Oil and Gas

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Acronyms and Abbreviations

EEA	European Environment Agency
EMSA	European Maritime Safety Agency
EPC	Environmental Pollution Centres
EU	European Union
FEPA	Food and Environment Protection Act
GBRMPA	Great Barrier Reef Marine Park Authority
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GNOME	General NOAA Operational Modelling Environment
IMO	International Maritime Organisation
IRC	Incident Response Contract
IOPC	International Oil Pollution Compensation Funds
IPIECA	International Petroleum Industry Environmental Conservation Association
ITOPF	International Tanker Owners Pollution Federation
LNG	Liquified natural gas
MARPOL	International Convention for the Prevention of Pollution from Ships
nmVOCs	Non-methane Volatile Organic Compounds
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OPEP	Oil pollution emergency plan
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation
OSPAR	Oil Spill Prevention, Administration and Response
PAHs	Polycyclic aromatic hydrocarbons
PSSA	Particularly Sensitive Sea Area
PTTER	PTT Exploration and Production Public Company Limited
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Region
UNEP	United Nations Environment Programme
USA	United States of America
US EPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds

6.1 Introduction

Oil is a generic term that can cover a very wide range of natural hydrocarbon-based substances and also refined petrochemical products. **Crude oil** and **petroleum products** can have a range of physical properties on the basis of which their behaviour in the marine environment can differ widely. These properties range from viscosity (the rate at which liquid flows), density, and specific gravity (density relative to water) (e.g. Hollebone 2017). The chemistry of crude oil can also differ widely, and includes ***saturates*** (aliphatics including alkanes) which are composed of carbon and hydrogen only, **aromatics** such as benzene, tolune, and xylenes, and polycyclic aromatic hydrocarbons (PAHs) such as naphthalene; and **asphaltenes** which are a mix of very large organic compounds (Hollebone 2017). The latter can have a tar-like consistency at low temperature, cannot be distilled, and can form **tar balls** (also known as surface residual oil balls; see ◘ Figure 6.1) that wash ashore and are persistent in the environment (e.g. Lorenson et al. 2009).

Oil can enter the marine environment from a range of sources, both natural and anthropogenic (human activities) and, depending on type, can persist for a long period of time (persistent) or disperse fairly rapidly (non-persistent). In a definition adopted by the International Oil Pollution Compensation Funds (IOPC), non-persistent oil (volatile in nature and tending to dissipate rapidly by Evaporation) consists of hydrocarbon fractions at least 50% of which, by volume, distils at a temperature of 350 °C and at least 95% of which distils at a temperature of 370 °C (Anderson 2001). Spilled oil can have a range of consequences on the environment, often depending on its level of persistence. This chapter considers sources, fate, and consequences of oil pollution, together with a brief discussion of gas pollution. It then considers some of the mitigation strategies available to minimise impacts from shipping and oil ex-

Figure 6.1 Tar balls are seen washed ashore on Okaloosa Island in Fort Walton Beach, Florida on June 16, 2010 (*Image* Gatrfan ▶ www.drewbuchanan.com—Own work, Public Domain, ▶ https://commons.wikimedia.org/w/index.php?curid=10668105)

ploration and exploitation activities, and to prepare for and respond to oil pollution in the event of an emergency (see also ▶ Chapter 16).

6.2 Sources of Oil in the Marine Environment

Oil is a naturally occurring substance that can enter the marine environment from a range of sources. These include seeps from the seabed; industrial and urban runoff into coastal waters and into rivers; and anthropogenic sources (human activities) including shipping and oil exploration and exploitation activities, and atmospheric sources through incomplete combustion of petroleum products from cars and aircraft. The total volume of oil entering the marine environment annually is unclear (GESAMP 2007). A study by the National Research Council (NRC 2003) estimated that more than 1.3 million tonnes (76 million gallons) of oil enter the marine environment each year, while a study by the European Environment Agency (EEA 2007) estimated global oil inputs of between 1 and 3 million tonnes (264–793 million gallons). However, a 2001 study estimated that around 4.63 million tonnes (1223 million gallons) a year entered the marine environment from transport and oil production activities (Clark 2001). Despite the lack of any accurate estimate of inputs, and the wide variation between estimates, these figures highlight that oil pollution poses a threat to the marine environment. This section will review the various sources of oil—both crude oil and refined oil (petroleum and other hydrocarbon products) entering the marine environment.

6.2.1 Naturally Seeped Oil

It is estimated that around 45% of crude oil entering the global marine environment comes from natural seepages through faults and cracks leading to geological formations under the seabed associated with oil reservoirs; that figure rises to around 60% in North American waters (NRC 2003). Globally, these natural seeps, which may have lasted for hundreds of thousands of years, are estimated to release around 600,000 tonnes (159 million gallons) of crude oil annually (NRC 2003). A study of natural offshore seepages and the accumulation of tar balls along the California coastline (Lorenson et al. 2009) identified that there are "*prolific, frequently chronic, onshore, and offshore shallow oil seeps*" in the area where tar balls wash ashore, together with oil seeping from rocky outcrops and cliff faces. This is in addition to anthropogenic sources such as shipping and offshore drilling rigs in the area. High concentrations of methane gas in the water column around natural seeps were also identified in that study. Figure 6.2 illustrates the fate and distribution of such naturally seeped oil showing that lighter petroleum hydrocarbons migrate to the ocean surface, together with methane, and enter the atmosphere. Heavier petroleum hydrocarbons either form a slick on the ocean surface, from which they can wash ashore, or fall back to the seabed.

6.2.2 Oil from Land-Based Sources

Land-based sources of oil include municipal wastewaters, urban runoff, and river discharges, together with industrial discharges, including non-refinery discharges and refinery discharges. River discharges can, according to the NRC (2003), come from both inland basins draining via major rivers to the sea, and from coastal basins which discharge directly to the sea. Urban runoff, such as untreated or insufficiently treated municipal sewage and stormwater, comes from a range of sources including cars, machinery, fuel spills, and waterborne or airborne pollutants that fall onto hard surfaces and are washed into rivers flowing into the sea (US EPA 2017). Pollution from land-based oil refineries can also occur as a result of accidents or operational discharges from coastal refineries or power plants, as in the case of the Jiyeh Power-Plant spill in Lebanon in 2006 (▶ Box 6.1) and intentionally

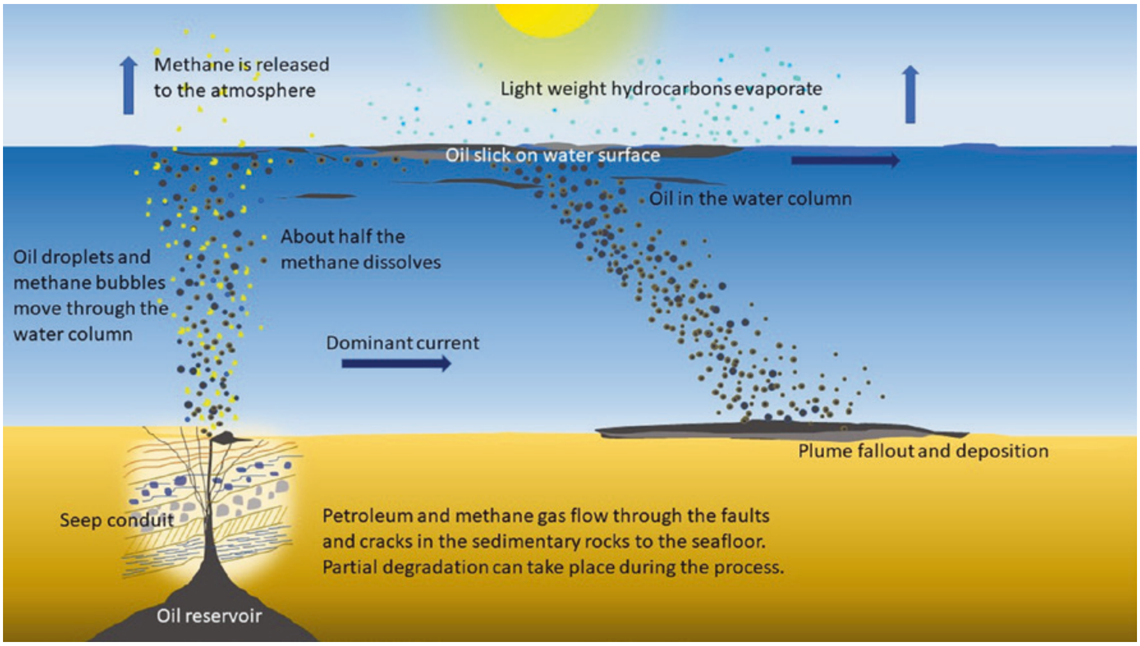

Figure 6.2 Fate and distribution of naturally seeped oil in the marine environment. Adapted from Cook, Woods Hole Oceanographic Institution by A. Reichelt-Brushett

Box 6.1: Jiyeh Power Plant Spill, July 2006

A large release of oil came from a land-based source occurred from the Jiyeh power-plant, a coastal plant located 28 km south of Beirut in Lebanon in July 2006. After a missile attack on fuel tanks at the power plant, an estimated 12,000–15,000 tonnes of heavy fuel oil entered the marine environment of the eastern Mediterranean Sea (Greenpeace 2007). However, efforts by the Lebanese Army, Civil Defence and other agencies, prevented approximately 20,000 tonnes of heavy fuel oil from leaking into the sea (UNEP/OCHA 2006). The ongoing conflict between Israel and Lebanon, including a naval blockade, meant that clean-up operations to deal with the spill were delayed, and more than 150 km of Lebanese coastline and 10 km of Syrian coastline were contaminated by oil as the spill was carried out to sea, and also dispersed along the coast of Lebanon (Greenpeace 2007). As a result, some sandy beaches and rocky shorelines were extremely contaminated by oil, while others were only moderately or lightly contaminated (Greenpeace 2007).

(e.g. with the destruction of over 730 oil wells by retreating Iraqi forces in February 1991 where huge volumes of hydrocarbons were released directly into the marine environment while additional volumes entered the marine environment indirectly as fall-out from numerous oil fires (Saenger 1994). The Gulf War oil spill was over 10 times greater than the Torrey Canyon spill (see also ▶ Chapter 1) in Britain in 1961 (Saenger 1994).

Due to the nature of land-based inputs, there is little data to estimate loads from these sources (NRC 2003), although recommendations were made in the NRC report to improve that situation. Those recommendations included a requirement for sampling of both petroleum hydrocarbons and PAHs, establishment of regular monitoring sites on major rivers, collection of stormwater samples from urban coastal cities, and determining how much of the inputs are from petroleum-derived PAHs rather than total petroleum hydrocarbon inputs that included non-petroleum-derived PAHs (Saito et al. 2010).

6.2.3 Oil from Shipping Activities

There are three main sources of oil pollution entering the marine environment from shipping activities, operational, accidental, and illegal (intentional) sources.

Operational pollution takes place during normal ship operations. In the case of oil tankers, this includes discharging bilge water containing oil (up to 15 mg/L in water) through an oily water separator, and discharging oily waters from cargo tanks. These are innovations introduced under the MARPOL Convention, Annex

Box 6.2: Examples of Accidental Oil Spills

Case 1: *Atlantic Empress*, West Indies, 1979—Collision

On 19 July 1979 two fully loaded very large crude carriers, the *Atlantic Empress* and the *Aegean Captain*, collided around 10 miles off the island of Tobago during a tropical storm. Both vessels started to leak oil and both caught fire, resulting in loss of life. While the fire on the *Aegean Captain* was brought under control, and the vessel was towed to Curacao where its oil cargo was removed, the *Atlantic Empress* continued to burn and was towed 300 nautical miles from land between 21 and 22 July. Following a large explosion on board it sank on 2 August. An estimated 287,000 tonnes of oil spilled from the *Atlantic Empress*, making it the largest ship source spill of all time (ITOPF 2018a).

Case 2: *Torrey Canyon*, United Kingdom, 1967—Grounding

On 18 March 1967 the oil tanker *Torrey Canyon* ran aground on Pollard Rock on the Seven Stones Reef near Lands' End, Cornwall. The entire cargo of 119,000 tonnes of Kuwait crude oil spilled from ruptured tanks over a 12 day period. Although various measures were attended to mitigate the slick (including aerial bombardment to try and burn the oil), a large oil slick reached the south west coast of England and the beaches and harbours of the Channel Islands and Brittany. The *Torrey Canyon* was the first oil spill to receive major coverage in the media, ultimately leading to International Conventions covering compensation for damage caused by tanker spills (ITOPF 2018b).

1, and have led to a decrease in operational pollution from shipping (IMO 2018a). Specific limits on inputs in various sea regions are also in place under the MARPOL Convention, with operational discharges permitted only outside those areas. Those limits are discussed in ▶ Section 6.4 of this chapter.

Accidental pollution can include oil spills from shipping accidents, including from collisions at sea (▶ Box 6.2, Case 1), or from a vessel sinking (e.g. sinking in severe weather conditions). It can also come from derelict vessels (unseaworthy vessels that are tied up and abandoned), vessels that have run aground (▶ Box 6.2, Case 2), and from historic wrecks [where residual fuel seeps out of a vessel that has sunk; commonly wrecks from World War II (NRC 2003)]. Poorly coordinated responses and challenges with international boundaries exasperate the impacts of accidental spills (▶ Box 6.3). Accidental pollution can also result from mechanical failure during loading and offloading operations in ports (although this may also be categorised as operational pollution).

The Torrey Canyon disaster discussed in ▶ Box 6.2 (Case 2) ultimately led to the introduction of the MARPOL Convention (International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (also known as MARPOL 73.78). This Convention, operated under the aegis of the IMO, covers accidental and operational oil pollution under Annex I. Its other Annexes cover pollution from chemicals (Annex II); goods in packaged form (Annex III): sewage (Annex IV); garbage (Annex V); and from air pollution (Annex VI)[1] (See also ▶ Chapter 16).

Box 6.3: The MV *Prestige* Oil Spill, Spain

Dr. Alexis Vizcaino, Marine Geologist and Geophotograher.

On November 13th, 2003, oil tanker MV *Prestige* burst offshore Galicia in Spain. Six days later, at 133 nautical miles off the Spanish coast in international waters, the *Prestige* broke in two and sank. Between the alarm call and the sink, the oil tanker was erratically sailing. The Spanish, Portuguese, and French authorities denied docking the boat somewhere protected from the heavy sea. The *Prestige* sailed 243 nautical miles (473 km) in those six days. Because of the semi-erratic path, the *Prestige* spilled around 70,000 tons (63,503 tonnes) of heavy oil in the open ocean (◘ Figure 6.3). The extensive oil slick spread throughout the Galician Coast and beyond, becoming the largest oil-spill catastrophe in Spain. The oil spill, helped by currents and wind, had an acute effect on seabird mortality (e.g. shags population dropped 11%; Martinez-Abraín et al. 2006) because of the extent of the pollution and the time of the year (many seabirds get trapped because of lives in contact with the sea surface). It also affected other species (e.g. sea turtles), although limited information is known.

Both stern and bow now sit on the southwestern edge of the Galicia Bank, at 3565 and 3830 m water depths, respectively (Ercilla et al. 2006). Numerous studies have been carried out to understand the associated risks. In 2004, the Spanish government hired Repsol (Spanish Oil Company) to extract the 13,700 tons (12,428 tonnes) left in the boat. The total clean-up cost USD 12 billion, being the third most expensive in the world's history.

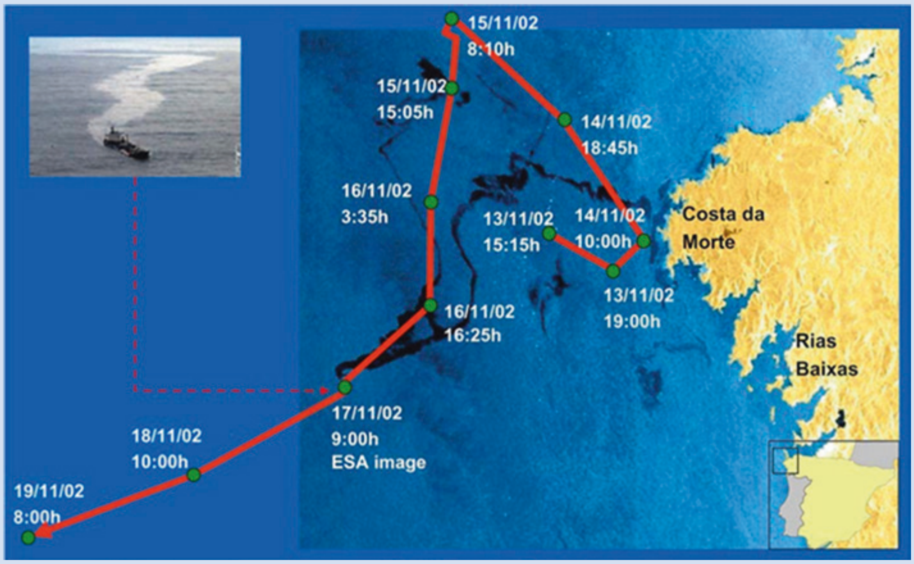

Figure. 6.3 ▶ Box 6.3: Composite image published in Marine Pollution Bulletin by Albaigés et al. (2006). The main picture corresponds to a satellite image of the spill taken on November 17th, 2002, two days before the sinking location with the conspicuous heavy oil slick. In red, track of oil tanker SM Prestige between 13th and19th November 2002. On the upper left corner, there is an image of SM Prestige and its oil slick on November, 17th. *Image*: Envisat ASAR instrument on 17 November 2002 and processed by the Earth Watching team on 20 November at ESRIN in Italy and finally published by ESA (▶ https://earth.esa.int/web/earth-watching/natural-disasters/oil-slicks/content/-/asset_publisher/71yyBC1MdfOT/content/galicia-spain-november-2002-april-2003/ (European Space Agency (ESA), licensed under CC BY-SA 3.0 IGO)

The *Prestige* was produced by Hitachi Shipbuilding Engineering in Japan, registered in Greece with Bahamas flag owned by the Liberian company Mare Shipping, run by the Greek company Universe Maritime and the load owned by the Russian Crown Resources. The boat was in poor ship structure conditions (▶ http://www.shipstructure.org/case_stud ies/prestige/Prestige.pdf). It sank after a complete hull failure in international waters off Galicia because no action was taken to avoid the accident or mitigate its impact.

Illegal oil pollution can occur during the normal operations of a ship (e.g. where the ship needs to clean out its bilges or cargo tanks and intentional discharges of oily waters and other noxious substances occur in restricted areas or in facilities provided by ports). In 2006, it was estimated that around 3000 major illegal hydrocarbon dumping incidents occurred annually in European waters (UNEP 2003). Many of these illegal discharges take place during the hours of darkness, where the likelihood of detection is low. However, the introduction of satellite monitoring for oil spills (e.g. the CleanSeaNet service operated by the European Maritime Safety Agency [EMSA 2018]), has increased the chance of a vessel being caught, or a spill being associated with a specific vessel. This has led to reduced rates of illegal discharges (see the discussion on oil spill monitoring in the North Sea in ▶ Box 6.4).

6.2.4 Oil from Exploration and Exploitation Activities

According to Devold (2013), oil production platforms in the sea include shallow-water complexes where several independent platforms are linked by bridges, large concrete fixed structures placed on the sea bottom (with oil storage cells resting on the sea bottom), and floating production platforms where crude oil is pumped from sub-sea wells and stored on board until it can be offloaded on to shuttle tankers. ◘ Figure 6.4 illustrates a range of typical oil and gas production facilities.

Oil pollution from exploration and exploitation activities can be both operational (including from drilling activities or pipelines transporting oil to the shore) and accidental.

Operational pollution can come from (1) drilled cuttings (solid material removed from drilled rock, to-

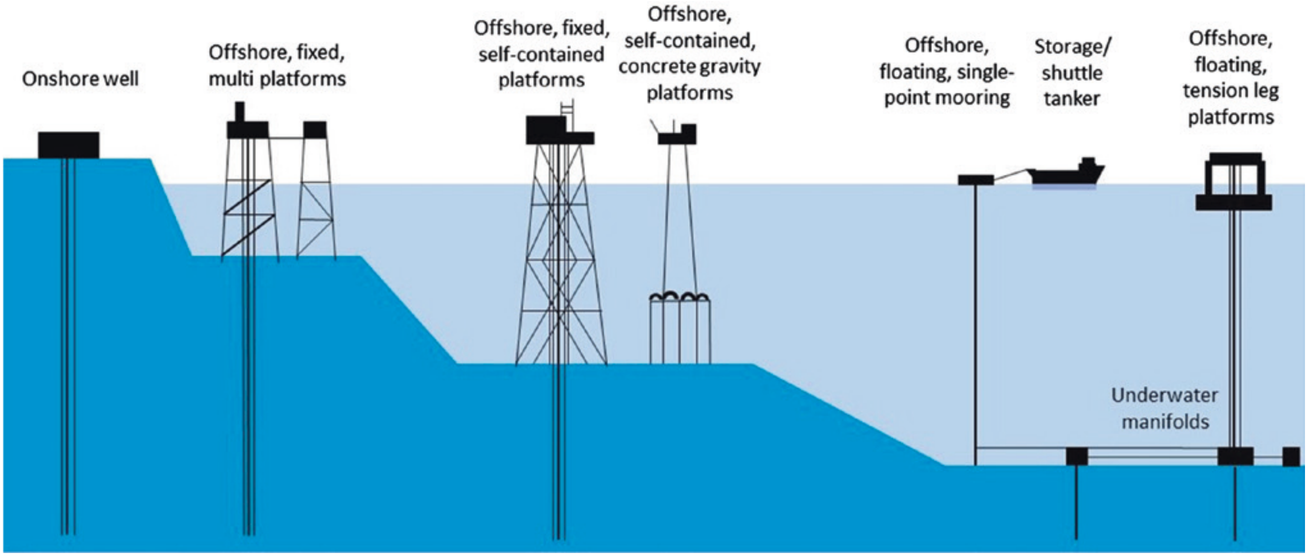

Figure 6.4 Basic schematic of oil and gas production facilities and infrastructure 2013. Adapted from Devold by A. Reichelt-Brushett

gether with muds and chemicals) which can contain oil-based muds, (2) produced water (water that comes from the reservoir as a by-product of oil and gas extraction), and (3) displacement water (seawater used for ballasting the storage tanks of offshore installations which is discharged into the sea when oil is loaded into those tanks). Piles of drilled cuttings at the base of a platform can have persistent, chronic, and long-lasting impacts (Henry et al. 2017). Cuttings were the major source of oil entering the marine environment of the North Sea from oil production activities between 1984 and 1999 (OSPAR Commission 2001). Stricter standards in that region have, however, resulted in virtually no oil entering the sea from that source since 2012 (OSPAR Com-

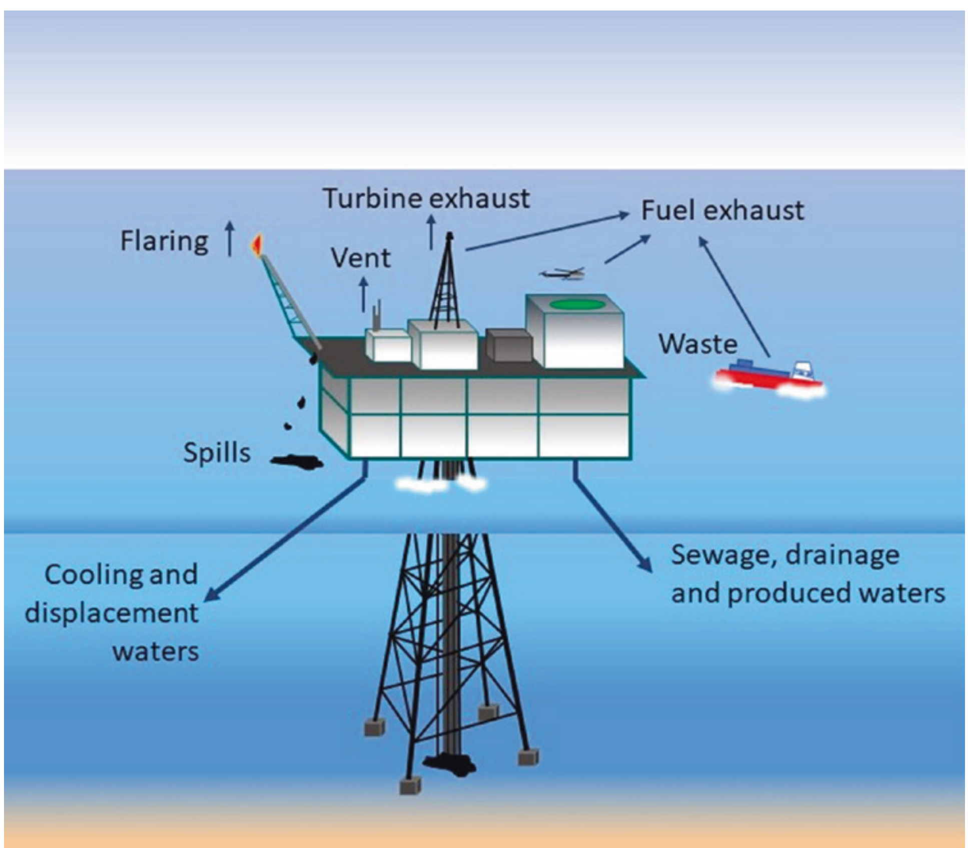

Figure 6.5 Sources of oil inputs from oil and gas exploration activities 2010. Adapted from OSPAR by A. Reichelt-Brushett

mission 2010, 2014), illustrating that measures can be taken to reduce or even halt oil pollution from specific sources.

Operational pollution can also come from the drains, sewage, and cooling water outflows on oil platforms, while oil can also be released by atmospheric deposition through flaring (the burning off of gas from the reservoir), and exhaust gases from the platform and the vessels serving it (Figure 6.5).

Accidental pollution can come from spills from the platform itself, or occur during the transfer of oil to ships, from storage tanks, or from pipelines. The most devastating oil spills occur, however, when there is a major accident on an oil platform, examples are set out in ► Box 6.4.

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Box 6.4: Examples of Accidental Oil Spills from Oil Platforms

Case 1: *Deepwater Horizon*, Manaconda, Gulf of Mexico, 2010

The drilling rig exploded and sank with the loss of 11 lives on 20 April, 2010. Over the next 87 days, and until the well was capped on 15 July, a spill of approximately 4.9 million barrels (1 barrel=159L) of oil occurred, despite the use of a range of technologies including skimmer ships, floating booms, in situ burning, and the use of dispersants. Oil from the accident dispersed widely (see Figure 6.5) and ultimately came ashore on the northern Gulf coasts of Louisiana, Mississippi, Alabama and Florida, with heavy oiling occurring along much of that coast and the most severe oiling observed in November 2010 (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011). The *Deepwater Horizon* oil spill had an acute impact on marine ecosystems, marine biota, and commercial fisheries in the Gulf of Mexico. For example, it had a detrimental effect on the abundance and composition of bacterial communities in beach sands in the Gulf of Mexico (Kostka et al. 2011), as well as on marsh vegetation in coastal salt-marshes in the Barataria Bay of Louisiana in the northern Gulf (Lin and Mendelssohn 2012). It also had a major impact on the wetlands of the Mississippi River Delta system in Louisiana, an area responsible for approximately one third of US commercial fish production (Mendelssohn et al. 2012).

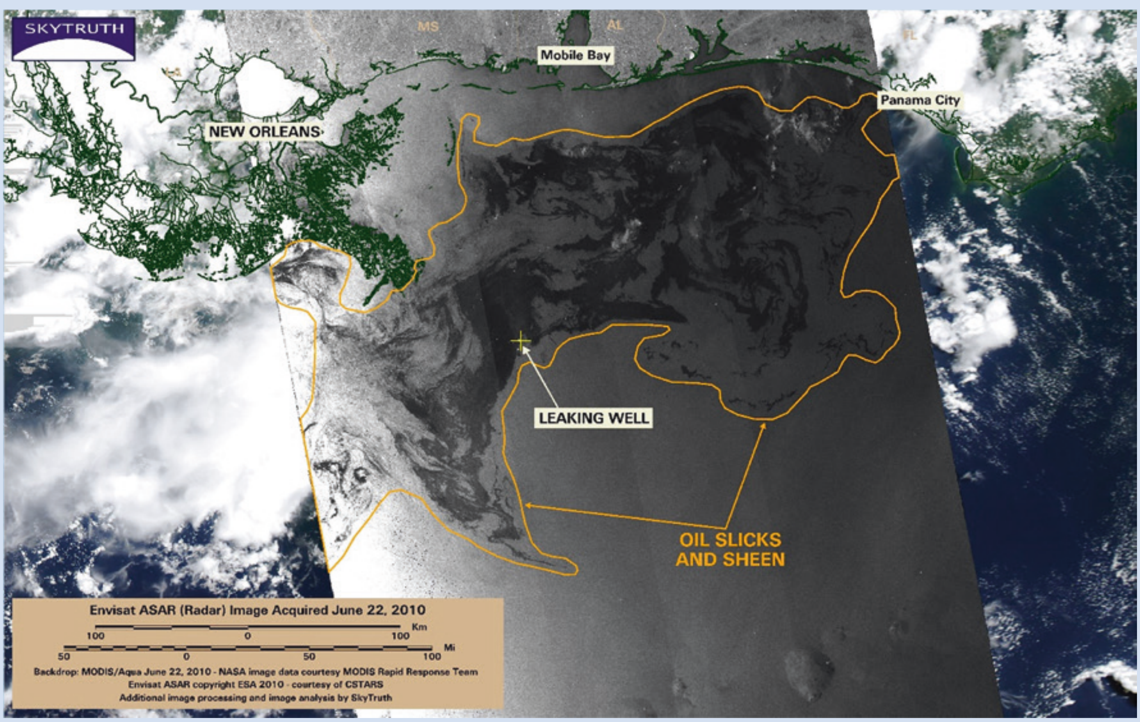

Figure 6.6 ► Box 6.4: With its ability to penetrate clouds and haze, this radar image taken by the ASAR instrument on the Envisat satellite illustrates the usefulness of radar imagery for oil pollution detection and mapping. Oil slicks and sheen from the ongoing BP/Deepwater Horizon spill—patchy in places—are spread across an area of 67,476 km^2 in the northeast Gulf of Mexico. The western edge of the area of slicks and sheen extends beyond the left side of the radar image. Radar image was taken at 03:48 UTC (10:48 pm June 21 local time). *Image*: "Deepwater Horizon Oil Spill—Envisat ASAR Image, June 21, 2010" by SkyTruth is licensed under CC BY-NC-SA 2.0

Case 2: *Montara* Wellhead Platformoil rig spill, Australian Continental Shelf, 2009 (by marine pollution student Dean Senti, 2019, Southern Cross University).

Located 250 km northwest of the Australian mainland (12° 41′S 124° 32′E), and close to Ashmore Reef and Cartier Island, the H1 Well of the *Montara* Wellhead Platform blew on 21 August 2009 (Figure 6.7). Over the next 74 days, it released approximately 23.5 million litres of light crude oil into the Timor Sea (Spies et al. 2017). Oil flowed into Australia's Commonwealth waters and, after several days, into Indonesian waters (Spies et al. 2017). Estimates of volumes of oil discharge range from 1500 to 2000 barrels (238,500 to 318,000 L) per day. The oil surface slick was visible from space, even remaining visible for weeks after the well was sealed on January 13, 2010.

Impacts of the spill included: oiled and dead seabirds; dolphins, seabirds, turtles, and sea snakes all interacting within the oil slick; reduction of seagrass and fisheries in Indonesia; and copious amounts of oil nearshore and at sea were also recorded (Spies et al. 2017). PTT Exploration and Production Public Company Limited (PTTEP) Australasia, owner of the *Montara* Wellhead Platform commissioned an environmental monitoring program, establishing a world-class body of independent scientific research (PTTEP Australasia 2013) in response to the incident. This research has studied marine life and ecosystems of the Timor Sea, making it the most comprehensive database ever generated for this region (PTTEP Australasia 2013). See also: ► https://www.awe.gov.au/environment/marine/marine-pollution/montara-oil-spill/scientific-monitoring-studies

Figure 6.7 ► Box 6.4: Aerial photo of the *Montara* offshore oil platform and West Atlas mobile drilling rig. On August 21, 2009, a well on the platform blew out as a new well was being drilled, and both the rig and the platform were immediately evacuated. Oil and condensate are spewing uncontrolled into the Timor Sea off Western Australia, and will continue to do so for at least 7–8 weeks until a new rig can be brought into the vicinity to drill a relief well. *Photo*: Chris Twomey, courtesy of WA Today "Montara Oil Spill—August 25, 2009" by SkyTruth is licensed under CC BY-NC-SA 2.0

6.2.5 Oil from Atmospheric Sources

As mentioned in previous sections, oil can also enter the marine environment from atmospheric sources, including the deposition of oil from incomplete combustion from car engines or from aircraft, and from flaring and exhaust gases from oil production platforms and their service vessels. The NRC (2003) identifies that volatile compounds escape to the atmosphere during production, transport and refining of hydrocarbons, with heavier compounds (Volatile Organic Compounds (VOCs)) being deposited to the sea surface. VOCs are also emitted by tankers at all stages including loading, tank cleaning and during a voyage, and the amounts discharged depend on properties of the cargo, the degree of mixing and temperature variations during a voyage, and whether vapour recovery systems are used (NRC 2003). The International Petroleum Industry Environmental Conservation Association (IPIECA 2018) identifies that there are two types of recovery systems that can reduce VOC emissions by up to 90% from oil storage ships: active recovery units use compression, condensation, absorption, and/or adsorption to recover VOCs, while passive recovery units use vapour-balanced loading/unloading with non-methane VOCs (nmVOCs) as a blanket gas for storage vessels.[1]

6.2.6 Natural Gas

Natural gas is a fossil fuel that has been mined from the sea floor for many years. Its formation, along with oil, depends on the ambient conditions in the reservoirs where the remains of animals and plants sank to the ocean floor, were compressed under deep layers of sediment, and then were converted by bacteria (aided by pressure and temperature) into precursor substances, and ultimately into hydrocarbons (WOR 2010a). The main offshore natural gas deposits are located in the Middle East, with the South Pars/North Dome located on the Iran/Qatar border considered to hold an estimated 38 trillion cubic metres making it the largest natural gas reserve in the world. Other offshore natural gas fields are located in the North Sea (currently the world's most important gas producing area), the Gulf of Mexico, Australia, Africa, and in the Commonwealth of Independent States (CIS; made up of Russia, Belarus, Ukraine, Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Moldova, Turkmenistan, Tajikistan, and Uzbekistan) and also off India, Bangladesh, Indonesia and Malaysia (WOR 2010a). Between 2001 and 2007, 25% of natural gas came from the North Sea, 25% from Australasia, and 15% from each of the Gulf of Mexico and the Middle East (WOR 2010a).

Natural gas is transported by sea in its cooled form as liquified natural gas (LNG), where it has been liquified at about minus 160 °C to make it more easily transportable. While the process of liquification consumes energy and adds to transportation costs, it is cheaper to ship LNG by sea in tankers rather than through pipelines (WOR 2010a). However, by doing so, emissions to air from ships, and at LNG facilities, will contribute to atmospheric pollution and, ultimately, marine-pollution (WOR 2010b). Notably, fire tests are mostly conducted on land and of the few tests on water the results differ markedly due to the turbulent mixing of the LNG and water resulting in greater heat transfer (Hissong 2007). In a response to these differences it has been recommended that modelling of evaporation and burning considers; the use of time-varying release rates, the use of physical properties of LNG, not methane, to use a time-step analysis that captures the time-varying release rates and the changes in properties resulting from composition changes as the LNG vaporises or burns, and to use parameters that reflect actual spill conditions, including turbulence between the water and LNG (Hissong 2007).

In a study by Malačič and co-authors (2008) on a proposed LNG terminal in the Gulf of Trieste in the northern Adriatic Sea 4 potential areas of concern were highlighted including products of chlorinated water, inputs of toxic mercury and other metals by sediment resuspension, toxicity of aluminium compounds in seawater due to galvanic protection of metal constructions, cooled and chlorinated seawater released by terminals spreading around the Gulf. It was suggested that the proposed technology could be improved to reduce the environmental impact, for example, construction of diffusers at the end of outfall pipes could lead to lower the resuspension and the use of alternative methods to battle the fouling (e.g. ultrasound as an antifouling approach) (Malačič et al. 2008). Furthermore, technology is available that allows for underwater platforms and pipes, that if used, would avoid the need for the offshore terminal, however, these would have their own impacts. Furthermore, air could be used as a heating medium instead of seawater (Malačič et al. 2008).

6.3 Fate of Oil in the Marine Environment

Contamination by oil fractions may persist in the marine environment for many years after an oil spill, depending on characteristics of oil such as type, spill size, and location (Tansel 2014). Kingston (2002) identifies that while salt marsh and mangrove swamp areas may recover within 2–10 years of a spill, in other areas where the oil is not physically removed, it can persist for more than 25 years. While physical factors can influence the speed at which oil disperses and oiled areas recover, it is also necessary to take action to clean up and recover oil in some areas. These aspects of oil pollution, together with activities to monitor oil pollution so that it can be dealt with rapidly, are discussed in this section.

6.3.1 Physical Factors Influencing Oil Degradation

According to ITOPF, (2018c) the principal factors influencing oil degradation, both on and in the sea, by weathering are spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation/sinking, and biodegradation (Figure 6.8).

ITOPF (2018c) describes the main processes involved in weathering as follows:

- **Spreading**—this takes place as soon as oil is spilled and the rate of spread depends on viscosity of the oil, its composition, and the ambient temperature. Low viscosity oils spread faster than high viscosity,

1 For further information on VOC recovery systems see: ▶ http://www.ipieca.org/resources/energy-efficiency-solutions/units-and-plants-practices/voc-recovery-systems/.

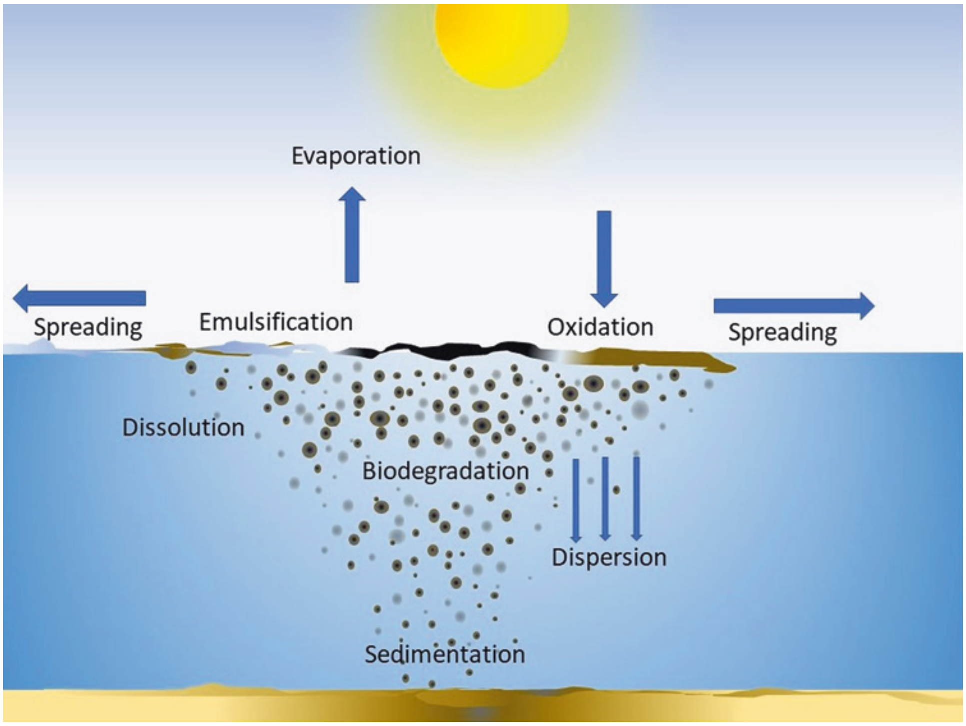

Figure 6.8 Weathering processes acting on oil at sea. Adapted from ITOPF (undated a) by A. Reichelt-Brushett

and oil becomes more viscous at low temperatures. After a few hours a slick may start to break up due to the action of wind, waves, and water turbulence, and this occurs more rapidly in strong currents and at high temperatures.

- **Evaporation**—light and volatile compounds (e.g. kerosene, gasoline, and diesel) evaporate more rapidly than heavier compounds (e.g. heavy fuel oil). As oil spreads, it evaporates faster due to the larger surface area, while surface wave conditions, wind speed, and temperature can also influence the rate of evaporation. The heavier compounds tend to form a thicker layer that is less likely to dissolve naturally.
- **Dispersion**—where waves and turbulence cause a slick to break up into droplets. Depending on their size these droplets will either remain suspended in seawater or rise to the surface and reform as a thin film on the sea surface known as a sheen. Dispersion rates depend on the nature of the oil and the sea state so that light, low viscosity oil will disperse rapidly in rough seas. The use of chemical dispersants, discussed in the next section, can speed up this process.
- **Emulsification**—where seawater and oil combine and seawater droplets are suspended as a water-in-oil suspension. Such an emulsion is very viscous and more persistent than the original oil, and resemble chocolate mousse in appearance, and have a light foamy texture. They weather more slowly than the original oil; mousses with 70% volume of seawater are thixotropic and may solidify when pumped into a salvage vessel or storage tank (Bridié et al. 1980).
- **Dissolution**—where water-soluble compounds such as light aromatic hydrocarbons (benzene, toluene) dissolve in seawater. However, the majority of light compounds are normally weathered more rapidly by evaporation and so dissolution is a less significant weathering process.
- **Oxidation**—where oils react chemically with oxygen to form either soluble products or form persistent tar compounds. These tars can form tar balls (such as those that occur along the California coastline from natural seeps (see Lorenson et al. 2009) where oxidation of thick layers of high viscosity oils or emulsions forms a protective outer coating of heavy compounds, and a softer, less weathered centre. Tar balls are generally small and can last for a long time after a spill.
- **Sedimentation/Sinking**—this generally occurs when oil is approaching the shore, once lighter compounds have evaporated, and the slick has been weathered. If the oil has a similar density to that of seawater, then floating, semi-submerged, or dispersed oil can come into contact with sediments and bind to them. In addition, oil that has washed ashore can mix with sand and sediments and then be washed back out to sea and sink. Where large amounts of sediments mix with spilled oil dense **tar mats** can form on the seabed.
- **Biodegradation**—this is where micro-organisms in seawater that use hydrocarbons as an energy source can partially or completely degrade oil to water-soluble compounds. Biodegradation can only take place at the sea surface since the process requires oxygen and takes place at a later stage than other

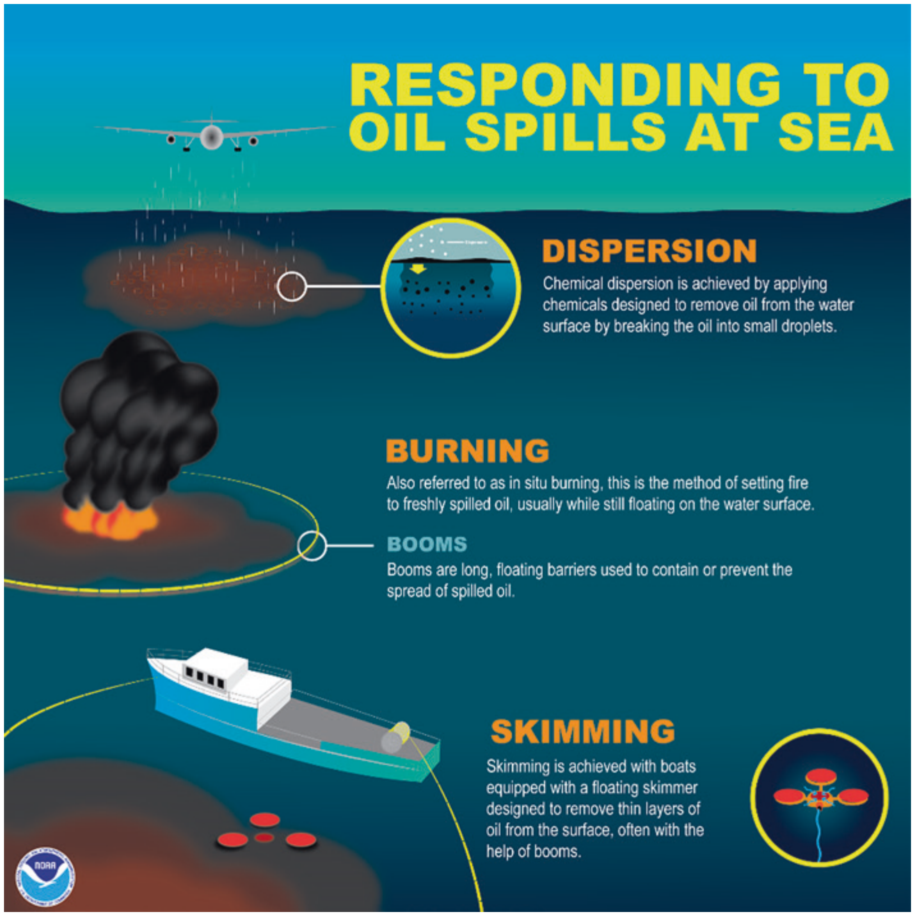

Figure 6.9 Various methods for dealing with oil spills at sea. *Image*: NOAA/ORR, undated, ▶ https://response.restoration.noaa.gov/about/media/how-do-oil-spills-out-sea-typically-get-cleaned.html

processes as it requires a slick to disperse and oil droplets to be created, allowing the micro-organisms to attach themselves to the oil.

6.3.2 Oil Clean-Up and Recovery Activities

A number of technologies are available to **clean-up** following an oil spill, including for the recovery of oil. These technologies include mechanical on-water containment and recovery systems such as booms and skimmers, the use of chemical dispersants, and in situ (i.e. on site) burning (see Figure 6.9).

The type of response method used will depend on factors such as the type of oil spilled, and the environmental condition where the spill is located (close to shore, in a harbour, near a protected area, or out at sea for example).[2] ITOPF (undated b) identifies a range of techniques available to contain and recover floating or beached oil including:

- protective booming in calm water or low currents where floating oil poses a threat to sensitive areas since booms can restrict oil from reaching those areas;
- using pumps and skimmers to remove floating oil that has not yet dispersed, and has not been mixed with debris;
- mechanical collection of high viscosity slicks, and those close to shore or stranded on the shoreline, can be done using excavators, bulldozers, and vessel-based cranes, for example; and
- manual collection by hand, with personnel wearing protective equipment and using hand tools and buckets.

The use of chemical dispersants can rapidly remove large quantities of oil from the sea surface in weather conditions that are too rough for containment and recovery, as dispersants sprayed from aircraft or ships will break up slicks and produce smaller oil droplets that biodegrade more rapidly than large droplets. However, dispersants work more effectively on low viscosity oils

2 For further reading on dealing with clean up and recovery activities for marine oil spills, see the range of ITOPF Technical Information Papers available at: ▶ http://www.itopf.org/knowledge-resources/documents-guides/technical-information-papers/.

Box 6.5: Oil Spill Monitoring in the North Sea

Since the late 1980s **aerial surveillance** has been conducted by the Bonn Agreement to monitor the North Sea for oil pollution (and pollution from other hazardous substances) (Bonn Agreement 2001). Over time a number of developments have occurred so that aerial surveillance data has become more accurate (Carpenter 2019). These developments include:

- from 1992 onwards the data includes daylight and night time surveillance activities;
- from 1997 the source of a spill has been attributed to either a ship, oil platform, or unknown sources (the latter generally being considered as illegal discharges, often taking place at night time); and
- from 2003 onwards, the number of observed spills makes a distinction between detections and confirmed mineral oil spills, the latter being spills where visual verification from an aircraft has taken place.

More recently, the Bonn Agreement has also made use of **satellite surveillance** imagery, provided by the European Maritime Safety Agency (EMSA) under its *CleanSeaNet* programme (EMSA 2018). This programme provides near real-time radar images to contracting parties of potential spills using synthetic aperture radar (SAR) satellites. Potential spills are reported to coastal states within approximately 30 min of detection (EMSA 2018). Spills detected using Side-Looking Airborne Radar (SLAR; imaging radar that point perpendicular to the direction of flight, mounted on an aircraft or satellite) are verified visually by the aircrew conducting Bonn Agreement surveillance flights (Carpenter 2019).

Monitoring of spills from oil production activities takes place through **direct monitoring** using sampling equipment on board manned and unmanned platforms, with samples taken to determine the average concentration of hydrocarbons discharges in produced water, displacement water, ballast water and drainage water (OSPAR Commission 2011). Samples have, since 2007, been assessed using gas chromatography, and before that infrared detection was used to measure oil in water concentrations. As a result of increasingly stringent emissions standards imposed by the OSPAR Commission, volumes of oil entering the sea from platforms has decreased significantly: almost 14 million tonnes of oil were discharged to sea in produced water in 2001, down to just under 4 million tonnes in 2012 (less than 30% of the 2001 volumes); and 262.2 tonnes of oil entered the sea in discharge water in 2001, down to 61.4 tonnes in 2012 (less than 20% of 2001 levels) (Carpenter 2019).

and are largely ineffective at higher viscosities. There are limitations on the use of dispersants close to shore or near coral reefs and mariculture (ITOPF, undated b).

In situ burning can be used on floating slicks where oil is freshly spilled, and can rapidly remove large amounts of oil from the water surface; however, a minimum thickness of oil is required to achieve such a burn and it will produce large quantities of smoke (ITOPF, undated b). As was described in ▶ Box 6.2 (Case 2), in the case of the *Torrey Canyon* an attempt was made to burn off the oil spill but this was unsuccessful as the attempt only took place several days after the spill, and after dispersants had been used on that spill (BBC 2008).

6.3.3 Oil Spill Monitoring Activities

Oil spill monitoring can be conducted in a number of ways including by the use of aerial surveillance, where a trained observer on an aircraft can spot a slick and determine whether it is oil or not, through the use of satellite imagery, and through direct monitoring on board oil platforms. The North Sea provides an example of a region where all three types of activity are undertaken, and there has been a significant decline in oil spills in the region since the mid-1980s (▶ Box 6.5).

◻ Figure 6.10 illustrates trends in flight hours, observed slicks, and the ratio between the two for oil spills identified in the North Sea by Bonn Agreement and EMSA activities. It is apparent that the number of oil slicks has declined significantly in the region since surveillance activities commenced, and the number of slicks observed for every flight hour has also significantly fallen.

6.4 Consequences of Oil Pollution

The impacts of oil entering the marine environment can be acute, where there is an immediate short-term effect from a single exposure in relation to the life-span of an organism (GESAMP 1993). They can also be chronic, where sub-lethal effects of exposure are long term (10% or more of the life-span of the organism in question), and

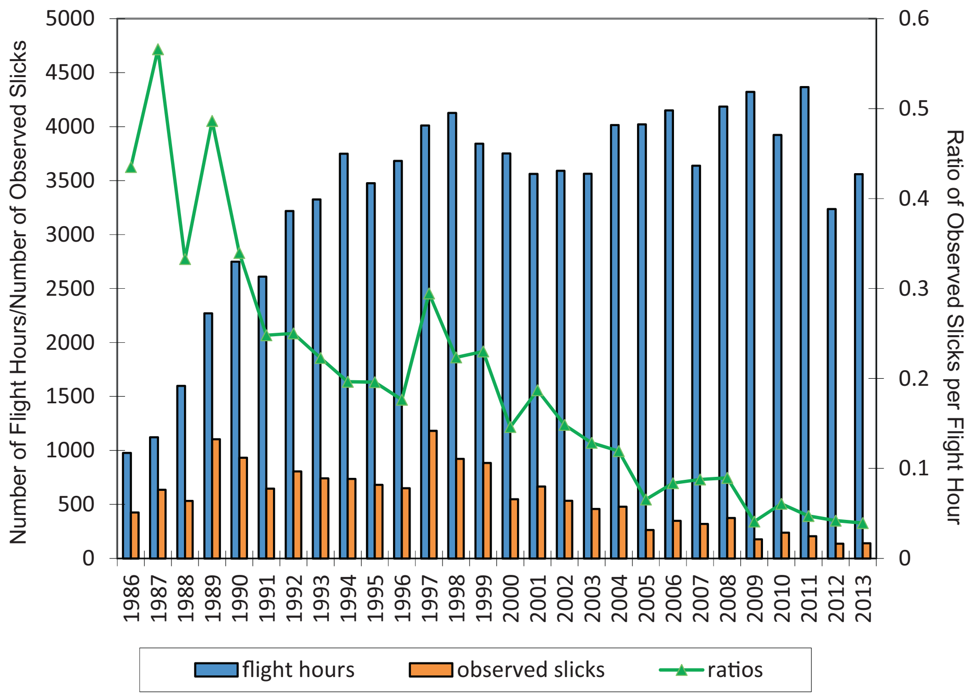

Figure 6.10 Bonn Agreement Aerial Surveillance Data for all North Sea countries, 1986–2013.[3] *Image*: A. Carpenter

Figure 6.11 Oil washes ashore at Grand Isle State Park, Grand Isle, La. *Photo*: US EPA—by Eric Vance. ▶ https://commons.wikimedia.org/wiki/File:June_4,_Oil_washing_ashore_at_Grand_Isle_State_Park,_La_(4683067430).jpg

where it takes a significant length of time for the toxic effect to be observable (Fingas 2012). Oil can impact on marine ecosystems such as shorelines (see Figure 6.11),

3 NOTE: 2008–2013 Annual Reports were, at the time of writing, available from the Bonn Agreement Secretariat at: ▶ http://www.bonnagreement.org/publications Reports for earlier years are available by writing to the Bonn Agreement Secretariata.

marshes and mangrove swamps (Kingston 2002; Duke 2016), and on a range of marine biota including mammals (Fair et al. 2000), seabirds (Schultz et al. 2017) invertebrates, and plankton (Brussaard et al. 2016). It can also cause commercial damage to fisheries (Mendelssohn et al. 2012) and aquaculture such as mussel beds, together with wild mussels (Soriano et al. 2006). In addition, the use of dispersants can have additional impacts on marine organisms such as copepods (Cohen et al. 2014).

6.4.1 Impact of Oil on Marine Ecosystems

WOR (2010b) presents an overview of how oil damages different habitats, ranging from exposed rocky and sandy shores (where regeneration of the shoreline can take anywhere from a few months to years), to salt marsh areas (where regeneration can take anywhere from 2 to more than 20 years). For protected rocky shores and coral reefs, WOR (2010b) indicates that regeneration can take anywhere from 2 to more than 10 years. The more sheltered a shore, the longer oil will remain in the environment.

Certain areas are at much higher risk of damage than others. For example, the Wadden Sea is an area between Denmark, Germany, and the Netherlands which contains the world's largest tidal flats system, large areas of coastal salt-marshes, accommodates over 5000 species of flora and fauna, and attracts over 10 million migratory seabirds annually (▶ https://www.waddensea-worldheritage.org/our-world-heritage). An oil spill in that region would potentially cause severe and long-lasting damage. The Wadden Sea, therefore has, since 2002, held Particularly Sensitive Sea Area (PSSA) status from the IMO under the MARPOL Convention. It fulfils ecological criteria such as ecosystem diversity and vulnerability to degradation by natural and human activities (IMO 2018b). This protection goes further than that for Special Areas under MARPOL (IMO 2018c) under which, for technical reasons relating to their oceanographical and ecological condition and to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. A range of areas have Special Status under MARPOL Annex I: Oil, these include the Mediterranean, Baltic, Black and Red Seas, the "Gulfs" area, the Antarctic area, North West European Waters, and Southern South African waters. PSSA Status has been granted to a wide range of areas including the Great Barrier Reef, Australia, the Wadden Sea, the Galapagos Archipelago, and the Tubbatah Reefs Natural Park in the Sulu Sea, Philippines (the area most recently awarded PSSA status).

An example of long-term impacts on marine ecosystems the heavy oiling from the *Deepwater Horizon*oil spill (see ▶ Box 6.3) has had a direct, significant, and long-lasting impact on marsh vegetation in coastal salt-marshes in the Barataria Bay area of Louisiana (Lin and Mendelssohn 2012). It also impacted the wetlands of the Mississippi River Delta system in Louisiana, an area responsible for approximately one-third of commercial fish production in the USA (Mendelssohn et al. 2012).

Oil spills can have different impacts on freshwater versus marine environments, for example, on free flowing streams and rivers compared to standing water in areas such as wetlands and salt-marshes. An overview of impacts in freshwater environments provides an understanding oil spills in these environments (US EPA 1999).

6.4.2 Impact of Oil on Marine Taxa

The most visible impact of an oil spill is oiled birds which have been directly coated by oil washing ashore on beaches (◘ Figure 6.11). However, there are many less obvious effects on marine taxa such as plankton, corals, and marine copepods (small or microscopic aquatic crustaceans that are food organisms for small fish, whales, turtles, and a range of crustaceans). There are also impacts on benthic invertebrates (bivalves such as clams and mobile crustaceans such as crabs, shrimp, and lobster) that live on the seafloor, and on intertidal/sub-tidal species that live in the zone between high and low tides (▶ Box 6.6). Fingas (2012) identifies a number of impacts on sub-tidal species:

- immobile species such as barnacles and mussels are most vulnerable to oil spills as they will become smothered with oil on each high tide, as also are shoreline plants and algae growing on rocks and sediments;
- some sub-tidal plants such as *Fucus* in North America can survive initial oiling, unless it is by heavy oil, but may be impacted on by long-term sub-lethal effects;
- kelp species, which live in deeper waters, are rarely covered with oil as they live in deeper waters, but they may also be impacted by sub-lethal levels of oil resulting in changes in leaf colour, reproduction and growth rates; and
- Seagrasses, for example, Eelgrass, are rarely directly oiled as they live in low intertidal areas; they take up hydrocarbons from the water column, however, which can result in death within a few hours at moderate levels or at low concentrations over a number of days. Seagrass beds may take several years to recover following an oil spill.

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Box 6.6: The Effects of a Small Oil Spill at Macquarie Island, Subantarctic

Adjunct Professor Stephen Smith, Marine Biologist, Southern Cross University, Australia.

World Heritage Listed Macquarie Island is located in the subantarctic region, halfway between Tasmania and Antarctica, and has been an important Australian research station since 1948. During a re-supply voyage in the austral summer of 1987, adverse weather led to the grounding of the re-supply ship *Nella Dan* resulting in the spillage of 270,000 L of light marine diesel oil into the sea and adjacent rocky shores. While no mortalities of megafauna (mammals and birds) were recorded, thousands of dead marine invertebrates washed up on oiled shores within days of the spill. Subsequent assessments of the impact focused on assemblages on open rocky shores (Pople et al. 1990; Simpson et al. 1995), and the diverse fauna inhabiting the holdfasts of bull kelp (*Durvillaea antarctica*) which dominate the lower shore. There were significant differences in the biotic assemblages between oiled and control sites in all habitats. In particular, patterns of assemblage structure in holdfasts were markedly different, with opportunistic species of worm (polychaetes and oligochaetes) dominating samples from oiled sites, and peracarid crustaceans (amphipods and isopods) dominating at control sites (Smith and Simpson 1995). The impact of oil on the population of the dominant isopod *Limnoria stephenseni* was a primary driver for these differences. This species feeds on the holdfast tissue, excavating tunnels and chambers that provide habitat for other species. In the absence of this keystone species, the internal spaces of holdfasts became filled with oil-contaminated sediment. Follow-up studies 7 years after the oil spill indicated that, while assemblages on the open shore had recovered, differences in holdfast assemblages persisted between control sites and some of the oiled sites (Smith and Simpson 1998). Traces of oil were still detectable in holdfast sediments and worms continued to dominate these samples. This series of studies demonstrates that even a relatively small oil spill can have long-lasting consequences in some marine settings.

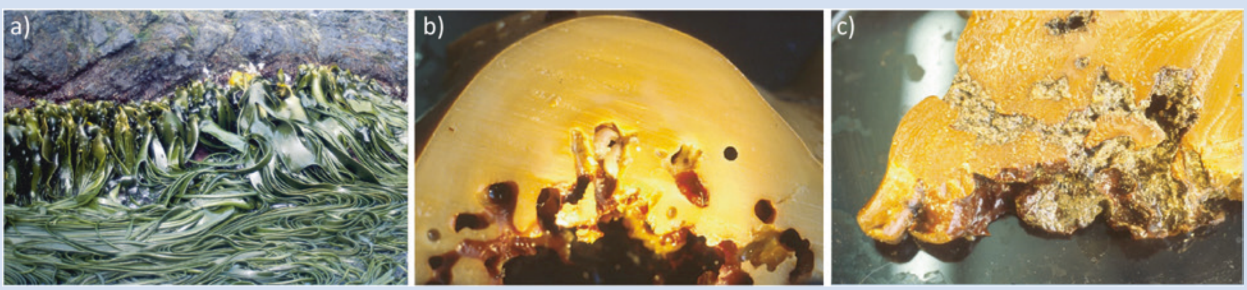


Figure 6.12 ► Box 6.6: **a** The bull kelp *Durvillaea antarctica* dominates the lower shore at Macquarie Island, **b** Sections of holdfasts showing the differences between oiled and unoiled sites: *Limnoria stephenseni* in situ in freshly excavated tunnels at unoiled sites, **c** sediment-filled spaces in holdfasts from an oiled site. *Photos*: S. Smith

Acute and chronic toxicity of petroleum hydrocarbons on marine organisms is dependent on a number of factors. These include concentration and length of exposure; persistence and bioavailability of specific hydrocarbons; how organisms accumulate and metabolise those hydrocarbons; the fate of those metabolised products; and how hydrocarbons or metabolised products interfere with normal metabolic processes such as growth, reproduction, and ability to survive (NRC 2003; Fingas 2012). For example, the *Deepwater Horizon* spill had a detrimental effect on the abundance and composition of bacterial communities in beach sands in the Gulf of Mexico (Kostka et al. 2011). Offshore drilling activities, and the accumulation of large amounts of drilling cuttings, can also have chronic impacts including a significant reduction in the number of taxa, abundance, biomass, and diversity around oil platforms (Trannum et al. 2010).

Fish, birds, and some species such as seals and dolphins, are often able to avoid surface slicks and move to other areas, although some birds mistake slicks for calm water and are oiled as a result (Fingas 2012) and air breathing organisms can be impacted due to their need to break the water surface. The immediate impacts on birds and surface breathing animals are highly visible (Figure 6.13), Peterson et al. (2003) also suggest that almost a decade after the *Exxon Valdez* tanker struck Prince William Sound's Bligh Reef in Alaska, in March 1989, chronic impacts were still being seen in a number of marine birds such as harlequin ducks (For further details of the impacts of the *Exxon Valdez* oil spill, see ► Box 6.7).[4]

4 For an illustrated timeline of recovery from the *Exxon Valdez* oil spill, 25 years after the event, see ► https://aamboceanservice.blob.core.windows.net/oceanservice-prod/podcast/mar14/exxon-valdez-timeline-large.jpg.

Figure 6.13 **a** "Gulf-Spill-2010-Washing-Oiled-Pelican-22" by IBRRC, licensed under CC BY 2.0 (*Photo*: Brian Epstein). **b** *Photo* "Rescuing a pelican" by lagohsep is licensed under CC BY-SA 2.0. *Photos*: courtesy of Louisiana Department of Wildlife and Fisheries. June 4 2010 Biologists from the Louisiana Department of Wildlife and Fisheries responded to 60 calls reporting oiled birds in and around Grand Isle Thursday June 3, resulting in the successful location and capture of 35 brown pelicans and 15 gulls. All of the birds were collected from areas in the Deepwater Horizon oil spill impact zone. **c** Gulf-Spill-2010-Washing-Spoonbill-28. *Photo*: Gulf Oil Spill Bird Treatment in Louisiana provided by IBRRC, Brian Epstein by IBRRC, licensed under CC BY 2.0. **d** "Oiled Turtled Rescued May 21" by lagohsep, licensed under CC BY-SA 2.0. *Photo*: courtesy of Louisiana Department of Wildlife and Fisheries

Dispersants used on oil spills can also have an impact on marine species such as copepods and can have acute effects including increased mortality. One example comes from the *Deepwater Horizon* spill where a dispersant used to break up the spill led to increased mortality rates amongst the common coastal copepod *Labidocera aestival* (Cohen et al. 2014).

Box 6.7: Short Term and Long-Term Impacts of Oil Spills

Exxon Valdez, Alaska, 1989—Grounding

On 24 March 1989 the oil tanker *Exxon Valdez* grounded on Bligh Reef in Prince William Sound, Alaska, and around 37,000 tonnes of Alaska North Slope crude oil escaped into the sound and spread widely. Limited dispersant spraying took place, as well as in situ burning. The at sea response concentrated on containment and recovery, but despite massive efforts less than 10% of the spill was recovered from the sea surface. The spill came ashore across 1000 km in Prince William Sound, along the south coast of Alaska, and as far west as Kodiak Island. It affected a range of shore types including rock and cobble (ITOPF 2018d).

Exxon Valdez—Impacts.

According to Peterson et al. (2003), the acute mortality (short term) phase of the spill had a number of severe impacts on marine taxa:

- mass mortality of between 1000 and 2800 sea otters initially, together with up to 250,000 birds within days of the spill. These mammals and birds came into contact with floating oil leading to loss of insulation which can result in death from hypothermia, smothering, drowning, and ingestion of toxic hydrocarbons;
- around 300 harbour seals were killed, most likely as a result of inhaling toxic fumes causing brain lesions, stress and disorientation; and
- mass morality among macroalgae and benthic invertebrates on oiled shores from a combination of chemical toxicity, smothering and displacement from habitat by after-spill pressure washing of rocky beaches.

Long-term population impacts of the spill included:
- chronic exposure over many years in sediment-affiliated species such as fish, sea otters, and sea ducks (in the latter exposure was related to sediments used for egg laying and foraging);
- chronic exposure to partially weathered oil identified in fish embryos and larvae; elevated mortality of incubated pink salmon eggs in oiled streams at least 4 years post-spill;
- limited to no recovery of sea otter populations in various areas, plus higher mortality rates in animals born after the spill; and
- higher mortality rates in harlequin ducks overwintering in the region identified in 1998; in 1999, elevated rates of an enzyme CYP1A found in the livers of adult pigeon guillemots feeding on shallow-water benthic invertebrates when compared to chicks fed only on fish.

6.4.3 Economic Damage from Oil Pollution

Oil gives fish and other animals an unpleasant smell and taste and, as noted previously, can remain in the environment for long periods of time with continued detrimental effects. Commercial fisheries are at particular risk of harm from oil pollution, particularly where a slick occurs near to farmed fish or shellfish operations, or close to breeding grounds where fish eggs and larvae are vulnerable to oil pollution (e.g. Whitehead et al. 2012). In such cases it may be impossible to sell the fish or shellfish produced in an area impacted by a spill. An example of this was following the *Sea Empress*oil spill off Milford Haven, Wales in 1996 (► Box 6.8).

The Environmental Pollution Centres (EPC) note that other economic impacts include loss of tourism as people stay away from visibly oiled areas, or areas where there has recently been a spill (EPC 2017). This can have a negative impact on local jobs, commercial enterprises, and accommodation and food providers. Fishermen and associated onshore support (fish handling, transport) can also lose their jobs while fishing bans are in place. Property values can decline as properties in an area close to a very large spill may also be at risk of being polluted.

Box 6.8: Economic Impacts of Oil Pollution on Fishing

Sea Empress, Wales, UK, 1996—Grounding
On 15 February 1996 the oil tanker *Sea Empress* ran aground in the entrance to Milford Haven, South Wales. While the tanker was quickly refloated, serious damage was caused to its centre and starboard tanks and around 72,000 of its 130,000 tonnes cargo (Forties Blend North Sea crude) and 370 tonnes of heavy fuel oil was released between initial grounding and final refloating. Around 200 km of coastline was contaminated, and required major shoreline clean-up efforts. Much of the coastline was within the Pembrokeshire Coast National Park, while main tourist beaches were also impacted, two months before the Easter holidays in the UK (Source: ITOPF 2018e).
Commercial impacts of the *Sea Empress* spill included a ban on both commercial and recreational fishing. Under the UK Food and Environmental Protection Act, 1985 (FEPA) monitoring of a voluntary ban on mussel harvesting was undertaken, as FEPA officials determined that mussels in the Milford Haven/Pembrokeshire Coast area had accumulated dangerous levels of oil. 200 km^2 were unfishable and mussel harvesting was discontinued until 12 September 1997 when all bans were finally lifted (Environment and Society Portal, undated).

6.5 Planning for, and Responding to, Oil Pollution Incidents

6.5.1 Context

No matter what safety measures are in place to prevent marine oil pollution, there is always a risk of an incident occurring from ships or offshore installations. As a result, a range of measures and strategies are in place to plan for such incidents, and to respond to them when they occur. Contingency planning, emergency management and response planning, and oil pollution monitoring are all necessary components in being ready to deal with marine-pollution by oil.

6.5.2 Oil Pollution Preparedness and Response Co-operation (OPRC)

The International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) was adopted in November 1990, following a conference in Paris in July 1989 at which the IMO was asked to develop additional measures to prevent pollution from ships. OPRC entered into force in May 1995. The Convention aimed to provide "*a global framework for international cooperation in combating major incidents or threats of marine-pollution*".[5] All nation states that are signatories to OPRC are required to put in place measures to deal with pollution incidents from oil (or from hazardous and noxious substances—a separate Protocol known as OPRC-HNS). These measures may involve a response at national level or in cooperation with other parties to the Convention.

Each State party is required to (1) establish a national system for responding to oil (or HNS) pollution incidents; (2) have a designated national authority, national contact point, and national contingency plan; and (3) have a minimum level of response equipment, communications plans, regular training, and exercises. They are also encouraged to develop bilateral or multilateral agreements to augment their own national capacity to respond to incidents.

OPRC has specific requirements for ships including that they carry on board an oil pollution emergency plan and that they report any incident of pollution to coastal authorities. For offshore installations in State waters, those installations must have Oil Pollution Emergency Plan (OPEP) response to oil pollution incidents. These should be co-ordinated with national agencies so that they are dealt with promptly and effectively. Seaports, oil terminals, pipelines, and other oil handing facilities are also required to have OPEPs and to deal with national authorities in the event of a spill.

6.5.3 Contingency Planning, Risk Assessment, and Emergency Response

Contingency planning for oil (or chemical) spills can help deal with such a spill in an efficient and effective way and help minimise the impact on the environment. ITOPF (2018f) identifies a number of factors that need to be considered in a plan. The factors fall under four main headings: risk assessment, strategic policy, operational procedures, and information directory. Factors that need to be considered include: determining the risks of spills and expected consequences; defining roles and responsibilities; establishing procedures when a spill occurs; and collecting supplementary information (contact details of relevant agencies, equipment inventory, sensitive area maps, restrictions on dispersant use, guidelines on preferred response techniques, sources of funding, for example). Maps showing areas which are most in need of protection are particularly important for areas where there may be a high ecological risk, a risk to commercial fisheries and aquaculture activities, or there are industrial plants such as power stations that use seawater for cooling. Examples of contingency plans and a risk assessment are set out in ► Box 6.9 and see also US EPA (1999).

5 For more information, please see the IMO website at: ► http://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Oil-Pollution-Preparedness,-Response-and-Co-operation-(OPRC).aspx (accessed on 18 October 2021).

Box 6.9: Contingency Plans and Risk Assessment

Contingency Planning—Mediterranean Sea Region

Contingency plans have been developed for the Mediterranean Sea under Article 4 of the Barcelona Convention (Convention for the Protection of the Mediterranean Sea Against Pollution 1976) (see UNEP/MAP, undated). This includes various protocols such as the Dumping Protocol (dealing with pollution dumped from ships and aircraft; UNEP (1972)) and the Offshore Protocol (dealing with pollution from exploration and exploitation activities (UNEP, undated). Under the auspices of REMPEC (the Regional Marine Pollution Emergency Response Centre for the Mediterranean Region) a range of plans for national preparedness and response plans, including contingency planning aspects, have been developed by the seventeen Mediterranean states that are contracting parties to the Convention (REMPEC, undated; Carpenter et al. 2017).

Rsk Assessment—Australia

An oil spill risk assessment for coastal waters of Queensland and the Great Barrier Reef Marine Park was undertaken in around 2000 (Queensland Transport and GBRMPA 2000). This resulted in the identification of several high risk areas including Torres Strait, Port of Cape Flattery, Moreton Bay, and the Whitsunday Islands. A range of maps covering shipping incident data, port and coastal traffic data, navigational hazards, and oil spill risk profile maps, were also developed at that time.

6

As an example of emergency response to oil pollution in European waters (with assistance provided to both European Union (EU) and non-EU states), the EMSA helps provide technical and scientific assistance in the area of ship-source pollution and in responding to pollution incidents. EMSA has in place a network of stand-by oil spill response vessels located in ports around Europe (see ◘ Figure 6.14).

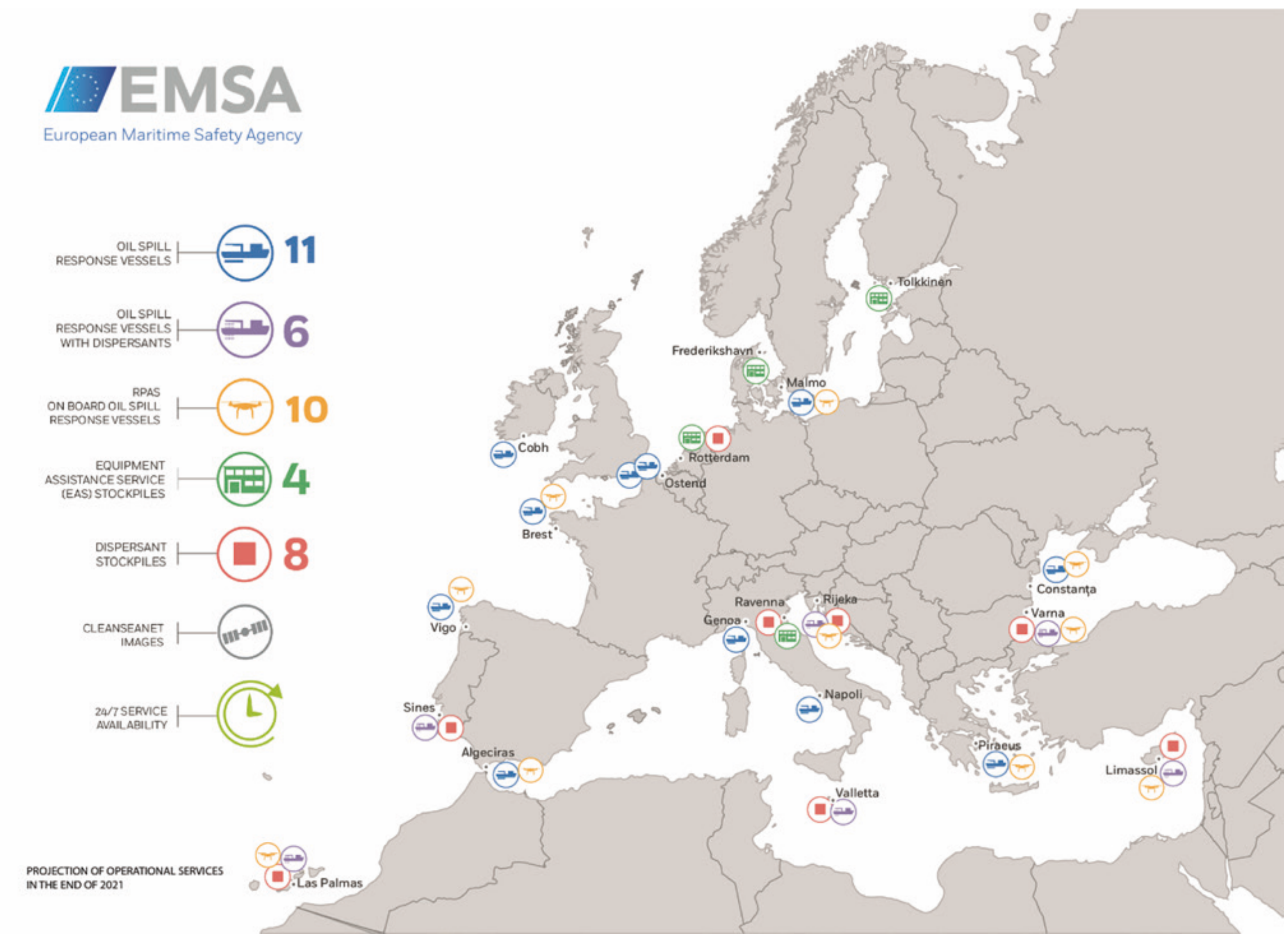
The ships forming the network keep trading in the vicinity of the area where they are based but once mobilised they should stop their commercial operations and be ready for pollution response activity within 24 h. Before entering the network, they are adapted to undertake oil spill response activities. They offer a large heated storage capacity to stay longer on operations and for easy discharge the recovered oil. They make use of a range of oil recovery systems such as rigid sweeping arms (a mechanical oil spill containment system consisting of a floating pontoon and an oil collection chamber), booms (temporary floating containment barrier to prevent oil from spreading), and skimmers (equipment which can recover oil from the water surface).

The choice of equipment used in a spill depends on factors such as weather conditions, type of oil, and the coverage area. The ships in the EMSA network are equipped with local radar-based oil slick detection systems and are ready to sail within 24 h of an Incident Response Contract being signed (e.g. EMSA 2019). This contract, between the ship operator and the affected State, includes details of the actual oil recovery operation and the cost of hiring vessels. Since oil pollution at sea is transboundary in nature, EMSA ships can also be mobilised by non-EU countries sharing a regional sea with the EU. For other examples of transboundary cooperation in dealing with oil pollution see Kelly (2016) for cooperation between the US and Mexico, the Pacific States/British Columbia Oil Spill Task Force (2011) for cooperation between the US and Canada, and IMO (2017) for cooperation between west, central and southern Africa.

6.6 Summary

Oil is a generic term that can cover a very wide range of natural hydrocarbon-based substances and also refined petrochemical products while natural gas is a fossil fuel that has been mined from the seafloor for many years. Both were formed when the remains of animals and plants sank to the ocean floor and were compressed under deep layers of sediment. Processes including the actions of bacteria, together with pressure and temperature, over a long period of time, converted those remains into hydrocarbon. Oil and gas reservoirs are found widely around the globe, both on land and beneath the seabed. These hydrocarbon deposits are extracted and become the fuel for cars, aircraft and ships, or are used to heat homes, or are converted into a wide range of chemicals for industrial processes.

Oil can enter the marine environment from a range of sources, both natural such as seeps from the seabed, or via human activities including shipping and oil exploration and exploitation activities, from the incomplete combustion of petroleum products from cars and aircraft, or via urban runoff via sewage and stormwater where pollutants fall on hard surfaces and are washed into rivers which eventually flow into the sea. Oil pollution incidents can range from very large, highly visible spills from an incident such as a tanker accident (*Torrey Canyon, Sea Empress, Exxon Valdez* for example) or from a major oil rig disaster such as the *Deepwater Horizon*, Manaconda accident. They



■ **Figure 6.14** Network of Stand-by Oil Spill Response Vessels in EU waters, April 2021 2021. *Source*: EMSA—regularly updated, see the website for the most recent version: ▶ http://emsa.europa.eu/we-do/sustainability/pollution-response-services/oil-recovery-vessels.html can also be much smaller such as when a ship illegally dumps oil out to sea while sailing at night or outside territorial waters.

Depending on the type of oil, ocean/sea surface and weather conditions, and the location of a spill (at sea or close to the shore), oil can have a rapid impact on marine life including seabirds, mammals, immobile species such as barnacles and mussels, for example, and on sub-tidal plants. Based on factors such as of oil type, sea and weather conditions, and location, oil can persist in the marine environment for long periods of time or disperse rapidly. While some estimates have been made about volumes of oil entering the marine environment from different sources each year, these estimates vary widely so it is not possible to determine the actual amount.

The main natural gas pollution source is the production and transportation of cooled gas in the form LNG, where natural gas is liquified at about minus 160 °C to make it more easily transportable by sea. Emissions to air from ships, and at LNG facilities, can contribute to atmospheric and, ultimately, marine-pollution as LNG vaporises or is burned during the operation of those ships and facilities. Even more so than with oil pollution, where there are at least some estimates of volumes, it is not possible to estimate how much natural gas pollution enters the marine environment each year.

There are a range of measures in place to try and reduce oil (and gas) pollution, including regulations to make oil tankers safer and less likely to spill oil in the event of an accident, measures to monitor discharges from oil production platforms, and aerial and satellite surveillance to spot an oil spill or prevent ships from illegally dumping oil overboard. There are also measures in place to plan how to deal with a spill in a timely way (contingency planning), and also making available specialist equipment and ships to try and remove as much oil as possible, or by placing booms around a spill to prevent it from spreading (emergency response planning). International cooperation in the event of a spill is necessary as pollution at sea is transboundary and can impact the waters of multiple countries as it is moved on ocean and tidal currents. It is important, therefore, that international cooperation to combat major incidents or threats of marine pollution, as well as well-planned local and regional actions to deal with smaller incidents, continues to take place to protect the marine environment from pollution.

6.7 Study Questions and Activities

1. What are the main anthropogenic (human) sources of oil entering the marine environment?
2. What types of equipment can be used to clean up or minimise the spread of an at sea oil spill?
3. Along with oil seeping from the seabed as a natural seep which greenhouse gas is often released from such a seep?
4. How does biodegradation work as a weathering process of spilled oil?
5. What is the main international convention dealing with oil pollution from ships?
6. What are some of the short-term and long-term impacts of oil pollution, both at sea and on land?

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