Other Important Marine Pollutants

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Contents

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Acronyms and Abbreviations

ALAN	Artificial light at night
ELP	ecological light pollution
NNS	Non-native species
NRC	National Research Council
NOAA	National Oceanic and Atmospheric Administration
PCPs	personal care products
STD	submarine tailings disposal also known as deep sea tailings placement (DSTP)
TCC	triclocarban
TCS	triclosan

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12.1 Introduction

"*Sorry! What did you say*?" Consider how easy it is to miss some conversation details when it is noisy. Communication is an important aspect of all social interactions for animals, many use sound as a means of communication particularly longer distance communication.

"*Is it day or night?*" Light deprivation can have dramatic effects, so can too much.

"*Too hot, too cold?*" We all have our preferences but there are critical points of temperature ranges and rates of change that are detrimental to us and to all organisms on Earth.

This chapter introduces you to some forms of marine pollution that you might not immediately consider pollution. The point that helps to provide clarity about these pollutants is if they cause adverse effects. Indeed, they do. Commonly, the less easily recognised marine pollutants are not chemically based, but rather mechanical, physical or biological.

12.2 Noise Pollution

Sound is constituted by mechanical disturbance (or vibration) that moves through a material (Bradley and Stern 2008; Penar et al. 2020) and is a fundamental constituent of the marine environment. Sound propagates energy through the ocean and, like with sound movement through air, it moves in waves. The knowledge of the feature of sound is essential to fully understand the impacts of sound on marine organisms; and parameters such as frequency, wavelength and intensity best describe the characteristics of sound (Peng et al. 2015) (▶ Box 12.1). Water being denser than air is a great medium of sound conduction as sound propagates faster in the sea than in the air. Being a liquid, water is less compressible than air and therefore transmits the sound wave faster when compared to air.

Sound is a part of the natural seascape. Oceans are naturally noisy with natural sounds originating from a great variety of sources.

The ocean is intimately coupled to the geosphere and the atmosphere and as such, most of the significant physical sources of natural sound occur at the interfaces of these media (NRC 2003). For instance, as described by the National Research Council (NRC 2003), many sounds originate in the atmosphere and enter the ocean surface; and elastic vibrations in the earth introduce sound into the underwater acoustic field.

Sound is regarded as an important feature of marine habitats, with most marine species relying on it for critical life functions (Hawkins and Popper 2017; Southall et al. 2020). Many marine organisms use sounds as a means of communication, thus overcoming the many complications that living in the sea implies. Communication is a vital aspect of all social interactions (Butler and Maruska 2020), and sound is an important part of communication. In fact, animals rely on sound signals that encode information about the sender's species, sex, motivation, reproductive state and identity (Butler and Maruska 2020).

In contrast to sound, **noise** is more specific and defined as any unwanted or disturbing sound (Kunc et al. 2016) and there are varieties of sources of underwater noise. Underwater ambient (sound) noise is a component of background noise, and it varies depending on depth, time and location. According to the National Oceanic and Atmospheric Administration (NOAA) ocean noise refers to sounds made by human activities, which can interfere with or obscure the ability of marine animals to hear natural sounds in the ocean. Excess noise affects both the anatomy and morphology of an organism, by mechanically damaging single cells as

Box 12.1: Characteristics of Sound

Sound is a form of energy, which enables us to hear. Sound travels in the form of waves; which are vibratory disturbances in a medium carrying energy from one point to another. Sound can be described by five characteristics, namely: speed (or velocity); frequency; wavelength; amplitude and time period. The frequency (f) of the wave is the number of oscillations in a second. The speed (v) of the wave is the distance travelled by the wave in one second. The wavelength (λ) is the minimum distance in which a sound wave repeats itself. Amplitude (A) is the maximum displacement of the particles from their original undisturbed positions. Time period (T) is the time required to produce 1 complete wave.

Relationship between period and frequency Eq. 12.1:

$$T = 1/f \text{ or } f = 1/T \tag{12.1}$$

Relationship between speed, frequency and wavelength Eq. 12.2 and 12.3:

$$V = f \times \lambda \tag{12.2}$$

$$V = \lambda \times 1/T \tag{12.3}$$

well as entire organs (Kunc et al. 2016). Sources of underwater noise can pose local impacts or regional and global impacts.

12.2.1 Natural Sources of Sound in the Sea

The underwater marine environment consists of **biotic** and **abiotic sounds** that are closely related to the survival and reproduction of marine organisms (Slabbekoorn et al. 2010). These natural sounds are both localized and dispersed and include surface waves, turbulence(wind), rainfall, water flow, seismic disturbances, cracking polar ice, and subsea earthquakes and volcanoes and sounds of biological origin (Bradley and Stern 2008; Peng et al. 2015; Hawkins and Popper 2017; Erbe et al. 2018). Natural biological sounds include whale songs, dolphin clicks and fish vocalizations among many others (NRC 2003). Background or ambient sound describes naturally occurring sounds from distributed sources. The combination of sounds produced by an ecosystem shows eco-acoustic complexity, and it is suggested that the more complex the natural soundscape, the healthier an ecosystem is (e.g. Linke et al. 2018; Di lorio et al. 2021).

Fish, marine mammals, invertebrates and other marine organisms produce natural biotic sound in the marine environment, and these are regarded as biotic or biological sources of sound (e.g. ◘ Figure 12.1). Biotic sounds can be produced in many different ways such as rubbing parts of the body such as bones, teeth or the valve of shells, mechanical flapping of teeth or plates; and compression and decompression of the bladder through muscle strength. Biotic sound in the sea is used to communicate, navigate, locate and avoid prey, mate detection, and orientation including locating appropriate habitats and locations (e.g. Lillis et al. 2014; Simpson et al. 2016; Hawkins and Popper 2017; Lecchini et al. 2018). Erbe et al. (2017) reported that marine mammals have evolved to use sound as their primary sensory modality-both actively (sound production) and passively (sound reception). A passive mode of sound is when an animal does not actively generate sound impulses but only responds to them with a particular behaviour and these include identification of predators, capture of prey and direction change. Through active sound animals can communicate during mating, search for food, navigate over long distances, fight for territory and social disputes, distract a predator to escape, stun and catch prey, and produce alarm signals. **Echolocation** is the ability to gain information from sounds produced by the animal that bounce off distant objects and return as echoes and is necessary for navigation. Examples of mammals that use echolocation include Odontocetes, sperm whales, finback whales and other dolphins ► Box 12.2.

Natural biotic sources of sound usually occur over an extremely broad frequency range; spatially very limited in extent and occur over a short time (Bradley and Stern 2008) and provide important information to marine organisms about their surrounding environments. Organisms vary in their complete sensitivity and spectral range of hearing (Peng et al. 2015) (◘ Table 12.1). Abiotic sounds usually occur over a broad frequency range but they generally have a wide distribution and are generated over a long time (hours/days) (Bradley and Stern 2008).

12.2.2 Anthropogenic Sources of Sounds in the Sea

Noise generated intentionally and unintentionally from human activities is usually regarded as anthropo-

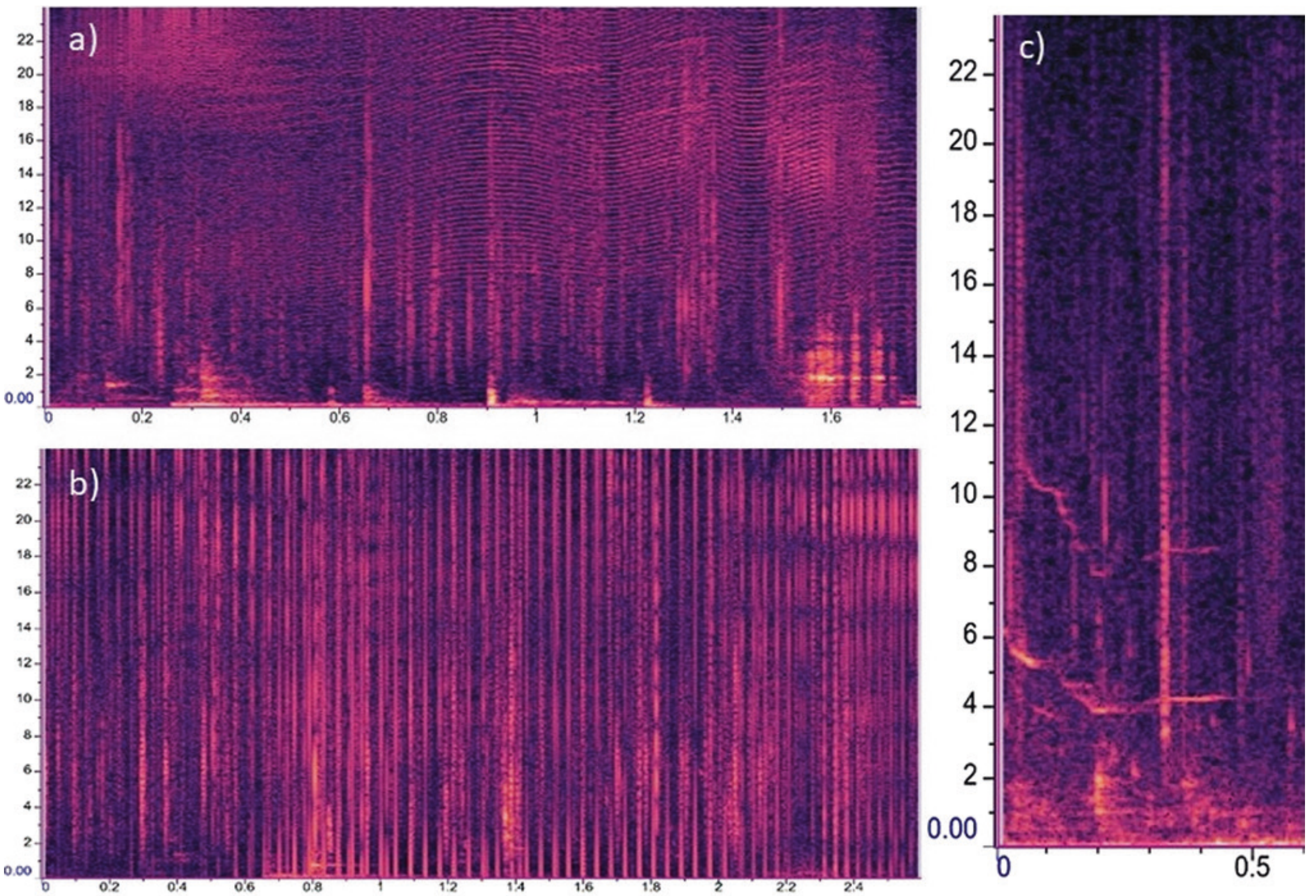


Figure 12.1 The spectrograms represent different sounds emitted by snubfin dolphins **a** burst pulse, **b** click train and **c** whistle. X axis represents seconds of the sound, y axis represents frequency (kHz) Click trains are mainly used for echolocation and are a unidirectional sound type. They are produced by directing clicks out of the melon of the dolphin towards a target. Whistles are omnidirectional and they are used for social activity and communication. There is not much knowledge on burst pulse but it is believed they are also used for hunting. *Images and caption text*: D. Cagnazzi

Table 12.1 Some examples of hearing range of marine species

Species	Hearing sensitivity	Source
Pacific bluefin tuna (*Thunnus orientalis*)	Most sensitive range 400–500 Hz	Dale et al. (2015)
Common prawn (*Palaemon serratus*)	Responsive to sound between 100–3000 Hz	Lovell et al. (2005)
Common octopus (*Octopus vulgaris*)	400–1000 Hz	Hu et al. (2009)

Box 12.2: Cetaceans, Seabirds and Ocean Noise

Cetacean and Ocean Noise

Marine mammals produce sound profusely for communication purposes. Odontocetes (toothed whales): emit echolocation clicks during foraging and navigation. Odontocete sounds are typically classified as whistles, burst-pulse sounds and clicks (Erbe et al. 2017) and produce mid and high frequency sounds around 1–150 kHz. Mysticetes (baleen whales): emits constant-wave tones, frequency-modulated sounds as well as broadband pulses (Erbe et al. 2017) and produce low-frequency sounds around 10–2000 Hz. Blue whales and humpback whales organsie sound into songs lasting for hours to days.

Marine mammals and other marine animals rely heavily on acoustics for navigation, hunting, reproduction and communication. Marine mammals such as whales and dolphins are highly adapted physiologically and behaviorally to utilize sound. Cetaceans are highly dependent on sound as their primary sense. Cetacean vocalizations cover a wide range of frequencies, from the infrasonic calls of the large Mysticetes (baleen whales) to the ultrasonic clicks of the Odontocetes (toothed whales) (Weilgart 2007) (see also ◘ Figure 12.1). The frequency of calls produced by the cetacean species is dependent on the body size. Larger body size correlates to lower frequency of calls; and cetacean calls and hearing span a broad range of frequencies because of highly sophisticated auditory systems. Mysticetes produce and use sound at the frequencies emitted by large ships, and are considered to be more sensitive at these low frequencies; whilst Odontocetes produce high frequency sounds as emitted by ships (see Erbe et al. 2019). It has also been shown that gray whales increased their vocalization rates and humpback whales have increased their vocalizations due to increased noise exposures from tourism vessels (Erbe et al. 2019).

Seabirds and Ocean Noise

Seabird families include Spheniscidae, Laridae, Stercorariidae, Procellariidae and Sulidae. Seabirds forage at sea but breed on land and hence use calls for communication to and from their colonies for their kin as well as partner recognition. Seabirds freely transit between air and water and enact key behaviours in both habitats (Mooney et al. 2019). However, with increasing human utilization of coastal areas, the soundscapes of these areas are changing. Anthropogenic noise seems to be a major stressor leading to the degradation of seabird habitat. Generally, noise pollution can affect birds by causing physical damage to ears, stress responses, changes in behavior, reproductive success, fright-flight responses, changes in vocal communications, habitat loss and changes in the ability to hear predators.

genic noise and more specifically in the marine environment as ocean or marine noise. Marine noise pollution is thus defined as any source of anthropogenic sound happening in the marine environment, which is capable of producing harmful effects on marine life.

Anthropogenic noise is a pervasive pollutant to almost all aquatic and terrestrial environments (Halfwerk and Slabbekoorn 2015). Many human activities generate noise within the hearing ranges of other animals, at sound levels above those found naturally and with different acoustic characteristics from natural sounds (Hildebrand 2009). The marine noise generated by human activities has amplified significantly since the industrial revolution (Frisk 2012); and hence the ocean is now reported to be 2–10 times louder compared to the preindustrial era (Hildebrand 2009; Frisk 2012). Escalating human population, coastal urbanisation, maritime traffic, oil extraction, civil and military sonars and ocean-based energy production systems (wind and wave energy farms) will continue to contribute to marine noise (di Franco et al. 2020).

Anthropogenic noises are multifaceted (Bradley and Stern 2008) and includes commercial shipping, oil and gas exploration, naval operations (e.g. military sonars, communications, and explosions), fishing (e.g. commercial/civilian sonars, acoustic deterrent, and harassment devices), dredging and drilling operations, marine renewable energy devices, research (e.g. air guns, sonars, telemetry, communication, and navigation) anti-predator devices, seismic surveys, cabling and other activities such as construction, icebreaking, and recreational boating (Hildebrand 2009; Jerem and Mathews 2020; Pieretti et al. 2020).

Underwater noise from shipping is a significant and pervasive pollutant with the potential to affect the marine ecosystems on a global scale (Clark et al. 2009; Williams et al. 2014; Merchant et al. 2015). In fact, ship noise is rising concomitantly with the increased use of shipping in transport and ships are becoming the most ubiquitous and pervasive source of anthropogenic noise in the oceans (Erbe et al. 2019; Vakili et al. 2020).

Anthropogenic noise can be categorised as either **high-intensity impulsive noise** or **low-frequency stationary noise** (Peng et al. 2015). High-intensity or acute marine noise pollution has a short duration and is often emitted repeatedly, over frequencies ranging from a few hertz (Hz) to hundreds of thousands of Hz. Low-intensity noise or chronic marine noise pollution has a longer duration with frequencies below 1 kHz (1000 Hz). Pile driving, underwater blasting, seismic exploration and active sonar application create high-intensity noise whilst ships and vessels generate low-frequency stationary noise (Codarin et al. 2009; Peng et al. 2015).

Chronic marine noise pollution is regarded as the main contributor to the increase in ocean background noise (Hildebrand 2009). Both acute and chronic marine noise pollution can co-occur and interact in producing their impact on marine life (di Franco et al. 2020).

12.2.3 Effects of Anthropogenic Noises

Increased anthropogenic noise imposes new **constraints on communication** (Vieira et al. 2021) such that it can interfere with the vocalizations emitted by many animals as well as the natural sounds that are used by animals for their routine behaviour. Biological sounds can be impaired by anthropogenic noise and possibly determine cascade effects at the population and community level (Kunc et al. 2016). In fact, noise exposure can change hearing capabilities.

The effects of anthropogenic underwater noise on aquatic life have become an important environmental issue (Thomsen et al. 2020) and a global concern which can cause auditory masking, behavioural disturbances, hearing damage and even death for marine animals (Peng et al. 2015; Halliday et al. 2020). Faulkner et al. (2018) further emphasised that underwater noise pollution poses a global threat to marine life and has become a growing concern for policy makers and environmental managers.

12.3 Light Pollution

Natural light at night is derived from the moon, the stars and the Milky Way (Ayalon et al. 2019; Duarte et al. 2019) whilst the day light is from the sun. The natural sources of light play a **fundamental role on the behavioural patterns of marine as well as terrestrial organisms** and the timing of the ecological processes (Ayalon et al. 2019; Duarte et al. 2019). The vast majority of species have evolved under natural and predictable regimes of moonlight, sunlight and starlight (Davies et al. 2014). Smyth et al. (2020) highlighted that photobiological life history adaptations to the moon and sun are near ubiquitous in the surface ocean (0–200 m), such that cycles and gradients of light intensity and spectra are major structuring factors in marine ecosystems.

With human population growth, the progress of energy supply for lighting and lighting technologies, **artificial light has steadily altered natural cycles** in many locations. Human population growth and migration to the coastal regions have led to an increase in the amount of lighting near coastal environments. Of emerging concern is the artificial light, which is now central to the functioning of modern society and concomitantly referred to as the **artificial light at night** (**ALAN**). ALAN is the alteration of natural light levels due to anthropogenic light sources (Cinzano et al. 2001; Falchi et al. 2016; Duarte et al. 2019) and is closely related to the rate of urban development, especially with the presence of outdoor night lights (Maggi and Serôdio 2020) (Figure 12.2). Artificial light is an emerging threat to global biodiversity (Reid et al. 2019) and is escalating swiftly in coastal habitats due to rapid urbanisation, fisheries and aquaculture.

ALAN affects the adjacent abiotic environment both directly (through light sources of variable intensity) and indirectly (through the formation of a skyglow) (O'Connor et al. 2019; Maggi and Serôdio 2020). The skyglow is a diffuse light field of low intensity, and continuous lighting that is detectable as a glowing dome over built up areas such as coastal settlements and marine infrastructure, spreading its influence on sub-urban and rural sites (Gaston 2018; O'Connor et al. 2019) (Figure 12.2b). Sources of ALAN include fixed lamps along the coastal streets, promenades, ports and marinas, lighthouses, oil platforms and from mobile sources such as commercial and tourist boats (O'Connor et al., 2019; Maggi and Serôdio 2020). The emission spectrum of the light sources creates vertical variability in the water column due to precise attenuation patterns amongst different wavelengths (Tamir et al. 2017).

Depledge et al. (2010) reported that light pollution occurs when organisms are exposed to light in the wrong place, at the wrong time or at the wrong intensity. Light pollution or **ecological light pollution** (**ELP**) describes all types of artificial light that alter the natural patterns of light and dark in ecosystems (Longcore and Rich 2004). Light pollution mainly affects nocturnal species by triggering unnatural processes that can result in important physiological and behavioral changes (Navara and Nelson 2007).

Artificial light disturbs a variety of fundamental biological processes such as the development of visual cells, pigmentation, growth, and development in the early life stages of fish (Boeuf and Le Bail 1999; O'Connor et al. 2019; Zapata et al. 2019); the structure and functions of invertebrate and fish communities in ecosystems (Davies et al. 2012; Zapata et al. 2019); harming biodiversity hotspots (Guette et al. 2018) spawning and settlement patterns of different species of corals and thus affecting the local and spatial community structure.

ALAN impacts species behaviour and inter-species interactions through the fluctuating visual surroundings (O'Connor et al. 2019). ALAN has prevalent effects on marine turtles (Tuxbury and Salmon 2005; Lorne and Salmon 2007; Dimitriadis et al. 2018), fish (Brüning et al. 2015; Pulgar et al. 2019), invertebrate communities (Jelassi et al. 2014; Underwood et al. 2017) and corals (Vermeij and Bak 2002; Gleason et al. 2006; Schlacher et al. 2007; Strader et al. 2015). Of concern is the light pollution on coral reefs since coral reef fishes depend on natural lunar cues to regulate reproductive periodicity in adults and the timing of reef-colonization by the larvae at the end of their pe-

Figure 12.2 Examples of light pollution: **a** from a small port facilities Port Denarau, Fiji *Photo*: Suhaylah Shah, student, Fiji National University, **b** port facilities near La Malagueta Beach, Spain *Photo*: Leo P. Hidalgo (@yompyz), CC BY-NC-SA 2.0, **c** coastal light pollution, Belfast, Ireland *Photo*: alister667 CC BY-NC-SA 2.0 and **d** tourist boats in overnight mooring Ha Long Bay, Vietnam *Photo*: gregdonohue CC BY2.0

lagic dispersal phase (Naylor 1999; Davies et al. 2013; Besson et al. 2017).

Several studies have highlighted the effect of ALAN on coastal organisms and habitats such as effects on settlement processes both in invertebrates and bacteria (Davies et al. 2015; Maggi and Benedetti-Cecchi 2018); changes in behaviour such as orientation and nesting of turtles, vertical migration of zooplankton and fish, anti-predator and locomotor activities, trophic pressure (Witherington and Bjorndal 1991; Underwood et al. 2017; Ludvigsen et al. 2018; Duarte et al. 2019; Maggi et al. 2019) and the composition of assemblages (Garratt et al. 2019; Maggi et al. 2020). Furthermore, ALAN also has an effect on predator–prey interactions (Cravens et al. 2018; O'Connor et al. 2019; Yurk and Trites 2000); species phenology (Gaston et al. 2017; Bennie et al. 2018); foraging behaviour (Underwood et al. 2017; Farnworth et al. 2018); and orientation (Lorne and Salmon 2007). O'Connor et al. (2019) observed that light pollution causes changes in behaviour, physiological function and post-settlement survival in surgeonfish (*Acanthurus triostegus*) larvae (Table 12.2). The distance from a source that results in an insignificant effect of ALAN will vary between species.

Symbiotic corals are highly photosensitive and are likely to be susceptible to ecological light problems since they are often found in shallow, clear water with relatively high light levels (Rosenberg et al. 2019). Rosenberg et al. (2019) reported that human instigated ELP could alter the natural light regimes of coral reefs by causing persistence disturbance or chronic stress. Oxidative stress and physiological effects from exposure to ALAN had been observed for scleractinian corals, *Acropora eurystoma* and *Pocillopora damicornis*, from the Gulf of Eilat in the Red Sea, from exposure to blue LED and white LED lights (Ayalon et al. 2019).

Seabirds of the order Procellariiformes (such as shearwaters, petrels and albatrosses) are nocturnal (active at night) so as to avoid predation; exploit bioluminescent and vertically migrating prey and navigate the night sky. However, these seabirds are vulnerable to artificial light and easily get disoriented by intense

Table 12.2 Some examples of outcomes of research studies investigating the impacts of light pollution on larval fish

Species or population	Source of light	Impact of ALAN	Source
Acanthurus triostegus (coral reef fish)	Overhead light with dimmable smd5050 white LED strip lights (6500 k, λp = 450 nm, placed 40 cm above the water surface, with a light intensity of 650–700 lx during the day (7 a.m.–7 p.m.). At night 20–25 lx from 7 p.m.–7a.m.	Larvae settled in dark areas. lowered thyroid hormone levels during metamorphosis; faster swimming rate, increased growth, decreased probability of survival, increased probability of predation	O'Connor et al. (2019)
Amphiprion ocellaris (anemonefish)	LED light programmed to 12:12 h light–dark photoperiod, measuring approximately 2000 lx during the day and 0 lx at night	ALAN at levels as low as ~15 lx resulted in significant negative effects on *A. ocellaris* reproductive success. Cool-white light (464 nm) had a greater impact on *A. ocellaris* hatching success than warm-white light (636 nm). Both light treatments resulted in smaller embryo sizes at the end of the developmental period	Fobert et al. (2021)

sources of artificial light. The vulnerability to artificial lighting varies between different species and age classes of birds and is influenced by season, lunar phase and weather conditions (Birdlife International 2012).

Sea turtles require regular intervals of natural diurnal and nocturnal light when they come ashore to lay their eggs (Silva et al. 2017). Light pollution tends to decrease the availability and suitability of sea turtle habitats and can become a crucial threat to entire sea turtle populations (Hopkins and Richardson 1984); especially nesting of adult marine turtles (Silva et al. 2017).

12.4 Thermal Pollution

Thermal pollution is the degradation of water quality due to changes in the ambient temperature of seawater, thus causing deleterious ecological effects. The influence of thermal discharges on aquatic ecosystems has become a significant issue in the field of marine and environmental protection. Thermal pollution can be caused by either hot or cold water discharges, and both the **rate** and **extent** of **temperature change** that deviates from normal conditions are important factors affecting marine organisms. Discharges from industrial activities are important sources of thermal pollution and in longer term, more subtle timeframes ocean warning from atmospheric change is considered a risk (e.g. Baag and Mandal 2022) and has been implicated in global coral reef bleaching events (Ainsworth et al. 2021). Community and ecosystem responses to thermal pollution include reduced species abundance, species richness and species diversity (e.g. benthic foraminiferal assemblages in Israel, Arieli et al. 2011) and may result in localised biological extinction (Dong et al. 2018).

A common cause of thermal pollution is the discharge of water, used as a coolant in industries, data storage centres and power plants (Abbaspour et al. 2005; Issakhov and Zhandaulet 2019; Mokhtari and Arabkoohsar 2021). Coolant waters may also contain contaminants such as metals through corrosion of infrastructure. When the coolant water is returned to the marine environment (usually at a higher temperature) it results in decreased availability of dissolved oxygen. Dissolved oxygen is essential for underwater life and if lacking may lead to deleterious effects such as fish kills (Speight 2020). An upsurge in seawater temperature also leads to seawater stratification (Huang et al. 2019). Seawater stratification occurs when isolated layers of water are formed with the upper warm layer (epilimnion) being separated by the cold layer (hypolimnion). Littlefair et al. (2020) stated that the hydrological layers give rise to distinct temperature and oxygen circumstances, thus creating different habitat niches for aquatic organisms which are adapted to particular temperature ranges (Speight 2020).

Many marine organisms have specific temperature needs, and hence rapid temperature changes can be deleterious (e.g. thermal shocks can result in reproduction difficulties and less resistance to diseases). Slower rates of temperature change can impact species if they exceed the upper (or lower) thermal tolerance level of species. Upper and lower **thermal tolerances** are not known for all species and research in this field highlights the complexity of the combination of responses to stressors including metabolic regulation, oxygen limitation and heat tolerance (e.g. Marshall and McQuaid 2020). Interestingly, the same species from different geographic locations can have different upper and lower thermal tolerances, highlighting population adaptability (Black et al. 2015). Furthermore, temperature change can result in increased sensitivity to other pollutants (Black et al. 2015) (see also ► Chapter 14). Notable consequences of artificial temperature rise include forced migration, massive fish kills as a result of slowing of metabolism, increased sensitivity to toxins, and loss of biodiversity.

Warming air temperatures over the past several decades have resulted in mass coral bleaching events in many parts of the world. The bleaching patterns vary spatially and temporally and are most common in tropical mid-latitudes (15°–20° north and south of the Equator) (Sully et al. 2019). Sully et al. (2019) further suggest that rates of change in sea surface temperatures are strong predictors of coral bleaching with faster rates of change correlating with higher levels of bleaching.

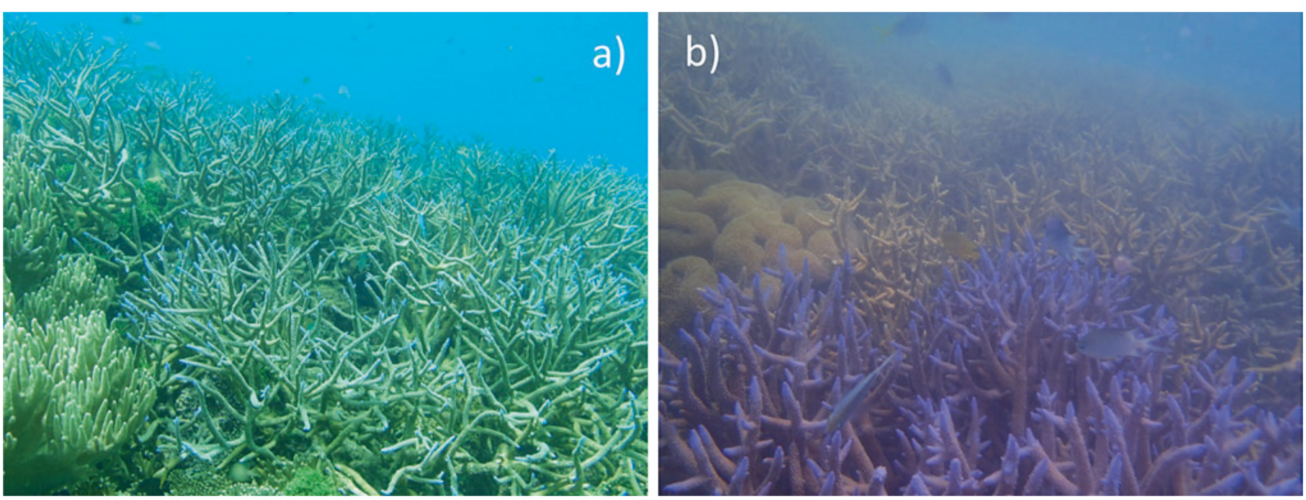
12.5 Particulates

Marine water quality is crucial for plants and animals that live in the sea; especially for marine species that rely on photosynthesis. **Water clarity** is an important water quality parameter and is a measure of how far light can penetrate through the water column. Light penetration is vital for the process of **photosynthesis** and contributes to the conditions that provide for the enormous diversity present in the ocean waters (◘ Figure 12.3). Kennicutt (2017) reported that access to sunlight is vital for the well-being of submerged aquatic vegetation, which aids as food and habitat for other biota. Water clarity is important as clear waters enable more sunlight to reach the photic zone, enabling the production of oxygen. Clear waters usually have low concentrations of suspended particles, and both natural and anthropogenic sources of suspended and dissolved solids affect water clarity (Kennicutt 2017). Dissolved substances as well as the productivity of phytoplankton also affect water clarity and colour. Floating plastic particulates are also of concern and have been discussed specifically in ► Chapter 9.

12.5.1 Particulate Organic Matter

Marine phytoplankton; mostly single-celled algae and bacteria are extraordinarily diverse in morphology, evolutionary history, and biochemical behavior. They make up most of the **organic particulate matter** in seawater via the process of photosynthesis (Pilson 2013) and while essential to ecosystem structure they too can become a problem due to increased nutrient availability (► Chapter 4). The formation of organic matter from phytoplankton is referred to as **primary production**; where carbon dioxide, water and other nutrients in the presence of sunlight are converted to organic matter. Organic matter can also enter the marine environment from river discharges, from the atmosphere, from photosynthesis by larger fixed algae along the shores, and by bacterial chemosynthesis on parts of the ocean floor (Pilson 2013). Organic matter composed of algae, plants and other animals is regarded as **autocthonous** organic matter whilst those composed of terrestrial material are **allochthonous**. In the aquatic environment, organic matter can be present as particulate organic matter and dissolved organic matter.

The organic matter present in aquatic ecosystems is typically composed of proteins, lipids, carbohydrates, humic substances (e.g. humic and fulvic acids), plant tissues (rich in cellulose and hemicellulose) and animals and other acids of different molecular weights (Benner 2003). Organic matter can undergo transformations in the water column of aquatic environments and later become part of the sediments. In aquatic eco-



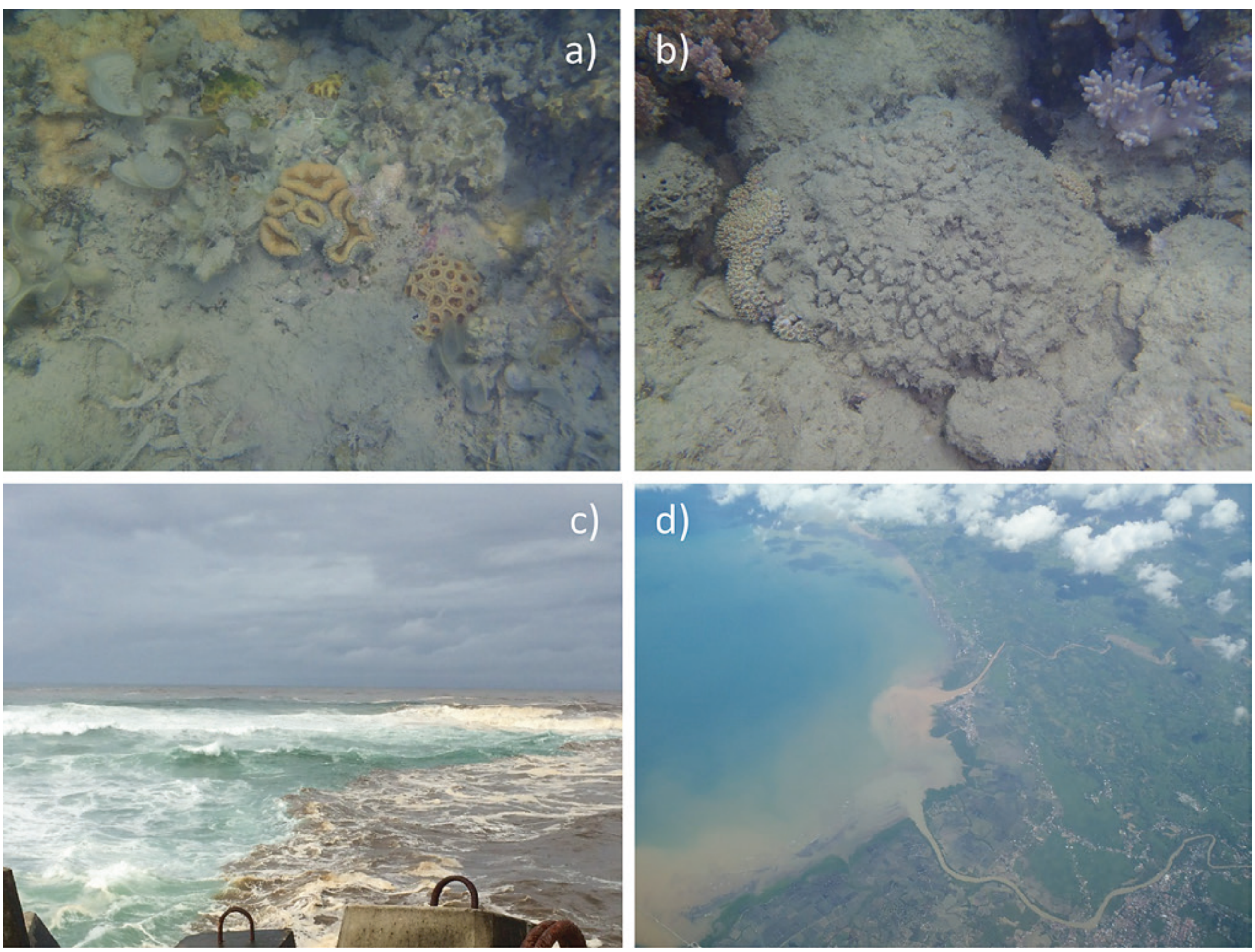
◘ **Figure 12.3** Scleractinian corals host dinoflgellates (Symbiodinium) that provide them with photosynthetically derived nutrients. These algae live within the coral and need access to light for photosynthesis. Picture **a** shows the high level of water clarity often associated with coral reefs, Pig Island, Papua New Guinea and **b** at times reefs are exposed to more turbid conditions during natural or anthropogenic disturbances. Species composition in consistently turbid waters can be markedly different from areas with high clarity waters. *Photos*: A. Reichelt-Brushett systems, sediments may receive large amounts of organic matter and as it settles through the water it provides essential energy for the deep sea. Most deep sea ecosystems are **heterotrophic**, waiting for food to sink from the euphotic zone (<200 m) and the surface production can vary both temporally and spatially resulting in variable deposition of organic matter to the sea floor (Ramirez-Llodra et al. 2010 and authors there in).

12.5.2 Suspended Sediments

Sediments are principally unconsolidated materials, products of modification of rocks, soils, and organic matter that have undergone weathering, transportation, transformation and deposition near the Earth's surface or in water bodies (Cardoso et al. 2019). Sediments at the bottom of the oceans have formed from particulate matter that settles out of the water column and may consist of coarse gravel, sand, clay and organic ooze, together with contaminants. Sediments in the oceans are repositories for physical and biological debris, and serve as sinks for a wide variety of chemicals. In aquatic ecosystems, sediments provide habitat and substrate for a wide variety of benthic organisms and chemicals that bind to sediment particles can cause grave pollution problems (Chapters 1, 2, 4, 5 and 6).

Regardless of any chemicals associated with suspended sediments the particles themselves can result in deleterious impacts on organisms and communities. As a physical pollutant, suspended sediments cause:

- reduce water clarity and limit the depth sunlight can penetrate for photosynthesis to occur;
- excess fine sediments can injure gills of some types of fish and shell fish;
- reduced visibility from reduced water clarity causes a reduction in the number of organisms that use visual methods to seek prey and hide from predators; and
- when they eventually settle sediments may smother sessile species resulting in death (◘ Figure 12.4).



◘ **Figure 12.4** **a** and **b** sediment smothered coral around Henning Island, Whitsunday Islands, Australia, **c** after a rainfall event turbid river waters mixing with ocean water at the mouth of the Richmond River, NSW, Australia, **d** terrestrial inputs of suspended sediment to the ocean, Eastern Indonesia. *Photos*: A. Reichelt-Brushett

Figure 12.5 Capital dredging works in Platypus Channel, Cleveland Bay, Australia in 1991 (insert bottom right). In the main picture suspended sediments can be seen drifting from the dredge site to the shores of Magnetic Island. The trailing suction hopper dredge in action. *Photos*: Dredging Assessment Project Team, James Cook University, 1991

Enhanced turbidity can be generated naturally from storms and terrestrial runoff, however, vegetation clearing in catchments and poorly managed riparian zones enhance soil loss to waterways which is subsequently transported to the ocean (Figure 12.4d). Port and harbour facilities for shipping require relatively deep water and entrances often need to be dredged to establish and maintain access. Dredging re-mobilises deposited sediment which can then be transported by tidal currents, settling in areas of low velocity. Figure 12.5 shows capital dredging works in 1991, in Cleveland Bay, Townsville, Australia. Sediments drifted from the dredging and dump sites and settled on coral surfaces around Magnetic Island offshore from Townsville (Reichelt and Jones 1994).

Throughout the world there are numerous examples of submarine tailings disposal (STD) also known as deep sea tailings placement (DSTP) (Vare et al. 2018). During STD operations tens to hundreds of thousands of tailings waste from terrestrial mining activities are discharged on a daily basis to the ocean at a depth between 80 and 150 m. The site of pipeline discharge is generally placed at the edge of a continental shelf, and tailings are meant to fall down the continental slope to rest in canyons (▶ Chapter 5, Figure 5.3). The process results in the smothering of marine species in the impact zone and contributes to turbidity in the water column due to plume sheering (Reichelt-Brushett 2012; Stauber et al. 2022).

12.6 Pathogens

Pathogens are organisms that cause disease to their host, with the severity of the disease symptoms referred to as virulence (Balloux and van Dorp 2017). They are widely diverse taxonomically and consist of bacteria, viruses, fungi and some parasites as well as unicellular and multicellular eukaryotes, potentially harmful to humans, marine species and ecosystems. Host–pathogen relationships are capable of influencing population dynamics, community structure, and biogeochemical cycles, and these are expected to shift in response to global climate change (Cohen et al. 2018).

Pathogens can be found in association with marine animals, phytoplankton, zooplankton, sediments and detritus (Stewart et al. 2008). Environmental factors such as salinity, temperature, nutrients and light influence the survival and sometimes the proliferation of pathogens (Stewart et al. 2008). Diseases have been identified as a major contributor to the decline of corals worldwide, particularly in the Western Atlantic (Bourne et al. 2009). The causes of disease are either from new pathogens or changed environmental conditions that affect the host, pathogen, environment relationship (Figure 12.6).

Pathogens cause illness to their hosts in a variety of ways such as direct damage of tissues or cells during replication, or through the production of toxins. Bacterial toxins are among the deadliest poisons known

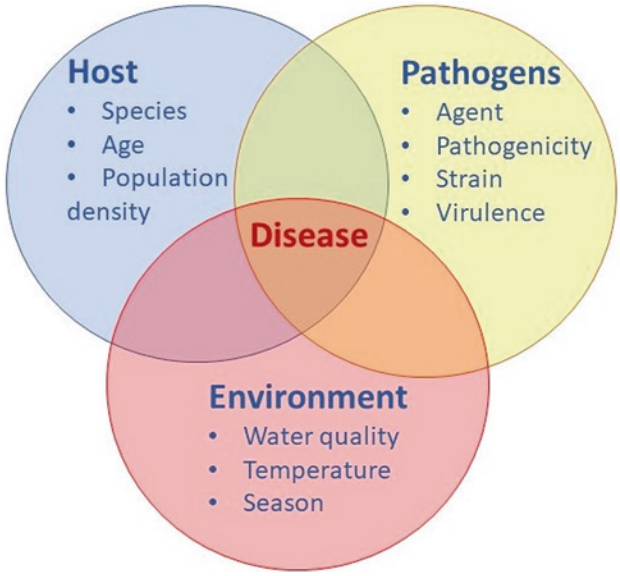


Figure 12.6 Host, pathogen and environmental factors that contribute to the causes of disease. By managing the interacting factors well, the further the circles will separate, reducing the size of the disease risk. *Image*: A. Reichelt-Brushett

and include famous examples such as tetanus, anthrax or botulinum taoxin (Balloux and van Dorp 2017). The majority of the antibiotic classes are originally derived from bacteria and fungi (some of which are derived from the marine environment); with 64% of antibiotic classes being derived from filamentous actinomycetes (Gomes et al. 2021). Marine actinomycetes produce secondary metabolites that show a range of biological activities including antibacterial, antifungal, anticancer, insecticidal and enzyme inhibition. Marine pathogens and other parasites play important roles in composing the makeup, diversity, and health of natural marine communities (Baskin 2006). They may also be responsible for a broad spectrum of acute and chronic human diseases such as gastroenteritis, ocular and respiratory infections, hepatitis, myocarditis, meningitis, and neural paralysis (Brettar et al. 2007).

Pathogens are divided as facultative or obligate pathogens depending on how intimately their life cycle is tied to their host (Balloux and van Dorp 2017). Facultative pathogens are primarily environmental bacteria and fungi that can occasionally cause infection and include many of the hospital-acquired bacteria involved in the antimicrobial resistance pandemic (Balloux and van Dorp 2017). However, obligate pathogens necessitate a host to fulfil their life cycle. For instance, all viruses are obligate pathogens as they are dependent on the cellular machinery of their host for their reproduction (Balloux and van Dorp 2017).

12.6.1 Sources of Marine Pathogens

Pathogens artificially introduced to the marine environment get carried via sewage effluent, ship ballast water, agricultural runoff (defecation/urination/shedding from human or animal hosts), stormwater runoff, human recreational, industrial processes, introduction of exotic species and plastics (Baskin 2006). Non-host environments such as water, decaying organic matter and abiotic surfaces are important constituents of the lifespan of some pathogens since these environments provide habitats in which pathogens may replicate or survive; thus facilitating transmission (Lanzas et al. 2019).

Corals belong to the phylum Cnidaria, which consist of organisms including jellyfish, anemones, and hydra that form polyps with stinging cells and scleractinian corals which are the major reef building corals. Coral reefs are declining world-wide as a result of global changes; and one of the factors of concern include destructive diseases. Sharma and Ravindran (2020) mentioned that pathogens and parasites causing infectious diseases of scleractinian or stony corals especially in India include bacteria, fungi, viruses, and parasitic infections by protozoans, metazoans and parazoans; which leads to partial or entire-colony mortality. These infectious diseases cause lesions or bands of tissue loss on the coral colonies, thus affecting the entire reef ecosystem (Sokolow 2009). Diseases lead to significant alterations in coral reproduction and growth rates, thus changing community structure, species diversity and abundance of reef-associated organisms (Loya et al. 2001). White band disease on *Acropora palmate* and *Acropora cervicornis* in the 1980s caused an estimated 95% reduction in colonies (Vollmer and Kline 2008). White pox disease in the Florida Keys reduced the cover of *Acropora palmata* by up to 70% (Patterson et al. 2002).

12.7 Personal Care Products (PCPs)

Personal care products (PCPs) are intended for external application on the human body and generally enter the environment unaltered during water recreation, washing, showering or bathing and are considered as **emerging pollutants** (▶ Chapter 13). PCPs that usually reach the aquatic environment are bioactive, pseudo-persistent, exhibit a high degree of bioaccumulation in aquatic organisms (Cortez et al. 2012; Montesdeoca-Esponda et al. 2018) and have been shown to impact marine organisms (Câmara et al. 2021). The environmental fate of PCPs depends on their physicochemical properties such as water solubility, adsorption behaviour, volatility and degradability (Montesdeoca-Esponda et al. 2018). Consequently little is known

Table 12.3 Some subgroups of personal care products (PCPs) and example compounds

Subgroups of PCPs	Example compounds
Antimicrobial agents/disinfectants	Triclosan Triclocarban
Synthetic musks/fragrances	Galaxolide (HHCB) Toxalide (AHTN)
Insect repellents	N,N-diethyl-m-toluamide (DEET)
Preservatives	Parabens (alkyl-p-hydroxybenzoates)
Sunscreen UV filters	2-ethyl-hexyl-4-trimethoxycinnamate (EHMC) 4-methyl-benzilidine-camphor (4MBC)

about the fate and the toxicity of PCPs introduced into the environment, hence, increasing attention is being placed on their occurrence, persistence, and potential threats to aquatic environment and human health.

PCPs include a large and diverse group of organic compounds used in disinfectants, soaps, shampoos, lotions, skin creams, toothpaste, fragrances/synthetic musks, sunscreens, insect repellants, and preservatives. The primary classes of personal care products include disinfectants (e.g. triclosan), fragrances (e.g. musks), insect repellants (e.g. DEET), preservatives (e.g. parabens) and UV filters (e.g. methylbenzylidene camphor) (Brausch and Rand 2011). UV filters are used to protect skin from UV solar radiation and usually contains chemicals of different chemical families such as benzimidazoles, camphor derivatives, triazines, benzotriazoles, cinnamates, salicylates, benzophenones, p-aminobenzoates (Câmara et al. 2021).

Many of these compounds are environmentally persistent, bioactive, potentially bioaccumulative and have lipophilic characteristics (Peck 2006; Mackay and Barnthouse 2010; Brausch and Rand 2011). Table 12.3 identifies some subgroups of PCPs and the characteristic compounds present in them see also ▶ Box 12.3.

12.7.1 Triclosan and Triclocarban

The PCPs Triclosan (TCS) and triclocarban (TCC) two distinctive **antimicrobial agents** used in soaps, deodorants, skin creams, toothpaste and plastics, among other things (see US EPA 2008); are frequently detected in seawater (McAvoy et al. 2002; Liu and Wong 2013); and are amongst the top 10 most commonly detected organic wastewater compounds for frequency and concentration (Kolpin et al. 2002; Halden and Paull 2015). The effectiveness of TCS against gram-negative and gram-positive bacteria resulted in its widespread use (Cortez et al. 2012). TCS is regarded as an environmental concern due to its photodegradation into dioxins and furans; structural similarity to Bisphenol-A; biological methylation due to formation of more toxic compounds; and its bioaccumulative and toxic nature (see Cortez et al. 2012) (Table 12.4). The TCS molecule possesses both the phenol (5-chloro-2(2,4-dichlorophenoxy) phenol) and ether (2,4,4-trichloro-2-hydroxydiphenylether) functional groups (Olaniyan et al. 2016). TCS consists of multiple halogen atoms and is highly xenobiotic; and hence many microorganisms lack the necessary metabolic pathways and enzymes to degrade it (Abbot et al. 2020) and therefore it is highly persistent and bioaccumulates in the environment (Halden 2014). Cortez et al. (2012) demonstrated via laboratory assays that TCS caused acute and chronic toxicity to gametes and embryos of *Perna perna* at concentrations not yet reported in marine surface waters. TCC (3-(4-chlorophenyl)-1-(3,4-dichlorophenyl)) is used as a broad spectrum antibacterial and antifungal agent in many personal care products. It is a trichlorinated binuclear aromatic compound which has toxic, persistent and bioaccumulating properties (Halden 2014). TCC concentrations have been measured at 6.75 µg/L in raw wastewater (Halden and Paull 2015).

12.7.2 Sunscreens

Sunscreens are of emerging concern both to human and environmental health; however, their regulation is constantly evolving, largely due to the potential risks related to the ingredients they contain (Labille et al. 2020). Sunscreens typically consist of an oil–water emulsion in which the major active ingredients are UV filters, incorporated in high concentrations (Labille et al. 2020). Sunscreen products contain active constituents that protect human skin from UV radiation. Ramos et al. (2015) reported that UV filters and stabilizers are assimilated into a wide range of manufactured products to provide protection from UVA (315–400 nm) and UVB (280–315 nm) radiation. These include organic compounds that absorb UV rays (e.g. cinnamates, camphor derivatives, benzophenones) and/or inorganic compounds (e.g. TCC (3-(4-ch, TiO_2 and ZnO), which act as chemical or physical filters preventing or limiting UV penetration (Corinaldesi et al. 2017; Carve et al. 2021).

Table 12.4 Some examples to ecotoxicological studies that assess the effects of personal care products (PCPs) on marine Biota

Species/population	Source and type of PCP	Impact	Citation
Marine mussel (*Perna perna*)	Triclosan (TCS) Prepared in the laboratory by mixing TCS with dimethyl sulfoxide	Laboratory assay results: Fertilization assay: fertilization was inhibited at mean concentration of 0.49 ± 0.048 mg/L Embryo-larval development was inhibited by 0.135 ± 0.028 mg/L Cytotoxicological assays: adverse effects at concentrations of 1200 ng/L and 12,000 ng/L. laborator results indicate acute and chronic toxicity to gametes and embryos of *P.perna*	Cortez et al. (2012)
King mackerel (*Scomberomorus cavalla*), leatherjacket (*Oligoplites saurus*), Mullet (*Mugil incilis*), Gafftopsail catfish (*Bagre marinus*), White sea catfish (*Genidens barbus*), crevalle jack (*Caranx hippos*)	Triclosan (TCS)	Detected in seawater samples but not in fish muscles. (perhaps bioaccumulation occurred in the liver which was not tested)	Pemberthy et al. (2020)
Marine bivalve (*Ruditapes philippinarum*)	Triclosan (TCS) OTNE (octahydro-tetramethyl-naphthalenyl-ethanone) BP-3: benzophenone-3 OCR: octocrylene TiO_2: inorganic UV filter	Accumulation of inorganic and organic PCPs in the clam tissue was of the order: BP-3 > TiO_2 > TCS > OC > OTNE BP-3 and TCS accumulated in the tissue at higher concentartions	Sendra et al. (2017)
Coral planula (*Stylophora pistillata*)	BP-3	In both darkness and light, BP-3 transformed planulae from a motile state to a deformed sessile condition. Coral bleaching occurred with increasing doses of BP-3	Downs et al. (2016)
Corals (adult) *Acropora* spp. *Stylophora pistillata* *Millepora complanata*	BP-3 OCR OMC (ethylhexylmethoxycinnamate) EHS (ethylhexylsalicylate)	Addition of low quantities of sunscreen resulted in release of coral mucuos; thus resulting in coral bleaching	Danavaro et al. (2008)
Limpets (*Cymbula oculus* and *Cymbula granatina*), Mussels (*Mytilus galloprovincialis*), Sea snail (*Oxystele sinensis* and *Oxystele tigrina*), Sea urchin (*Parechinus angulosus*), Starfish (*Marthasterias glacialis*)	TCS	Not detected	Ojemaye and Petrik (2022)

Box 12.3: Some Personal Care Products (PCPs) of Concern

4-methylbenzylidene-camphor (4-MBC)

This compound is an organic UVB filter and is referred to as enzacamene. It is a high lipophilic component, easily absorbed through the human skin and exhibits a toxic activity as estrogenic endocrine disruptor. 4-MBC shows myriad effects on aquatic organisms, for instance, laboratory studies have shown that 4-MBC causes oxidative stress to an aquatic protozoan, *Tetrahymena thermophile,* resulting in inhibited growth and developmental defects in embryonic zebrafish (Li et al. 2016); toxicity to *Mytilus galloprovincialis* and *Paracentrotus lividus* (Paredes et al. 2014); and reduced growth, alterations on behaviour, imbalance of neurotransmission related endpoints and decreased enzyme activity were reported in Senegales Sole due to varied concentrations of 4-MBC (Araujo et al. 2018).

benzophenone-3

This compound is also referred to as oxybenzone or 2-hydroxy-4-methoxphenyl phenylmethanone and is a class of organic UV filter that is used in organic products to prevent burning of the skin by UVA and UVB radiation. Benzophenone-3 is known to cause a bleaching effect to coral, inhibiting growth and possibly killing the organism; and causing the mobile planulae to become deformed and trapped within its own calcium carbonate skeleton (Downs et al. 2016). Oxybenzone is also an active ingredient in PCPs including body fragrances, hair styling products, shampoos and conditioners, antiaging creams, insect repellants, as well as hand soaps (CIR 2005). In addition, the oxybenzone sunscreens can promote viral infections in corals, resulting in additional bleaching events (Danovaro et al. 2008). Oxybenzone can cause deformities in juvenile coral and damage their DNA and is a skeletal endocrine disrupter.

As the number of vacationers visiting the world's oceans increases, the rate of sunscreen inadvertently washed into these marine environments also rises. UV filters enter the environment directly from sloughing off while swimming and other recreational activities or indirectly via effluent from waste water treatment plants (Brausch and Rand 2011). Whilst these compounds have relatively short half-lives in seawater; they are continuously reintroduced via recreational activities and wastewater discharge, making them environmentally persistent (Horricks et al. 2019). UV filters are considered to be ubiquitous environmental contaminants of increasing concern, due to their bioaccumulation potential, and as endocrine disruptors (Ozáez et al. 2013).

Miller et al. (2021) mentioned that UV filters used in sunscreens and other PCPs may impact coral health on a local scale and also affect other marine species (► Box 12.3). Research studies have suggested that exposure of corals to several widely used UV filters have produced negative health effects including bleaching and mortality (see Miller et al. 2021). Research findings of Danovaro et al. (2008) and Downs et al. (2014, 2016) raised public concern and Hawaii became the first place to take legislative action to ban Benzophenone-3 (BP-3) and octinoxate (EHMC).

12.8 Non-native Species

Non-native species (**NNS**) (synonyms: exotic, alien taxa, non-indigenous, allochthonous, introduced) are species, sub-species or lower taxa introduced outside of their natural range and outside of their natural dispersal potential, dispersed by direct or indirect, intentional or unintentional human activities (Walther et al. 2009; Occhipinti-Ambrogi and Galil 2010; Rotter et al. 2020). NNS can be introduced and spread to waters through several different pathways (e.g. Alidoost Salimi et al. 2021). The major threat to indigenous species diversity and community structures occurs as a result of human-mediated introduction of a marine species outside their natural range of distribution (Rotter et al. 2020). NNS are a component of global change in all marine coastal ecosystems (Occhipinti-Ambrogi 2007) since they are a major threat to global biodiversity. Scientists and policy makers increasingly see the introduction of alien species as a major threat to marine biodiversity and a contributor to environmental change (Bax et al. 2003).

Harbours are known introduction foci of NNS, acting as recipients of new introductions and as sources for regional spread (Peters et al. 2017). Aquaculture is another primary pathway of the introduction of NNS (e.g., Wang et al. 2021), Additional to these, NNS can **hitch-hike** clinging to scuba gear between uses, attached to marine litter or debris, or in consignments of live organisms traded as live bait and plants and animals destined for the aquarium trade (Ruiz et al. 1997; Bax et al. 2003; Godwin 2003; Padilla and Williams 2004; Cagauan 2007; Molnar et al. 2008; De Silva et al. 2009; Anderson et al. 2015; Wang et al. 2021). Interestingly, NNS have been used in restoration programs and for biological control, sometimes with devastating consequences.

Table 12.5 Some examples of Non-Native Species (NNS) impacting locations of intentional or unintentional introduction

Species or population	Location (obtained from)	Introduced to	Impact	Citation
Red mangrove (*Rhizophora mangle*)	South Florida	Moloka ‘i, Hawai ‘i O’ahu	Introduced to stabilise shorelines Successful invasion on the island of Hawaii, obnoxious odors (Anoxic conditions) and clogging of tidal streams	Chimner et al. (2006), Allen (1998)
Seagrass (*Halophila stipulacea*)	India	Eastern continent of Africa, Madagascar, the Red Sea and the Persian Gulf	Fast spreading, competes with native seagrasses	Den Hartog (1970), Short et al. (2007), Willette et al. (2014)
Orange keyhole sponge (*Mycale grandis*)	Indonesia	Hawaii	Threat to corals	Coles et al. (2007), Coles and Bolick (2007)
Encrusting sponge (*Chalinula nematifera*)	Indo-Pacific	Isla Isabel National Park	Overgrows corals, dead skeletons and coralline algae	Ávila and Carballo (2009), Turicchia et al. (2018)
Hard corals (*Tubastrea coccinea, Tubastrea tagusensis,* and *Tubastrea micranthu*)	Indo-Pacific	Brazil	Caused significant environmental, economic, and social impacts	Creed (2006), Lages et al. (2011)
Predatory seastar (*Asterias amurensis*)	native to the coasts of northern China, North Korea, South Korea, Russia and Japan	Tasmania, Australia	Threat to mariculture and wild shellfish fisheries	Ross et al. (2003)
Devil firefish (*Pterois miles*) and red lionfish (*P. volitans*)	Aquarium trade	Atlantic waters off south east USA, Gulf of Mexico and the Caribbean	Threat to biodiversity, outcompete native species	Ballew et al. (2016)

Some NNS can have slight impacts within their new habitat; whilst others can become invasive and pose serious threats affecting marine biodiversity, coastal economies, local cultures and livelihoods and human health. If NNS succeed in attaining high abundances, then they have the potential to displace native species, disturb ecosystem processes and function, change community structure, impact human health, decrease native biodiversity and cause substantial economic losses (Mack et al. 2000; Grosholz 2002; Bax et al. 2003; Simberloff 2005; Ojaveer et al. 2015). Furthermore, NNS may bring with them new diseases and parasites, and genetic modifications (e.g. aquaculture species) (Cook et al. 2016).

Davidson et al. (2015) reported that marine macroalgae are a major constituent of NNS worldwide, having current estimations of introductions in excess of 300 species. The NNS usually have fast growth rates, morphological plasticity, production of tetraspores in abundance and grow on other algae (Russell 1992; Smith et al. 2002). Red alga *Kappaphycus alvarezii* was widely farmed in the Philippines in the 1960s (Bixler 1996; Sulu et al. 2004); in Hawaii from 1970 (Conklin and Smith 2005); and in the Gulf of Mannar from 1990 (Kamalakannan et al. 2014); and established populations have spread outside the farmed areas in India, Tanzania, Panama, Venezuela, Hawaii and Fiji (Rodgers and Cox 1999; Ask et al. 2003; Chandrasekaran et al. 2008; Sellers et al. 2015). *Kappaphycus alvarezii* is cultured in close proximity to coral reef ecosystems such as Kãne'ohe Bay, Hawai'i and the Gulf of Mannar, India (Rodgers and Cox 1999; Chandrasekaran et al. 2008) and tends to reduce the density and diversity of native fish and decreases the species richness and abundance of native macroalgae, coral and other benthic macrofauna (Neilson et al. 2018; HISC 2019).

Other examples of red algae including *Gracilaria Salicornia*, *Acanthophora spicifera* and *Hypnea musciformis* have been known to cause problems in Hawaii (Alidoost Salimi et al. 2021). *Gracilaria Salicornia* leads to the acidification of water, causing coral reef deterioration (Martinez et al. 2012) whilst *A. spicifera* and *H. musciformis* were observed to smother corals and algae (Smith et al. 2002). Further examples of other NNS that have had significant environmental impacts are highlighted in Table 12.5.

There are wide ranging action programs to deal with invasive marine species and websites dedicated to educating people about these and their impacts on biodiversity. Some examples include:

- Lionfish: ▶ http://lionfish.gcfi.org/index.php (Figure 12.7)

Figure 12.7 Lionfish, native to the Indo-Pacific are a pest species in the Atlantic Ocean off south east USA, the Gulf of Mexico and the Caribbean. *Photo*: A. Reichelt-Brushett

- Northern Pacific Seastar: ▶ https://dpipwe.tas.gov.au/conservation/the-marine-environment/marine-pests-and-diseases/pest-identification/northern-pacific-seastar
- Black Striped Mussel: ▶ https://nt.gov.au/marine/for-all-harbour-and-boat-users/biosecurity/aquatic-pests-marine-and-freshwater/black-striped-mussel
- Red Mangroves: ▶ https://malamaopuna.org/our-work/past-work/mangrove-removal-waiopae/.

It is helpful to tackle an invasive species problem when it is relatively small and when the reproductive effort of the introduced population is not at its maximum. There are basic frameworks to develop invasive marine species management plans that can help direct effort to ensure cost-effective returns. Some programs are government-funded, but others are driven by community organisations and partnerships.

12.9 Summary

This chapter has introduced you to some of the many other marine pollution problems that are being tackled in many different ways. It is a diverse chapter highlighting sources and impacts from noise, light, temperature, particulates, pathogens, personal care products, and non-native species. To understand each of these topics requires focused research activity, and this research highlights the need to develop solutions. Mitigating marine pollution is an essential research area now and in the future. ▶ Chapter 15 provides a helpful introduction to marine pollution mitigation and habitat restoration.

12.10 Study Questions and Activities

1. Investigate the upper and lower thermal tolerances of some marine species. Record your findings.
2. Find out about the biology of a non-native species (NNS) that has been introduced in your home country. What are the ecological and economic consequences of this introduction?
3. How can suspended sediment impact marine species? Provide an example of a species that may be impacted in each of the ways described in the dot points of ▶ Section 12.5.2.
4. This chapter is unlikely to have covered all the 'other' pollutants in the marine environment that have not had chapters dedicated to them in this textbook. Form a group and discuss pollutants that have not been covered in this textbook. Send your recommendation to the Editor as there might just be a second edition of the book.

12

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