assisted by K. Summer

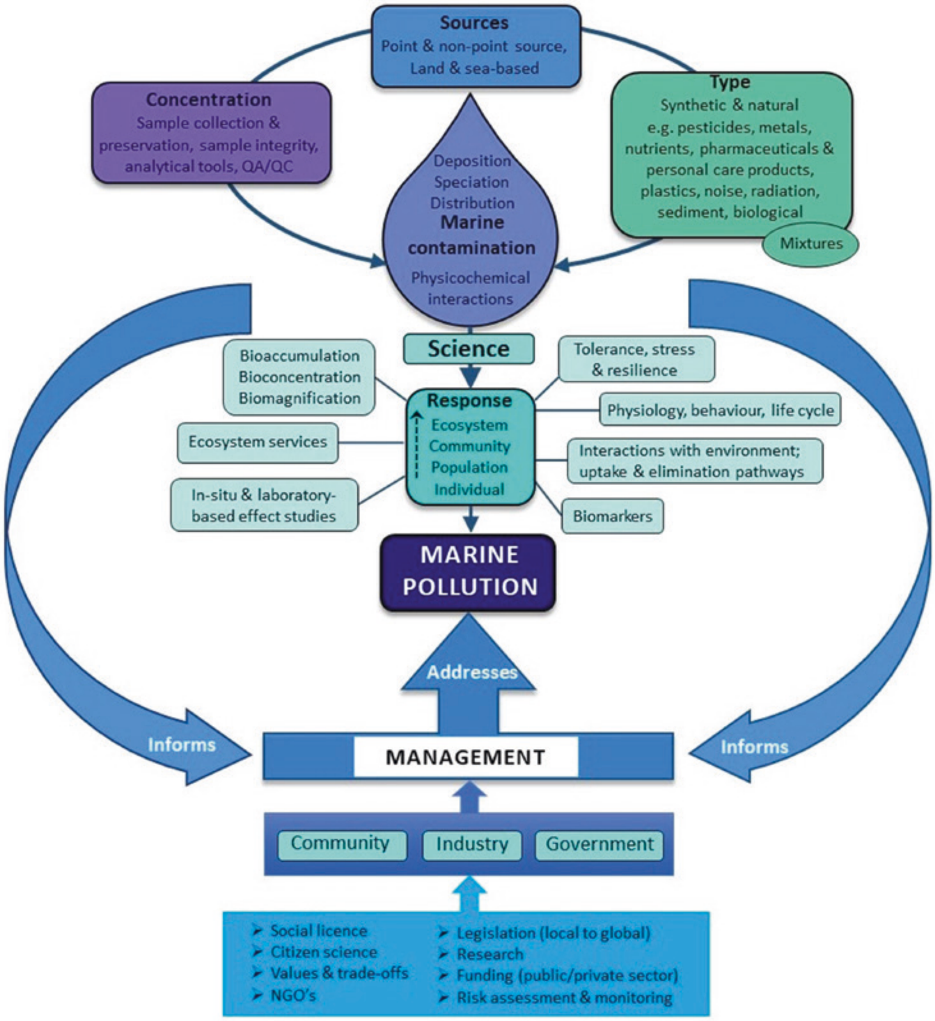

Figure 1.7 The multidisciplinary nature of marine pollution studies. *Image*: designed by A. Reichelt-Brushett and created by K. Summer

the first global conventions to protect the marine environment from human activities and has been in force since 1975. Its main purpose or objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter. Currently, 87 States are signatories to this convention. In 1996, the **London Protocol** was agreed upon to modernise the Convention and, eventually, replace it. The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering the prevention of pollution of the marine environment by ships from operational or accidental causes and has had various modifications over the years (► Chapter 16). Importantly, these conventions and protocols do not cover discharges from land-based point and non-point sources. Consequently, management of land-based marine pollution and practices such as submarine tailing disposal and sewage discharge rely on local and national legislation for approval, operations, and control. There are other relevant conventions such as Minamata Convention on Mercury that have reduced the serious consequences of marine pollution (► Box 1.4) (see also ► Chapter 16).

Box 1.4: The Minamata Disaster

Between 1932 and 1968, a chemical production plant run by Chisso Co. Ltd. intentionally and knowingly discharged untreated methylmercury (MeHg)-laden wastewater into fresh water and marine environments surrounding what is now Minamata City in Japan. MeHg is a deadly neurotoxin, and in the 1950s and 1960s, people who consumed local seafood developed mysterious neurological symptoms including sensory disturbances, visual field constriction, and ataxia. More than 200 infants were born with Minamata disease between 1955 and 1959.

Also, in the 1950s, people in the vicinity of the chemical plant noticed fish floating on the water surface, barnacles appearing unable to stick to boat hulls, huge numbers of shellfish being washed on shore with open shells, and the seaweed appeared to have stopped growing.

By March 2001, thousands of people had died, and more than 10 000 had received financial compensation from Chisso Co. Ltd and the Japanese government. In 2010, there were 2271 official Minamata disease patients in the Minamata area, and more than 40,000 people exhibited partial symptoms.

A criminal trial in 1988 found the chief of the acetaldehyde plant and the president of Chisso Co. Ltd. guilty of intentionally diverting the wastewater drainage channel towards the river without treating the effluent, despite being (perhaps only somewhat) aware of its extremely high toxicity. Both were imprisoned for 2 years in 1979.

This tragic event led to the Minamata Convention on Mercury, which was signed on 16 August 2017. In 2019, there were 102 member countries of this convention.

(See Hachiya, 2012; Yorifuji, 2013; UNEP, 2018, 2019; Yokohama, 2018.)

On a final note the seventeen United Nations sustainability goals are an urgent call for action by all countries in a global partnership. Goal 14, Life Below the Water, has 10 targets that this book has import relevance to and can support people in realising these goals. This global partnership includes low-, middle-, and high- income and, being an open access resource, it is freely accessible to the anyone with Internet access. It will hopefully provide benefit to those wanting to learn about improving the sustainability of their marine environment and acting on their knowledge.

Targets for Goal 14 -Life below the water:

- 14.1 Reduce marine pollution
- 14.2 Protect and restore ecosystems
- 14.3 Reduce ocean acidification
- 14.4 Sustainable fishing
- 14.5 Conserve coastal and marine areas
- 14.6 End subsidies contributing to overfishing
- 14.7 Increase the economic benefits from sustainable use of marine resources
- 14.a Increase scientific knowledge, research and technology for ocean health
- 14.b Support small scale fishers
- 14.c Implement and Enforce international sea law For more information: ► https://www.globalgoals.org/ and ► https://sdgs.un.org/goals/goal14

1.9 Summary

Marine pollution has been created by human activities both on land and in/on the ocean. As consumers, we are all contributors to the increasing global resource demand, manufacturing, and waste production. By definition, a contaminant is a substance present in the environment where it should not normally occur, or at concentrations above background levels, while a pollutant is a contaminant that causes adverse effects in the natural environment. In order to understand how contaminants become pollutants, knowledge of seawater chemistry and how this influences the behaviour of contaminants and their toxicity is important. There is a wide and ever-expanding range of potential polluting substances, and the risk of pollution caused by any one or combination of these will depend on their sources, transport, bioavailability, and fate. Furthermore, organism interactions with their surrounding biotic and abiotic environment influences their exposure to contaminants and the subsequent potential impacts on their health.

Scientific research linked to a weight of evidence approach can be used to inform decisions that reduce the risk of environmental impacts associated with human activities. Importantly, the coastal environment has far different challenges associated with pollution reduction compared to the open ocean. Major pollution incidents have raised the public, political, and scientific profiles of marine pollution, and legislative frameworks now address ocean dumping. We are still faced with the challenge of how to reduce the incidence of pollution and manage the impacts and improve degraded systems. This is a challenging, multidisciplinary field of study requiring collaboration between scientists, governments, industries, and communities to enhance our understanding and knowledge, and develop solutions to reduce waste production, improve management capability, and therefore reduce the threat of marine pollution now and into the future.

1.10 Study Questions and Activities

1. Research an accidental pollution incident that greatly impacted marine environments. Write a paragraph that includes information as to how, where, and when the accident occurred, what happened, what the immediate consequences were, and what the reported long-term consequences have been (if any). Investigate whether any recent follow-up studies have been done to assess effects.
2. Explain (in your own words) the difference between contamination and pollution. Describe the advantages and disadvantages of the two definitions.
3. Identify an important land-based source of marine pollution, state the contaminant(s) that are associated with it, and briefly describe what is known about the effects on marine ecosystems.

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