Ship-source spills – it's more than just oil

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For over 50 years, ITOPF has attended on-site at marine spills worldwide on behalf of the shipping industry. ITOPF staff have provided objective technical advice at over 800 incidents in 100 countries, gaining unparalleled insight into changing trends in ship-source pollution. Spills of oil were originally the focus of ITOPF's activities, initially from tankers and later from a wide range of ships. Over time, there has been a dramatic and sustained reduction in both the number of oil spills and the quantity of oil spilt from tankers, as ITOPF's statistics demonstrate. Though spills of oil cargoes and bunker fuel remain at the core of ITOPF's work, its activities have expanded in recent years to include other pollutants, such as vegetable oils, hazardous and non-hazardous chemicals, coal, foodstuffs, plastics and the myriad of other products transported in container ships. Almost two thirds of the incidents ITOPF attends now involve non-tankers and in the past 20 years, 14% of all attended incident involved products or substances other than, or in addition to, oil.

Oil spill events can cause environmental damage and typically attract considerable media attention. However, other marine pollutants also have the potential to cause environmental damage and pose significant challenges for responders. This paper draws on ITOPF's first-hand experience to examine some of the recent trends in spill response, using case histories to highlight key issues involved with the response of spills of assorted oils and cargoes at sea.

Introduction

Over its 51 years of existence, ITOPF has attended more than 800 pollution incidents in 100 countries, with many more cases handled remotely. A database of accidental oil spills from 1970 onwards from tankers and other vessels is maintained by ITOPF, constituting a unique source of information regarding incidents of this type. Over the last 51 years, ITOPF has observed a progressive downward trend in the number of oil spills per year from tankers: while the average number of medium and large oil spills in the 1970s (i.e. >7 tonnes) was approximately 79 per year, in the last decade this average has decreased to approximately six spills per year (ITOPF, 2020). In 2019, three such spills were recorded by ITOPF, representing the lowest ever number of spills recorded in a given year. However, these statistics are based solely on tanker spills and therefore represent only a portion of all global pollution incidents.

In 1999, ITOPF expanded its remit to include other types of vessels and consequently started to attend more spills of Cargoes Other Than Oil (COTO) than previously, and recorded data related to these incidents.

In this paper, the term ‘COTO’ encompasses a wide range of products and substances that are transported by sea in bulk (liquid or solid) or packed in containers. This definition includes what the OPRC-HNS Protocol defines as Hazardous Noxious Substances (HNS), as well as non-hazardous products. The term ‘COTO’ was originally created for internal use at ITOPF when it was realised that not all cargoes that ITOPF were responding to were incorporated under the term ‘HNS’. Since the precise definition of a Hazardous and Noxious Substance differs between some convention texts (e.g. OPRC-HNS Protocol 2000 and HNS Convention 2010), for the purpose of clarity, we choose to use the acronym ‘COTO’ to distinguish between oil (crude and bunkers) and every other substance that is transported at sea as cargo. For the sake of simplicity, subsequently in this paper the word ‘oil’ by itself refers to crude oil and/or fuel oil (persistent oil).

ITOPF has attended 393 spills in the 20 years since 2000, 61% of which have involved incidents with non-tankers. Of these 393 spills, ITOPF has attended 57 incidents involving COTO, of which 31 resulted in a spill of COTO (Figure 1). These statistics give a snapshot of the relative frequency of COTO spills.

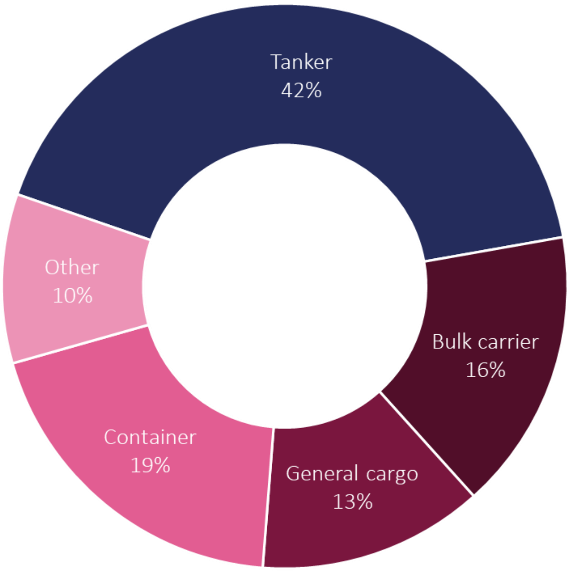

Figure 1*. Graph showing the percentages of different vessel types attended by ITOPF in the last 20 years that resulted in a spill of COTO (*31 incidents).

Whilst historically, large oil tanker spills were the subject of intense public scrutiny and media coverage, in recent years, spills of COTO have increasingly become a cause for concern. Through a combination of increasingly robust legislative measures and advances in ship design and navigation, the maritime community has sought to reduce the frequency of pollution incidents in general, with incidents involving COTO garnering greater focus in recent years.

In the last 20 years, ITOPF has attended 31 incidents, and advised remotely on numerous others, involving spills of different types of COTO (Table 1 and Figure 2). These include, inter alia, solid bulk cargoes (e.g. cement, ore, grain); bulk liquids (e.g. benzene, hydrogen peroxide, sodium cyanide); plastics (e.g. nurdles, polypropylene bags) and vegetable oils (e.g. palm oil/stearin).

Table 1: Number of incidents attended on site by ITOPF in the last 20 years that resulted in a spill of COTO (31 incidents), distributed according to the type of COTO involved.

Type of COTO	Number of incidents
Bulk chemicals	11
Bulk cargo	10
Other (including mixed substances)	6
Plastics	2
Vegetable oils	2

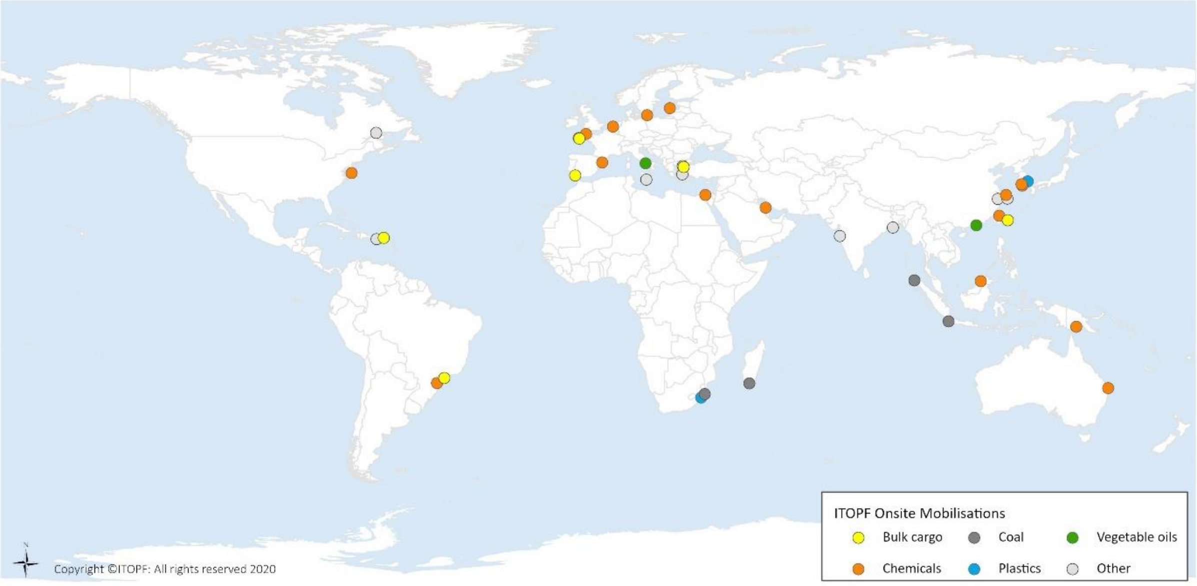

Figure 2. Map showing the geographical spread of all COTO incidents, some not resulting in spills of COTO, attended by ITOPF in the last 20 years (37 incidents).

Once spilled, each of these substances pose their own risks to environmental and economic resources, as well as a set of response challenges that are typically distinct from spills of crude oil or bunkers.

This paper will address the characteristics of some of the most common COTO spilled in the marine environment. Drawing from ITOPF's first-hand experience, issues and challenges related to clean-up, environmental damage, and hazards posed by COTO will be described and discussed.

Containerised cargoes

It has been estimated that on average, 1,582 containers were lost every year between 2008 – 2016 (World Shipping Council, 2017). This figure is likely to be an underrepresentation of the true numbers, given that there is no established system to identify actual container losses throughout global trade, and no overarching framework to prevent container losses at sea. Given the multitude of COTO that can be carried onboard during a containership voyage or even within an individual container, the potential for different types of COTO to be spilt in the marine environment can be high for an incident involving containerships.

In 2018, the global containerised trade was 152 million Twenty-foot Equivalent Unit (TEU) with the major trades' routes being East-West across Asia-Europe and Trans-Pacific routes (UNCTAD, 2019). Asia was by far the region with the largest container port throughput by region in 2018, with approximately 510 million TEU, considerably more than the second largest, Europe, with approximately 125 million TEU port throughput. In the last 20 years, ITOPF has attended 72 incidents involving containerships, comprising 30% of the total number of non-tanker incidents attended. Of these 72 incidents six resulted in a spill of COTO, although this figure may be an underrepresentation. The authors are aware of other incidents involving container ships, particularly involving containers lost at sea and suggest therefore that this statistic reflects only a portion of container losses.

Containers, independent of their contents, can represent a navigational hazard, particularly in areas of high shipping traffic, sometimes resulting in the suspension or modification of marine traffic due to the navigational risks posed. In addition, sunken containers can be difficult to locate, and once found, may require dive surveys to assess damage and appropriate response. These factors have the potential to severely hamper or entirely preclude at-sea response efforts.

In the event of the release of containerised cargoes, the spilled product(s) need not correspond to dangerous goods in order to result in serious human health, environmental and economic impacts. For example, the deterioration of perishable goods inside containers can cause a build-up of gases within the container, such as hydrogen sulphide (H_2S), a highly toxic and flammable gas of particular danger in confined spaces. In such cases there may be human health implications for responders. In some cases, such as the MSC NAPOLI incident in 2007, beached containers can be subject to scavenging by the public, highlighting the importance of access restrictions to reduce potential public health risks.

Similarly, another issue to consider when responding to container ship incidents is that temperature changes and moisture uptake by some cargos can cause structural changes which can put extra weight and pressure on the container. This can in turn compromise the integrity of the container, leading to an increased risk of further releases of cargo. A recent case in a container yard in Ningbo, China (in which ITOPF provided remote advice) involved the spill of mineral oil from structurally damaged containers during handling operations. These containers were loaded with flexi-tanks filled with used mineral oil which during transportation are believed to have expanded, damaging the structural integrity of the containers.

The integrity of any packaging and labelling of products inside a container can also be impacted by unintended physical changes of the products themselves. This can create situations in which labelling can become unreadable adding further complications to the already difficult process of identifying spilt cargo and hence any hazards posed by the cargo. The danger posed by unidentified packages is particularly high for responders or the public encountering spilled products in amenity areas.

Dangerous goods

The transport of dangerous goods is regulated by various codes developed by the International Maritime Organisation (IMO). The International Maritime Dangerous Goods (IMDG) Code concerns the transport of dangerous goods in packaged form. One of the objectives of this code is to unify the identification of goods being transported without opening the container or the packaging. Other international instruments relating to the transport of dangerous goods include the Hazardous and Noxious Substances (HNS) Convention and the International Conventions for the Prevention of Pollution from Ships (MARPOL) Annex 1 and Annex 2.

Of all the COTO spills that ITOPF has attended in the last 20 years, 19% have resulted from container ships. A challenge that may arise in incidents involving packaged chemicals and other dangerous goods is their identification and risk analysis under the inherent time pressure of emergency response. The process could be hindered further if some containers or packages are mis-labelled or given generic or ambiguous product names.

For many dangerous goods spills, initial response usually consists of monitoring and evaluating the risks posed by cargo, prior to undertaking any form of active response. During the salvage operations following the MSC CHITRA incident in 2010, one container that was known to carry approximately 2,800 1.5 kg cannisters of aluminium phosphide was compromised. Aluminium phosphide reacts with water and moisture in the air to produce phosphine gas, which is highly toxic and flammable. Since the contents of that container was known and it was being monitored, work was immediately halted, and air quality monitoring was carried out. This incident demonstrates the importance of labelling and monitoring when dealing with substances which have the potential to present risks to human life. Assuring the safety of those involved in a response operation should always be a foremost concern during all phases of the response.

This incident, like many involving dangerous goods, also involved challenges of waste disposal. In another case, YUSUF CEPNIOGLU, the issues with dealing with dangerous goods waste were significant. This incident, in Greece in 2014, involved a spill of inert products such as clothing material and shoes, in addition to hazardous products such as aerosol cans and packaged solvents. One of the issues of this response, that can typify non-bulk spills, is the oiling of cargo with spilt bunker fuel.

It is important to note that all cargoes become hazardous waste when mixed with bunker fuel. However, the aerosols involved in this incident were classified as a hazardous waste product, independent of the oil. The requirements for disposal meant the treatment for the oiled spray cans was significantly more costly per tonne than the treatment of other oily waste, prompting responders to painstakingly segregate the aerosols from other oiled waste. This case illustrates how costly and time-consuming treating hazardous waste can be, and how the amount of time taken for the waste disposal segregation is important to consider when dealing with multiple streams of hazardous waste.

The incidents described above highlight some of the many issues that can arise from packaged dangerous goods-related incidents. From the difficulties posed in accurately identifying containerised dangerous goods and assessing the hazards to human health and the surrounding environment, to the challenges associated with waste management, response to incidents of this nature are often complex.

Plastics

With an estimated 12.2 million tonnes of plastic waste entering the marine environment, predominantly from land-based sources, each year (Sherrington, 2016), plastic marine pollution has become a major environmental concern in recent years. By virtue of their diverse physical and chemical properties, plastic pollutants behave in a variety of ways, dictating the nature of their impact. For example, many plastics float to the sea surface or remain suspended in the water column, while others will sink to the seabed. As such, the pathways of exposure of environmental and economic resources are often distinct from product to product. Some of the major issues associated with marine plastic pollution arise when plastic is ingested by marine organisms and enter the food chain, or when marine life is entangled or smothered. One study found that all species of turtle are affected by plastic pollution in some form, along with 66% of marine mammal species and 50% of all seabird species (Kühn *et al,* 2015).

In the case of spills of plastics from ships, which is estimated to contribute 0.6 million tonnes per annum (Sherrington, 2016), a swift response can be crucial both to maximise recovery rates and to reduce the exposure of the spilt cargo to the marine environment, hence reducing the likelihood of the product being ingested or causing entanglement and/or smothering.

ITOPF has recently been involved in a case in South Africa concerning a spill of approximately 49.5 MT of plastic nurdles from two lost containers. Nurdles are plastic pellets used as feedstock for the production of plastic products. The nurdles spilt in this incident were approximately 5 mm in diameter. Due to various factors such as inclement weather and strong local currents, the plastic nurdles washed-up on a long stretch of high energy coastline. The nature of the spilt material meant that clean-up operations were time and labour intensive, using manual processes to select, separate, and remove the nurdles mixed with sediment on the beaches. Responders used scoops, sieves, rakes and vacuum cleaners to manually remove the plastic nurdles. The contractor designed and utilised a nurdle recovery machine to separate nurdles from the beach sediment and other mixed debris, which helped surface nurdle retrieval.

In this case, the fact that part of the affected coastline fell within designated protected areas complicated the operation, since special permits needed to be obtained for subsurface nurdle recovery and the deployment of machinery. For example, to be able to dig trenches and pits to search for buried nurdles, a lengthy application processed was required, extending the operations. Given the size and density of the nurdles, they were easily remobilised by successive tides, greatly complicating the coordination between surveying teams and the clean-up teams.

The clean-up of plastic pollution poses unique challenges if compared with the clean-up of oil. One of the challenges is that plastic can typically only be cleaned from shorelines by laborious manual techniques, supported by mechanical means, whereas oiled shorelines can be treated with a variety of in-situ techniques such as surf washing, flushing or pressure washing. Also, since plastic may not be biodegradable, it may be difficult to reach agreements on endpoints for the response with potentially high levels of pre-spill plastic pollution. The law of diminishing returns still applies, as with oil spill response, when agreeing on endpoints.

As an example of the above, the previously mentioned MSC CHITRA involved the stranding and entangling of plastic sheeting in sensitive mangrove habitat. The plastic was not readily biodegradable and so actions were taken to manually remove the oiled plastic from the environment, while attempting to minimise damage to the highly sensitive habitat. Whereas, in other areas of mangrove habitat without heavy oil contamination and with no oiled plastic material, no further clean-up response was undertaken in order to minimise the damage caused to the mangrove habitat, as per international practices. This example highlights how clean-up operations of non-biodegradable products such as plastic may require a higher degree of intervention than oil which is more readily biodegradable substance.

Bulk cargo

Chemicals

Incidents involving spills of chemicals can be very difficult to respond to (Häkkinen & Posti, 2013). Chemicals can be transported in either bulk or packaged form, and while only about 10% of the world's chemicals are transported in bulk, these make up the most volume of chemical marine trade (Purnell, 2009). Chemical spills can be difficult to recover once spilt, depending on their characteristics. Dangerous goods can be roughly split into four categories based on their behaviour in seawater; evaporators, dissolvers, floaters and sinkers, although some products may incorporate more than one of these categories of behaviour. In addition, decisions as to the most appropriate response, if any, need to be taken based on the health and safety of responding to spills of bulk chemicals.

In 2012, ITOPF attended a spill of approximately 104 MT of styrene monomer in the Port of Tarragona, Spain. ITOPF consulted fate and behaviour models using ChemSIS, a chemical spill dispersion model developed by the National Chemical Emergency Centre (NCEC). These predicted that, like many spills of volatile petrochemical products, most of the product (in this case 99%) would evaporate within a few hours. Chemical products, such as styrene in this incident, can undergo different fates depending on environmental variables such as wind velocity, temperature and humidity. For instance, the rate of evaporation of styrene from the sea surface increases with increasing wind speed. A small proportion of styrene can also disperse as droplets of styrene in the water column due to the wave action caused by the higher wind speed. In this case, aided by favourable wind conditions which corralled the pollutant to a collection point, responders were able to pump a significant proportion of the spilled product to shore. Under different ambient conditions, styrene’s propensity to rapidly evaporate and to a lesser extent, disperse and dissolve, would have precluded any form of recovery.

Another example of an incident involving chemicals that ITOPF attended involved 13,000 MT of methyl tert-butyl ether (MTBE) and 1,300 MT of isobutylaldehyde (IBAL) from the chemical tanker STOLT VALOR in 2012. The incident involved an explosion and a fire and, as both chemicals are highly flammable, some of this cargo was expected to have burnt off. ITOPF provided advice on the potential impacts in the event of a spill. MTBE is a volatile and flammable liquid that will float on water. It forms highly flammable vapours that are heavier than air and will therefore sink to the water surface if released at sea. The rate of evaporation, typically relatively high, is dependent on the wind speed and temperature, as with many other chemicals. MTBE is also moderately soluble in water, and the proportion of the product that would dissolve is also dependent on the weather prevailing at the time of the spill. In calm waters, a larger proportion of product would evaporate, whereas in rough seas an increasing proportion of MTBE would disperse into the water column and dissolve. These fates and characteristics are important to note when responding to chemical incidents such as this one, where high concentrations of flammable vapours over slicks can create significant health and safety issues.

While bulk chemicals can vary greatly in their characteristics and behaviour, many chemicals evaporate, dissolve and dilute rapidly when released from the carefully controlled transportation environment during a spill. Once spilt, the rapid fate behaviour of many chemicals can mean that any ecological impacts are usually acute and localised. Another significant concern during bulk chemical spills is the hazards to human health that can arise, which can impact on the response effort.

Vegetable oils

ITOPF have been involved in a number of incidents involving spills of vegetable oils in recent years, including palm oil and palm stearin. All vegetable oils (e.g. sunflower seed oil, soybean oil, palm oil) are included in the HNS Convention 2010, as well as MARPOL Annex II and the International Bulk Chemical Code (IBC Code) classified as a ‘dangerous liquid carried in bulk’.

Generally, all vegetable oils are insoluble in water, are readily biodegradable and bioavailable (mainly via ingestion) and with very low acute toxicity (e.g. Zhou *et al*, 2019). Despite the relatively low toxicity of vegetable oils, smothering effects, which may interrupt normal biological functions such as foraging, respiration or thermo-regulation can pose serious risks to marine wildlife. The physical properties of vegetable oils make the majority prone to float and spread across the surface of seawater once spilt. However, some oils have relatively high melting points (e.g. palm stearin melting point is 40-62°C) and solidify once in contact with the seawater. The degradation of vegetable oil landed on the shoreline following a spill at sea can cause unpleasant rancid odours, impacting the amenity value of the affected area. Response techniques are dictated by the state of the oil, which depends on the properties of the product, as well as the sea and ambient temperature and conditions. At-sea response to solid vegetable oils can include containment using booms and recovery using mechanical grabs, fishing trawl nets and scoops. For liquid vegetable oils, at-sea response can also include containment using booms, and then weir skimmers with appropriate pumps to recover the floating liquid. For vegetable oils that strand on the shoreline, manual removal is usually suitable for solids. Care needs to be taken as some stranded solid vegetable products can re-mobilise and liquify under the heat of the sun, and hence cause further impacts. Liquid vegetable oils can be flushed using low-pressure washers with boom containing any run-off to avoid additional contamination.

In 2017 ITOPF was involved in a spill of 1,016 MT of palm stearin following an incident with the chemical tanker GLOBAL APOLLON. The properties of the product meant that it acted as a floating solid after release into the sea (this specific palm stearin cargo had a melting point of 58°C, well above the temperature of the sea). The product initially formed large clumps which were gradually broken down into progressively smaller pieces. This made the recovery at-sea much more difficult, and enabled wind and wave action to further spread the solid oil over larger areas. Trajectory modelling, based on wind and current data, predicted landing on three nearby islands, which proved to be the case, and allowed some forward planning and activation of local resources to occur relatively swiftly. Within two weeks, 191 MT of palm stearin had reportedly been recovered from the sea and beaches.

A monitoring study investigating the impact of the GLOBAL APOLLON spill found that the ecological risk posed by the incident was relatively transient and short-term (Zhou *et al*, 2019). The study concluded that although marine gastropods exhibited high levels of fatty acids four months after the incident, on the same period of time the concentration of fatty acids in seawater and sediment samples had returned to normal background levels.

The speed at which the spilt vegetable oil changed form once spilt highlights the importance of responding quickly, as they can quickly be broken down in the environment into small pieces reducing the encounter rate (however, increasing biodegradation rates due to the small size particles). The low adherence to surfaces make responding to vegetable oils relatively easy to contain and collect when compared to other COTO, as well as oil.

Dry bulk cargo

It has been estimated that approximately 2.15 million tonnes of dry bulk cargo is likely to enter the oceans as pollution as a consequence of cargo being lost during operations such as loading and unloading, transhipment and washing of cargo holds (Grote *et al*, 2016). ITOPF has attended 79 incidents involving bulk carriers in the last 20 years, of which eight involved a spill of the transported cargoes such as soybeans, dry fertiliser, wheat, maize, coal, and cement.

While most incidents involving bulk cargoes are due to groundings or collisions/allisions, one challenge that is specific to some dry bulk cargoes is the relationship between the cargo itself and the causation of some incidents. This may by the case for cargos such as coal (due to generation of toxic and flammable gases and/or spontaneous combustion), grains (due to cargo shift), and ore (due to liquefaction). In a review by Skuld (2018) P&I Club, seven vessels were recorded as having capsized due to the liquification of nickel-ore cargo in as many years. When ore transported in bulk liquefies (due to high moisture content), it has the potential to cause stability issues, potentially resulting in capsizing and sinking.

Decomposition of spilt products will invariably release unpleasant and potentially toxic fumes, posing risks to human health. In addition, when stranded on the shoreline, spilt food products can attract pests, resulting in further public health and amenity impacts.

An example of the impacts that spilt food products can cause is highlighted in a spill of approximately 3,000 MT of wheat cargo from the vessel FENES in 1996. The wheat covered an area of approximately 2,500 m^2 of seagrass bed habitat. Emissions of hydrogen sulphide and methanol were generated by the wheat degradation, affecting the response effort. Responders had to delay the clean-up operations, as well as ensure appropriate Personal Protective Equipment (PPE) was available, and training was undertaken. Post-spill monitoring was undertaken to investigate the wheat degradation process and bacteriological developments in the polluted area, which noted a serious impact on approximately 3.9 hectares of seabed habitat (Cedre, 2002).

Another bulk foodstuff cargo that ITOPF has dealt with in the last twenty years is rice. This type of grain, if discharged in bulk, while being a relatively benign product, can cause adverse impacts on local marine life by the same reasons described above for wheat. Furthermore, when discharged in large quantities, the rate of degradation is typically relatively slow when compared with other types of grain. Added to that, rice can absorb seawater, becoming buoyant, and consequently be carried to the shoreline, depending on the local currents and waves. As in the case of other grains, exposure to seawater and biodegradation can result in the release of methane and hydrogen sulphide gases, with all the previously mentioned consequences that these gases pose. The ANGEL 1 incident in Mauritius in 2011 involved a spill of rice cargo. The main concerns regarding the spilt product was the increase in biological oxygen demand, and subsequent impacts on marine organisms, as the rice was spilt in a shallow lagoon area. Post spill monitoring surveys were undertaken to assess the fate and impacts of the rice, and no attempts were made to remove the spilt rice.

Coal is one of the most common dry bulk cargo spills attended by ITOPF, having attended on site four coal spills in the last 20 years, comprising 9% of all COTO spills in the last 20 years.

Although a typically inert cargo, incidents involving coal present various challenges to response teams. However, if spilt in natural environments, coal is considered by GESAMP (Group of Experts on the Scientific Aspects of Marine Environmental Protection) to be non-hazardous, non-toxic, and non-irritant with no bioaccumulation potential. Regarding the total volume shipped globally, coal is the second largest bulk commodity shipped, behind iron ore, and represents approximately 25% of the total dry bulk cargo shipped every year (OpenSea, 2016). Indonesia was the largest exporter of coal in 2018, with a world percentage of 44% of the market share, with China being the largest importer of coal with 19% of the market, closely followed by India with 18% (UNCTAD, 2019).

In many cases, the behaviour and to some extent, the impacts of spilt coal depend on the physical characteristics of the cargo, namely the particle size (Sanchez, 2014). Typically, coal particles have a greater specific gravity than seawater, so most spilt cargo is expected to sink, however, coal particles less than 1 mm (the estimated size of ~15% of a given coal cargo, Johnson *et al,* 2006) can remain on the sea surface or suspended in the water column for days and weeks. Therefore, the spatial extent of the impact is very much dependent of particle size of the transported coal as it will dictate how currents and waves will act on its dispersal once spilt. What is initially observed as a dark plume of coal dust can get dispersed in the surrounding waters to the extent that the coal becomes unobservable. A study by Lucas *et al* (2012) found that particles between 1-10 mm often sink in the vicinity of the incident site. Nevertheless, the action of currents and waves can break-up the coal particles, facilitating its transportation. In fact, particles of this size have been known to travel many nautical miles and accumulate in different areas from its origin (García Murcia & Ahrens, 2014).

Particles larger than 10 mm in size usually sink to the sea floor and can potentially smother benthic habitats and associated marine life. Usually the impacts of coal are restricted to physical effects, rather than chemical ones. For example, coal settling on the sea floor can reduce the amount of light that reaches the seabed. This smothering and light reduction impacts can cause reduced primary productivity, reduced access to food, crushed or trapped endobenthic organisms, and affect the settlement and growth of sessile organisms (e.g. Hillaby, 1981; Berry *et al,* 2016, 2017). While plumes of many different substances can cause light attenuation, the effects are usually short-lived and mobile animals are able to move away from the plume, lessening the impacts. The actual impacts of this smothering and light attenuation depend where the coal has settled: smothering of live coral on coral reefs will have much more severe environmental impacts than a bare sea floor in an industrial area, for example. Physical smothering effects were considered a significant problem in all coal incidents attended by ITOPF.

The non-lethal impacts of coal spills on marine life is important to understand when coal spills occur, particularly if they occur near any sensitive habitats such as coral reefs, or near valuable resources such as fisheries. Coal fines suspended in the water column can cause damage by abrasion in the respiratory organs of organisms that inhabit this environment (Ahrens & Morrisey, 2005). Therefore, if spills of coal fines occur close to vulnerable life stages of organisms, such as coral reefs which act as nursery areas for many species of fish, the impact has the potential to be significant. Assessing the number of coal spills ITOPF have attended, coal fines were a considerable problem in 6% of incidents.

In addition to the physical impacts of coal spills, coal does contain traces of Polycyclic Aromatic Hydrocarbons (PAHs), heavy metals and other trace minerals. It is well understood that the combustion of coal causes the release of heavy metals and trace minerals (Sanchez, 2014). However, coal does not undergo the same degree of degradation when spilt into seawater and hence is considered chemically inert because the bioavailability of the compounds within coal is very low in typical open sea conditions (Beckingham & Ghosh, 2017).

As part of the wreck removal operations of SMART, a coal carrier which grounded off Richard’s Bay, South Africa in 2013, coal was recovered from the sea floor around the incident site and relocated to other areas of the bay. In this case, the release of heavy metals from the relocated coal was highlighted as an area of concern, due to the well documented acidifying effect of coal piles, which are known to result in the release of leachates in certain land-based scenarios. As a result, a monitoring programme was implemented to regularly monitor pH levels, thus enabling the assessment of the likelihood of any elements being leached into the environment and the need to undertake more targeted monitoring. In this case, a combination of the coal's physical and chemical properties, its rapid dispersal and the fact that the area in question was an open system with good water exchange, negated any significant changes in pH, precluding the need for further investigation.

In 2018, ITOPF attended a spill of approximately 7,200 MT of coal from the vessel MARINE POWER in Indonesia. In this case, coal was stranded across approximately 3 km of uneven shoreline in a remote location with no road access. With wave action, coal became mixed with sediment and coral rubble with successive tides, increasing the time required to collect the spilt cargo, and its potential to cause environmental impact. In this case, coal became buried rapidly, making it difficult to separate from sediment, which combined with the incident's remote location made for a logistically challenging and protracted response.

Response operations following coal spills typically feature mechanical (such as suction pumps, diggers, scoops) and manual recovery methods. Whilst suction pumps and mechanical grabs are effective methods, neither is particularly selective, resulting in the removal of vast quantities of sediment. Given the remote nature of the area affected by the MARINE POWER spill, waste selectivity was very important, and therefore ITOPF worked alongside contractors to build a system which sorted coral rubble and carbonate sediments from the coal, as well as separating coal by size to segregate the waste and to minimise the amount of waste generated by the response.

Discussion

The multitude of different COTO transported in bulk or in packaged form raise numerous and often unique, response challenges in the event of a spill. As discussed throughout this paper, these challenges arise as a consequence of not only the inherent properties of the spilled product, but also the substance's interaction with the multitude of environmental and socio-economic factors that ultimately determine its impact. Furthermore, the heterogeneity of such substances in comparison with, for instance, heavy fuel oils, complicate effective response planning at an operational level.

Of the various COTO addressed in this paper, once spilt, vegetable oils have a behaviour which is closest to crude or fuel oil. In fact, some spills of vegetable oil can be both detected and dealt with using similar techniques and equipment that is commonly used to tackle crude or bunker spills. Even in the case of palm oil/stearin and other vegetable oils with high melting points, parallels in response methods can be drawn with stable water-in-oil emulsions, or oils with high pour points, although there are important differences in the nature of the impacts caused.

Currently, regarding public perception and media attention, oil spills are still deemed by the media much more newsworthy than spills of COTO. The unpleasantness in terms of aesthetics of oil spills, the smothered fauna, the perceived toxicity of the product and, ever more important, the changing public perception regarding fossils fuels, contribute for the high interest that oil spills generate amongst the public.

An example of this can be found in two cases that occurred in Brazil. At the end of October 2018, large bales of compressed latex sheets, each weighing almost 100 kg, arrived at shorelines in the northeast region of Brazil and were observed in nine states, from Maranhão to Bahia. These bales washed up on shorelines over several months. The origin of these bales is claimed to be a vessel that sank in 1944, located at ~5,700 m depth (Teixeira, 2019). The numbers of these bales are very likely to be several thousand. Although the appearance of these bales was covered by the local media, not much attention was given to it, and apart from the sporadic removal of some bales, there was not a concerted clean-up effort. It was observed by ITOPF that one year after the occurrence of the first landings, the sheets which form the bales are now becoming separated and fragmented into ever smaller pieces, and consequently spreading over a much larger area. Given the non-biodegradable character of latex, these bales are, and until removed will continue to be, a source of a very persistent form of pollution that has the same characteristics of plastic pollution.

In another incident in Brazil, towards the end of August 2019, oil originating from a spill of unknown origin, started to appear on the shoreline in the State of Paraíba (northeast region of Brazil). By December (2019) the mystery oil had spread to 11 states (between Maranhão and Rio de Janeiro), affecting an area of approximately 3,500 km. This incident was attended by ITOPF. This event generated very intense media coverage and the Brazilian national contingency plan was activated. A significant effort was made by the authorities in terms of clean-up, and large numbers of volunteers helped on the clean-up efforts, which were carried out up to a very high standard.

Although the environmental impact caused by latex would be quite different from that resulting from the oil spill, these two cases serve to highlight the current differences in perspective and approaches for spills of oil and spills of COTO.

This picture is rapidly changing; recent campaigns against plastic litter in the oceans, and a worldwide ever-increasing awareness and focus on the anthropogenic footprint on the natural environment, mean that attention and concern regarding the impacts of spills of COTO might also increase with this trend. In fact, a comparison between the percentual number of worldwide searches done on Google since 2004 for the terms “oil pollution” and “plastic pollution” shows a decreasing trend for “oil pollution”, in contrast with the increasing trend for “plastic pollution” (Figure 3). It should be noted that while the number of incidents involving oil spills from vessels is decreasing, oil spills are typically sporadic and accidental, whereas plastic pollution is a chronic problem of increasing waste issues worldwide. These differences could contribute to the relative fluctuations in these search terms.

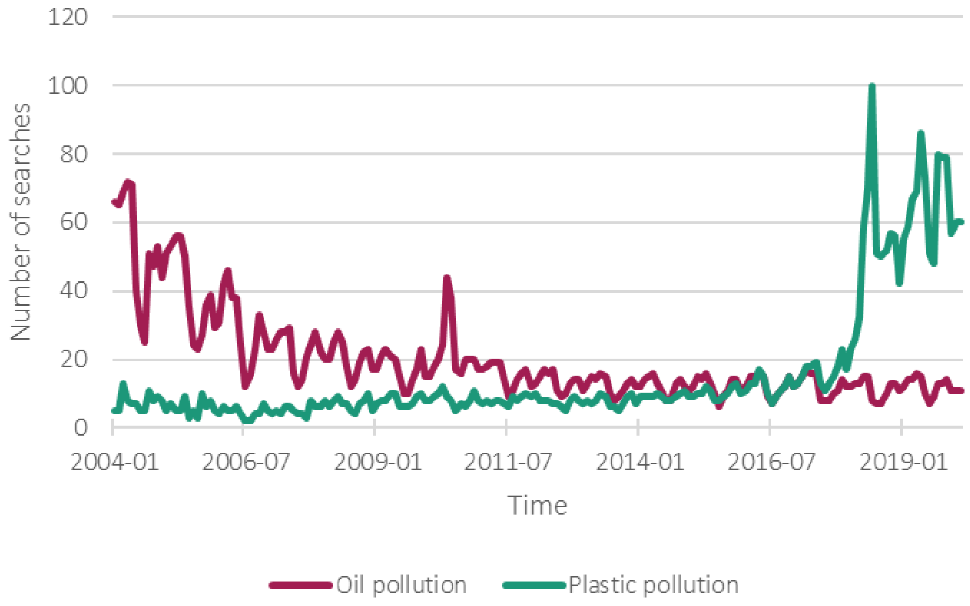

Figure 3. Trend comparison between Google online searches using of the terms "oil pollution" and "plastic pollution" from January 2004 to January 2019. Data source: Google Trends.

Amongst this changing background of awareness and perception, there is continuous work by the IMO and other governing bodies to regulate COTO. Some of the regulatory regimes governing COTO have been mentioned in this paper. The various conventions, codes and protocols relating to COTO not only categorise COTO differently but have differing definitions for what are HNS, depending on the objectives of the regulations. Some regulations govern the safe transport of cargo by vessels and hence define substances as HNS if they require restrictions and protocols to increase the safety and decrease the risks associated with transporting these substances, such as the IMDG and IBC Codes. However, if the regulations aim to provide procedures for compensation relating to any damage caused by COTO, these regulations may categorise substances based on their impacts on the environment and socio-economic resources, such as in the HNS Convention 2010.

The two conventions relating to safety of merchant ships at sea and pollution prevention are SOLAS 74 and MARPOL 73/78, respectively. These conventions refer to various codes, all of which correlate to the transport of cargoes. In addition, two protocols, the 2000 OPRC-HNS Protocol and the HNS Convention 2010 (not yet ratified) relate to contingency planning, and compensation and liability, respectively and deviate widely on the definition of HNS. Therefore, different COTO are included under some regimes and excluded from others. For instance, plastic is included under the 2000 OPRC-HNS Protocol but excluded from the HNS Convention 2010 except in very specific explosive and flammable forms. The differing definitions, inclusions, and exclusions of COTO between various regulations can create issues when responding to spills of COTO.

One such issue raised in this paper is the time-intensive task of identifying the specific COTO spilled and the appliable regulations to guide the response effort under the inherent time pressure of an emergency response. The specific descriptive number associated with the substance, such as the UN Number or CAS registry number, needs to be identified quickly, and the relevant risks and appropriate responses identified using the applicable code, for example. For a spill involving one COTO, identifying the applicable risks and responses can be labour-intensive, and for spills involving more than one COTO, this is amplified. When responding to spills of COTO, it is imperative for responders to be informed of the relevant regulations to ensure a safe and appropriate response, such as identifying the shipboard pollution incident emergency plan, required for specific COTO under the 2000 OPRC-HNS Protocol.

Spills of COTO have occurred at much lower frequency then spills of oil over the period assessed for this paper. As a result, the systems and processes currently in place regarding COTO spills are relatively untested. This can be of particular concern in regions that have not experienced a spill of COTO recently, if at all, especially if new protocols have been incorporated since the last COTO incident. As with oil spill response, thorough preparedness through relevant contingency plans and exercise drills can increase the readiness of any country for a spill of COTO.

International regulations, such as included in the 2000 OPRC-HNS Protocol which governs contingency planning, are in place to guide national planning concerning preparedness. However, while the existing regimes govern safety and antipollution measures relating to transportation and compensation protocols, amongst others, the regulations lack robust and practically applicable protocols for operational responses to COTO spills. While information can be gathered on whether a COTO is considered an HNS, how it might react when spilled, and what safety precautions to take for responders, there is currently a lack of comprehensive references for practical operational methods aimed at COTO spills.

Conclusion and future outlook

Presently, there is a marked increase in public awareness and interest towards environmental issues worldwide. This trend suggests that in the future, spills of COTO will receive increasing attention from the media and public.

In recognition of growing concerns of the risks posed by spills of COTO (particularly spills of HNS), many national authorities have sought to integrate provisions within their response frameworks to mitigate the risks posed by such incidents. For the most part, from an organisational perspective, the differences between responding to a crude/bunker spill and a spill of COTO are generally not extreme. As highlighted throughout this paper, the significant challenge lies at an operational level, since (with the exception of vegetable oil spills) spills of COTO seldom share similar characteristics with crude or bunker spills. As such, even for the more common substances, the methodologies and equipment required to tackle spills of COTO are yet to be fully established.

We are at a stage in which better preparedness regarding spills of COTO is urgently required at an international level. With this purpose, the development of a culture of cooperation focused on spills of COTO (similar to what exists among several oil related organisations, e.g. IPIECA, CEDRE, NOAA, ITOPF), to facilitate the sharing of experiences and lessons learnt regarding spills of COTO is required and efforts in this direction should be fomented.

Despite the differences in approach regarding the response to spills of COTO and oil, one thing is common to all spills: preparedness and speed of action in response is paramount.

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