

Oil Pollution in Spanish Waters



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Abstract Spain has one of the largest coastlines in Europe (ca. 8,000 km) which constitutes an important source of economic revenue (e.g. fisheries, tourism, etc.). This chapter firstly discusses the ecological and socio-economic importance of Spanish waters and shores, to show the potential impact that an oil spill may have on the provision of goods and services from these areas. This is followed by an overview of the major sources of oil pollution, from maritime accidents and operational discharges, and the description of the Spanish oil pollution prevention, preparedness and response system, which has been supported by an ambitious investment plan after the *Prestige* incident. Finally, the importance of an efficient coordination between the surveillance and source identification services of oil spills is illustrated with several case studies.

Keywords Aerial surveillance, Marine oil spills, Oil fingerprinting, Oil pollution, Operational forecasting, Preparedness and response, Spanish waters

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1 Introduction

Spain, located in southwestern Europe and surrounded by the Atlantic Ocean and the Mediterranean Sea, has one of the largest coastlines in Europe (ca. 8,000 km) which are the source of important economic revenue (e.g. fisheries, tourism, etc.). In addition to the mainland territory, two archipelagos, the Balearic and Canary Islands, enlarge the Spanish territorial waters and increase the area of marine surveillance to nearly 1.5 million of km², three times the size of the national territory (Fig. 1). This very large area is highly exposed to the impact of maritime

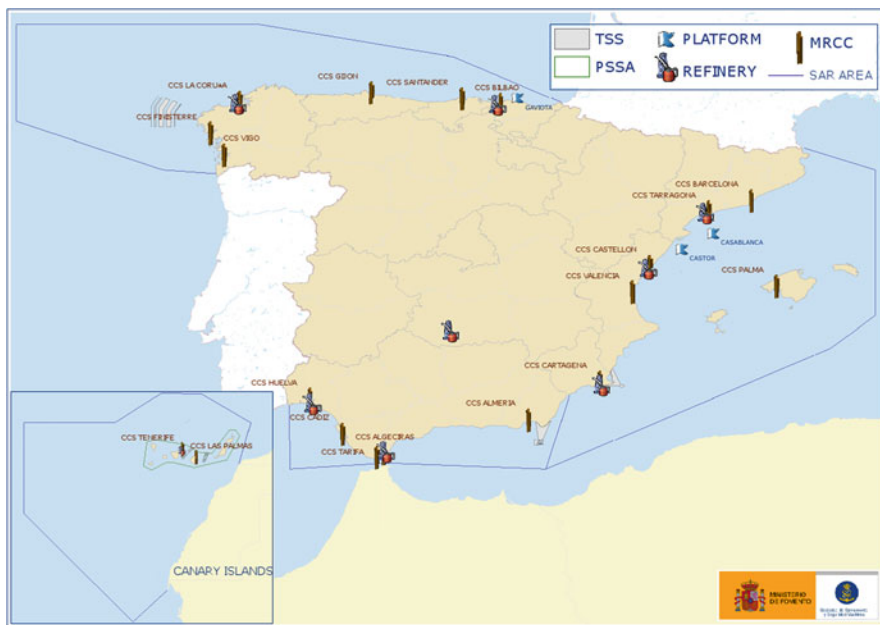


Fig. 1 Area for SAR responsibility (1.5 million of km²)

activities, mainly ship transport, which can be the source of accidents and operational discharges resulting in spills of oil and hazardous substances.

Being aware of its high risk of marine pollution and having experienced one of the largest oil spills in this century (the *Prestige* oil spill), Spain has worked to implement the international conventions and the European legislation and recommendations. Moreover, it has established a national solid system for preparedness and response to marine pollution [1]. Setting up the necessary policies and resources, ensuring coordination and cooperation at a national and international level and being at the forefront of technology have been the basis of this system. The system has been strengthened through bilateral and regional agreements with neighbouring countries.

Since 1989, specific action investment plans, covering the strategies in rescue and pollution issues, were established every 4 years by the state administration. The IV Plan (2002–2005) had to be reviewed due to the *Prestige* incident and an extra funding was approved. But the major investment effort was made under the V Plan (2006–2009), which allowed to substantially increase the human and material resources and to take a leading position in Europe. After the fifth plan, the most ambitious and comprehensive, an 8-year investment plan (2010–2018) was established. Today, this National Rescue and Pollution Response (NRPR) Investment Plan is in place and aims to ensure an efficient use of the owned resources.

This chapter will firstly discuss the ecological and socio-economic importance of Spanish waters and shores, to realise the potential impact that an oil spill may have. This is followed by an overview of the major sources of oil pollution, both intentional and accidental, and the description of the Spanish oil pollution prevention, preparedness and response system, which is reinforced by an efficient coordination between the monitoring and source identification of oil spills.

2 Ecological and Socio-economic Importance of Spanish Waters and Shores

Due to its geographical location, with around 8,000 km of coastline, the Spanish marine and maritime sectors play a very important role in delivering ecosystem goods and services [2], but they can be affected by external pressures, like urban development and maritime transport, being Galicia (1,720 km), Balearic Islands (1,342 km) and Canary Islands (1,545 km) the most exposed coastal zones [3].

The Spanish coast, both on the Mediterranean and Atlantic sides, is considered a strategic area given the many zones of great ecological, cultural, social and economic value. From the socio-economic perspective – both for tourism and traditional activities such as fishing and aquaculture – Spain's coastal zones are very valuable and their great diversity must be taken into account [4].

The most important coastal ecosystems of the Spanish coast include the following: seabeds (both rock and sandy); cliffs; beaches, sandbanks and dunes, and

coastal wetlands, including inlets, estuaries, deltas, marshlands and coastal lagoons, fens, coastal lakes and salt flats. These different and special ecosystems are of great importance due to their landscape, socio-economic and educational values. In mainland, the abrupt relief, peripheral characteristics and high average elevation combine to produce an abundance of cliffs in several coastal regions (a total of 4,021 km of cliffs), although there are also 2,000 km of beaches. The rest of the coast is low-lying (1,271 km) or has been transformed as a result of artificial works (600 km).

This extremely varied range of ecosystems is further reinforced by the marked differences between Spain's Mediterranean and Atlantic coastlines. The Mediterranean zone has an abundance of beaches. The semi-enclosed Mediterranean Sea exerts a major influence on the characteristics of the zone, and accumulation processes are often seen in river mouths that lead to the formation of the giant Ebro Delta. On the Mediterranean side, unlike the Atlantic, there are no significant tides and no large areas of low-lying coast flooded by tides. The most ecologically valuable parts of this coast are the coastal wetlands, the dunes, the rocky mountains that produce the cliffs, the small islands and islets and some areas of seabed, notably the fields of *Posidonia oceanica* seagrass.

Extensive cliff systems are common on the Atlantic coast. Here the sea dynamics is more pronounced and the tidal range is considerably greater, as is wave intensity (the tidal range is 10–50 times greater on the Atlantic coast compared to the Mediterranean). The Galicia coast is extremely rugged with many water entries and exits (rías) of high ecological importance. For its part, the Cantabrian coast is long and straight, with steep slopes running into the sea, an abundance of cliffs, few beaches and small 'rías'. Beaches and dune formations are common in the southern part. The dunes can occasionally be very tall or in some cases form mobile coverings which are displaced by the wind. Another notable characteristic of this part of the coast is the extensive wetlands, among them the impressive Doñana National Park, which contains a vast array of animal life.

The Canarias archipelago comprises seven main islands and some smaller islets of volcanic origin. The relief of most of the islands is extremely abrupt, with a northern coast formed by tall cliffs and a more open and sandy southern coast where most of the beaches are located. Compared to their overall size, the Balearic Islands have a large coastline, which is rugged in nature, with beaches in small inlets, as well as abrupt coastline, beaches and lagoons. The archipelago boasts a wide range of environments of ecological importance.

Natural conditions drive the distribution of the activities along the coast: tourism, industries, fisheries and agriculture can be seen as the main activities, with fisheries and industrial activities mostly concentrated in the north coast and tourism and agriculture in the Mediterranean and the Islands.

It is important to note that over the last 50 years, the Spanish coast has undergone extensive transformation and has become a strategic element of the country's economy. The importance of sun and sand tourism and of the energy sector – for which oil and gas are supplied by sea – and the ever-increasing role of sea trade are key economic factors behind this transformation. Most coastal zones in Spain have

gradually adapted to these new economic roles, and traditional activities such as fishing and agriculture have been relegated to a place of secondary importance.

However, the intensive use of coastal areas has triggered a series of environmental, social and economic imbalances which need to be taken into account in keeping with the principles of sustainability.

One of the most visible aspects of the transformation undergone by the Spanish coast is the occupation of coastal areas by urban development. The occupation rate varies from region to region but has been high over the last 40 years. The zones most affected are without doubt the ones that have experienced the most rapid growth in tourism. Tourism in Spain has evolved from being a residual sector in the economy during the 1950s to become at present the main source of wealth in the country [5, 6]. Around 10% of the gross domestic product (GDP) of Spain is directly or indirectly linked to beaches, which are one of its most marketed products. The two archipelagos and the Mediterranean coast account together for 75% of the country's regulated accommodation and receive 85% of all foreign tourists as well as 60% of domestic tourists in Spain.

A second important factor causing imbalance is the increasing alteration of coastal dynamics due to the high amount of human intervention on the coastline. Yachting marinas are a good example of the proliferation of such structures along the Spanish coast, which can also be a source of marine pollution. Reduction in the quality of coastal water bodies may have serious repercussions on the vitality of marine ecosystems.

Besides these particular activities and uses of the coastal areas that can be affected by an oil spill, the open waters are also associated with different socio-economic activities, notably fishing and maritime transport, which should also be taken into account in the context of marine oil pollution because they can be severely impaired (fishing) or be a potential source of the problem (maritime transport).

As has been mentioned, Spain is an essentially maritime country, with a long, narrow continental shelf rich in fisheries resources. The bulk of the Spanish fleet (around 9,700 vessels) fishes in four fishing zones: the Cantabrian Sea (north-west), Gulf of Cadiz, the Canary Islands and the Mediterranean. Fisheries are often critical to particular coastal regions. This is notably the case in Galicia, in which most of Spain's fishing activity is concentrated. Specifically, over 50% of the Spanish catch is landed in this region. This makes it the most important fishing region in Spain and in the European Union as a whole and the most dependent on this activity [7].

However, Spain is Europe's second biggest consumer of fish products (40.5 kilos per person/year, behind Portugal's 59.8 kilos), and it became clear over the years that production in national fishing grounds was insufficient and fisheries have therefore been developed beyond Spain's territorial waters. To meet the demand not covered by traditional fishing, marine aquaculture has been constantly growing in recent years. In Spain, aquaculture is geared essentially to the cultivation of bivalve molluscs, especially mussels, and – to a lesser extent – fish farming. The Galicia coast is one of the first producers worldwide, with more than 200,000 tons/year.

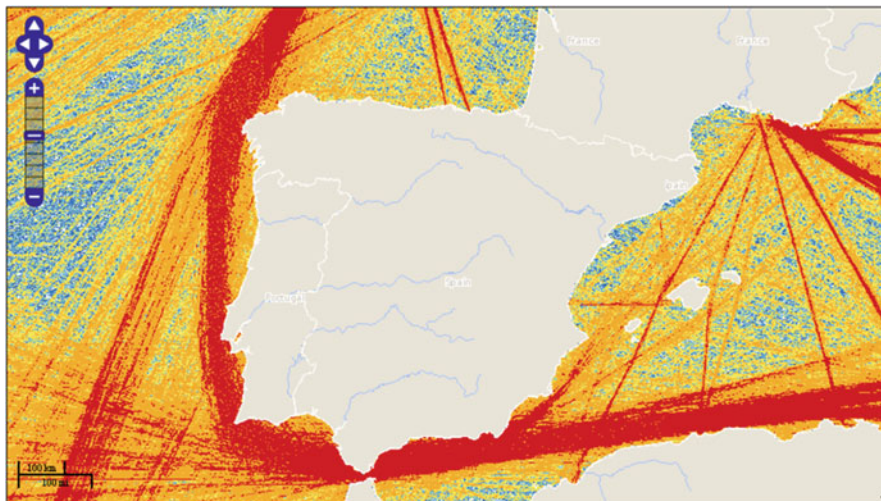


Fig. 2 Density of commercial shipping around the Spanish coasts (<http://globalmarine.nceas.ucsb.edu/>)

On the other hand, maritime transport is of major importance today due largely to the more open economies now present in developed countries. Much of the European Union's foreign trade is conducted by sea. In the specific case of Spain, maritime transport accounts for 53% of Spanish foreign trade. Spain can therefore be considered a strategic area for international shipping and a logistics platform in southern Europe. Due to its geographical location, it holds a high sea traffic density (Fig. 2).

At present, the network of primary ports in Spain is state-run and is managed by a public body which coordinates and regulates the system and has considerable operational autonomy. For their part, ports not belonging to the 'general interest' category (commercial and fishing ports, marinas) are the responsibility of the regions.

All issues described above are implied, as actors or receptors, of the environmental and socio-economic impact of an intentional or accidental oil spill. Establishing connections between ecosystem characteristics and human's benefit can lead to develop a much more proactive approach in the integrated management of the coastal zones (IMCZ) and the design of an adequate response in the case of incidental events. In this respect, the assessment of the ecological and economic oil spill impacts for a set of management options has been investigated, and several models have been proposed as a result of the *Prestige* accident [8].

The ecosystem service concept can be also useful at that point because it emphasises the real notion of both protecting nature and benefiting man at the same time [9]. Understanding of provision of ecosystem services (quantification), understanding of the benefits to human well-being from ecosystem services (valuation), and creating incentives for the sustainable provision of such ecosystem services (policies, good governance, alliances, etc.) should be recognised as a

precondition for a sustainable future of our seas and coasts. In this way, innovative schemes for linking public and private efforts to protect ecosystems by ensuring the provision of ecosystem services need to be raised because whoever benefits from those services should have a responsibility in its proper care [2].

3 Major Sources of Oil Pollution

Considering the data of the last 10 years, an average of 374 pollution incidents are managed every year by the Spanish Maritime Safety and Rescue Agency (SASEMAR), approximately one per day (Fig. 3).

Figure 4 shows the distribution of these emergencies according to the geographical area (a) and to the different pollution sources (b). The number of pollution emergencies is decreasing since 2013 considering the average of the second subperiod, established from 2009 when the surveillance system was consolidated. Places with higher maritime traffic density, with greater port activity and with a larger number of installations, have more pollution incidents. Although the source is unknown in 77.5% of the cases, vessel polluting represents a 17.5%, installations from land a 3.5% and rigs just a 0.5%.

3.1 Maritime Transport

Maritime transport is driven by the increasing flows of energy products and containers. In this respect, shipping activity is characterised by a significant volume of traffic which only transits around the Spanish coasts, without entering any port (Fig. 2).

The Maritime Rescue Coordination Centres (MRCCs) (SASEMAR) in Spain provide the vessel traffic service (VTS). They are equipped with state-of-the-art monitoring systems and communication technologies to give VTS in the Traffic Separation Schemes and in the Particularly Sensitive Areas in which vessel reporting is mandatory.

Fig. 3 Number of pollution emergencies managed by SASEMAR



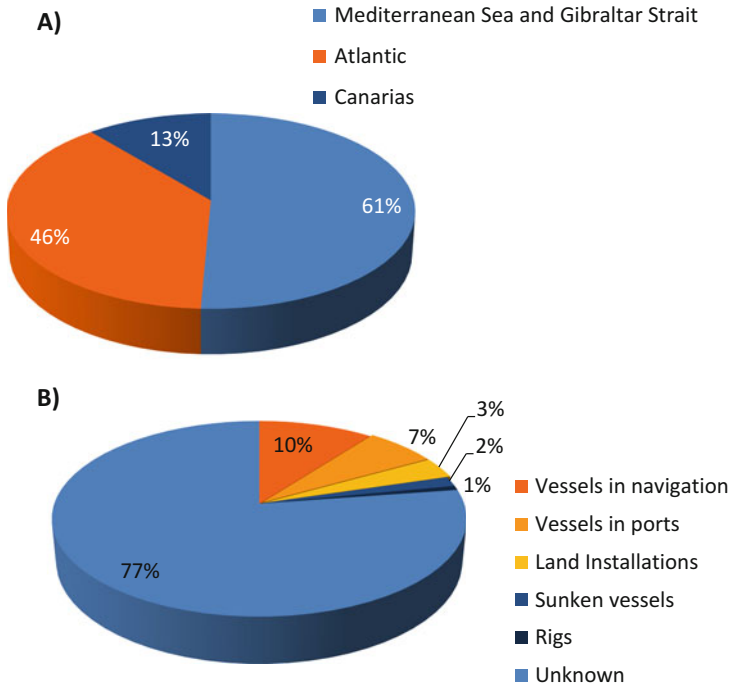


Fig. 4 Distribution of pollution emergencies managed by the Spanish Maritime Safety Agency. Average data in a 10-year period time (2006–2015), according to the geographical area (a) and to the different pollution sources (b)

Spain has eight IMO-adopted Traffic Separation Schemes (TSS): four in the Atlantic Ocean and four in the Mediterranean Sea. Off Finisterre, Banco del Hoyo and two in Canary Islands (Eastern TSS between Grand Canary and Fuerteventura and Western TSS between Grand Canary and Tenerife) are located in the Atlantic. In the Strait of Gibraltar, Off Cabo de Gata, Off Cabo de la Nao and Off Cabo de Palos are located in the Mediterranean Sea. In Finisterre and Strait of Gibraltar TSS, mandatory reporting systems are in place, while in Cabo de Gata reporting is voluntary. The Traffic Separation Schemes are equipped with monitoring systems to detect and track vessels (VTS radar, radio direction-finding systems, Automatic Identification System (AIS)) and communication technologies between MRCCs and vessels (digital selective calling system LLSd and VHF and MF/HF radio).

Spain has two Particularly Sensitive Sea Areas recognised by IMO: the Western European Waters, shared with UK, France and Belgium, and the Canary Islands. Ship reporting is mandatory in these areas through WETREP report in Western Europe and CANREP report in Canary Islands.

According to the traffic controlled in the two most important established TSS, around 106,000 of vessels are passing every year through and crossing the Strait of Gibraltar, and approximately 39,000 of ships are going through Galicia’s maritime motorway (Table 1).

Table 1 Maritime traffic through the Traffic Separation Schemes (TSS)

TSS	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Off Finisterre	41,942	42,067	42,508	40,331	40,530	38,946	36,532	35,687	35,979	35,749
Gibraltar Strait	96,188	84,691	106,497	104,596	112,943	116,691	109,395	106,366	108,354	111,092

Table 2 Results of the aerial and satellite surveillance of Spanish waters [10]

	Aerial surveillance		Satellite surveillance	
	Detections/100 flight hours	Red-handed/100 flight hours	Detections/10 satellite images	Red-handed/10 satellite images
2010	13.2	2.1	–	–
2011	8.0	1.8	–	–
2012	4.6	0.95	2.7	0.00
2013	3.8	1.2	3.1	0.04
2014	2.1	0.5	2.3	0.05

Maritime traffic can cause oil pollution either coming from accidents or operational discharges. The most common source of oil pollution from maritime traffic is that generated as a result of vessel's operations. Some of the operational discharges are accidental, due, for example, to fuel transfer; and some are deliberate. Through overflight and satellite surveillance, Spain controls ship's compliance with MARPOL's pollution prevention standards (Table 2). Vessel discharges from tank cleaning have been detected failing to meet MARPOL requirements, because they were above the water line or near the coast. Discharges of sewage from passenger ships were found to have oil through samples taken in the water. But the most frequent illegal discharges are coming from bilge waters, oil-bearing residues produced in all types of vessels, to be retained on board, separated from fuel and discharged into reception facilities on land for treatment and disposal. Furthermore, the Mediterranean Sea is defined by MARPOL as a special area due to its oceanographic and ecological conditions, and all operational pollution is illegal. But still a lot of spills are detected there as shown in Fig. 4a.

In addition to operational pollution, accidental pollution may occur from time to time due to structural damages, collisions or explosions, which may conclude with the grounding or sinking of the vessel. The figures show that 15 major marine oil spills have occurred during the last 50 years in Spanish waters (Table 3). The geographic distribution of these accidental spills shows that the north-west coast has been the most affected, where the heavy traffic with adverse meteorological conditions concurs (Fig. 5). Of particular importance was the *Prestige* oil spill, in 2002, which extended the pollution over 800 km of the Atlantic coastline [11]. Fortunately, these oil spills have been significantly reduced both in number and released quantity during the last decades, due to the improvement in pollution prevention measures adopted by public authorities and the tanker industry.

3.2 Port Facilities, Oil Terminals and Oil Refineries

In 2014, the traffic of merchant ships in the Spanish harbours was of more than 100,000 units [13]. Due to the high shipping density and the navigation risks, ports need traffic monitoring systems. Three Traffic Separation Schemes have been

Table 3 Marine oil spills in Spanish waters

Major marine oil spills (1965–1999) ^a					
Name	Date	Location	Cause of spill	Quantity of oil spilled	
<i>Bonifaz</i>	July 3, 1964	9 miles W off Cape Finisterre, Galicia	Collision	500 tonnes of bunker fuel	
<i>Spyros Lemnos</i>	November 1, 1968	Cape Finisterre, Galicia	Structural damage	15,000 tonnes of Venezuelan heavy crude oil	
<i>Polycommander</i>	May 5, 1970	Vigo Bay, Galicia	Grounding	15,000 tonnes of Arabian light crude oil	
<i>Golar Patricia</i>	November 5, 1973	130 miles N off Canary Islands	Explosion	10,000 tonnes of bunker oil	
<i>Splendid Breeze</i>	December 6, 1973	Between the Canary Islands and Madeira	Structural damage	2,000 tonnes of bunker fuel	
<i>Urquiola</i>	May 12, 1976	Entrance to La Coruña harbour	Grounding	101,000 tonnes of Kuwait crude oil	
<i>Andros Patria</i>	December 31, 1978	Off the coast of La Coruña	Explosion	60,000 tonnes of Iranian heavy crude oil	
<i>Turgut Reis</i>	December 15, 1979	170 km N off La Coruña	Structural damage	220 tonnes of diesel oil	
<i>Khark 5</i>	December 19, 1989	400 miles N off Las Palmas (Canary Islands)	Explosion	70,000 tonnes of Iranian heavy crude oil	
<i>Sea Spirit</i>	August 6, 1990	14 miles off Tarifa, Andalucia	Structural damage	9,860 tonnes of heavy fuel oil	
<i>Aegean Sea</i>	December 3, 1992	La Coruña, Galicia	Grounding	67,000 tonnes of light crude oil	
Marine oil spills (2000–2015) ^b					
Name	Date	Location	Cause of spill	Oil on board or spilled	Oil removal from wreck
<i>Prestige</i> (oil tanker)	November 13, 2002	Off Cape Finisterre, Galicia	Structural damage	77,000 tonnes of M-100	X
<i>Spabunker</i> (barge)	January 21, 2003	Algeciras Port, Andalucia	Weather conditions	1030 tonnes of IFO 180 100 tonnes of MDO 100 tonnes of MGO	X
<i>Sierra Nava</i> (refrigerator ship)	January 28, 2007	Algeciras Port anchorage	Grounding	350 tonnes of IFO 380	

(continued)

Table 3 (continued)

Marine oil spills (2000–2015) ^b					
Name	Date	Location	Cause of spill	Oil on board or spilled	Oil removal from wreck
<i>Don Pedro</i> (ro-ro)	July 11, 2007	1 mile off Ibiza's Port	Collision with submerged rock	150 tonnes of IFO 180 60 tonnes of DO	X
<i>New Flame</i> (bulk carrier)	August 12, 2007	0.7 miles S off Punta Europa	Collision	700 tonnes of IFO 380	
<i>Savinosa</i> (barge)	September 9, 2008	Tarragona Port	Grounding	750 tonnes of FO 260 tonnes of GO	
<i>Fedra</i> (general cargo)	October 10, 2008	0.5 miles E off Punta Europa	Grounding	370 tonnes of IFO 380 60 tonnes of DO	
<i>Tawe</i> (bulk carrier)	October 11, 2008	Algeciras Port anchorage	Grounding	150 tonnes of IFO 180 60 tonnes of MGO	
<i>Casablanca Platform</i>	December 22, 2010	Casablanca Platform Tarragona	Operational spill	8,000 litres of crude oil spilled	
<i>Nexo Maersk</i> (container carrier)	May 22, 2013	38 miles ENE off Valencia Port	Operational spill	200 litres of HFO spilled	
<i>Woodford</i> (product tanker)	September 1, 1937 (sank) September 3, 2009 (pollution)	35 miles NE off Castellón	Spanish Civil War	450 m ³ HFO	X(2012)
<i>Oleg Naydenov</i> (fishing vessel)	April 14, 2015	16 miles SW off Punta Maspalomas (Gran Canaria)	Fire on board	1,400 tonnes IFO 380 70 tonnes of lube oil	X
<i>Nele Maersk</i> (container carrier)	September 7, 2015	70 miles SE off Barcelona	Operational spill	35 tonnes of IFO 380 spilled	

^aCEDRE [12]^bSASEMAR



Fig. 5 Major oil spills in Spanish waters

established by the Spanish government in ports: these are the approaches to Vigo, Castellon and Barcelona ports.

Taking into account the pollution incident records from the Spanish Maritime Safety Agency in the last 5 years, an average of 28% of the pollution incidents have taken place in ports. A large number of incidents resulting in small discharges of oil products in the inner waters of the harbours are registered every year. The usual causes are cargo-handling operations, bunkering, oil transfers on board and cleaning operations on the deck. Normally, spills are easily contained with the available response systems provided by the shipowner or by the port, but sometimes oil spills spread on the port area with a great impact on the public opinion.

On the other hand, eight harbours are the major load and discharge centres for oil products, which hold the oil terminals of coastal refineries (Fig. 1). In 2014, 11,494 laden oil tanker movements carrying 110 million tons of oil products were recorded in all Spanish ports. In this case, spills are usually due to operational accidents during the charge and discharge of the oil products.

Moreover, almost all oil refineries are located in coastal areas and their effluents are directly discharged to sea. However, these effluents are conveniently treated in

wastewater treatment plants and discharged following strict environmental regulations, so that oil spills have been recorded very rarely.

Finally, there are three offshore rigs: Casablanca, in Tarragona, where crude oil is obtained, Gaviota in Vizcaya and Castor in Castellón, where gas is stored. Additionally, there is an underwater installation Poseidón, in the Gulf of Cádiz, where gas is obtained. In Spanish waters, an average of 1 pollution incident per year comes from rigs, taking into account data from the last 10 years (2006–2015).

3.3 *Land-Based Sources*

Urban and river discharges are the main land-based sources of oil pollution in coastal zones. All Spanish coastal urban areas are served by wastewater treatment plants whose final effluents are directly discharged to the marine environment, usually through submarine outfalls. These effluents may contain oily wastes and lubricant oils from domestic spills, commercial and industrial activities and urban runoff. Urban runoff may also incorporate wet and dry atmospheric deposition. Storm waters will eventually reach rivers or coastal wastewater treatment plants (WWTPs) or will be directly discharged through the sewage system in coastal cities, which may increase the levels of hydrocarbons in the coastal environment and nearshore sediments, although no visible slicks are observed. In the Mediterranean coast, the major loads of hydrocarbons can take place in short periods, e.g. during flood events, due to a wash-out effect of pollutants originating from vehicular emissions accumulated during the dry summer season [14].

On the other hand, river water incorporates pollutants from non-coastal land-based runoff, and municipal and industrial effluents. As rivers represent a transport pathway for hydrocarbons to the marine environment, hydrocarbon loads are tightly linked to the water cycle and dominant uses of drainage basins. The hydrography of Spanish rivers is typically characterised by great irregularity, with marked reductions in river flow during summer and occasional flooding.

The attempts to estimate the oil inputs to the sea from land-based sources have frequently used data of per capita releases of hydrocarbons in municipal wastewater or urban runoff. Some recent studies on coastal municipal WWTP in the Mediterranean provide additional data to refine the above estimations [15].

A comprehensive assessment of the oil pollution in the Mediterranean basin has recently been published [16]. An overview of the main oil marine pollution sources and estimations of their inputs, including offshore oil production, port facilities, shipping, refineries and land-based activities (e.g. urban runoff), as well as the levels and trends of hydrocarbons in the different marine compartments and their biological effects, is presented.

4 Oil Pollution Prevention, Preparedness and Response

4.1 Organisation

Marine pollution prevention, preparedness and response in Spain are responsibility of different authorities, some national and others belonging to the nine coastal autonomous communities.

At a national level, the Maritime Authority plays the most important role. The General Directorate of the Merchant Marine (DGMM), part of the Ministry of Public Works and Transport, is responsible for the management of the maritime navigation and the civil fleet, as established in the consolidated text of the Spanish Law for State Ports and the Merchant Marine, approved by Royal Decree 2/2011 of September 5 [17]. Among its duties, the Maritime Authority must prevent marine pollution coming from ships, platforms and other installations in waters where Spain has sovereignty, sovereign rights or jurisdiction and must protect the marine environment.

Attached to the Maritime Authority stands the Spanish Maritime Safety Agency (SASEMAR). It is a national body that operates under the Maritime Authority and provides the services of search and rescue, maritime traffic control and pollution prevention and response. This public agency, created in 1993, has its own resources and is fully empowered to act in order to meet its tasks. Together, the Maritime Authority and SASEMAR need to establish the regulations and procedures to respond to pollution at sea.

In addition, other state directorates take part in the marine pollution prevention, preparedness and response mechanism. The Directorate General for the Sustainability of the Coast and the Sea, being part of the Ministry of Agriculture, Food and Environment, is responsible for the protection of the marine and coastal environment, ensuring its public and unrestricted use. And the Directorate General for Energy Policy and Mines, part of the Ministry of Industry, Energy and Tourism, is responsible for licencing the offshore oil and gas industry.

The coastal autonomous communities, according to their own statutes, are responsible for pollution prevention and response in their coastline and interior waters. Some coastal autonomous communities' statutes even go further and can participate with their own resources in pollution incidents in their territorial waters.

In Spain, there are 46 ports of general interest which are coordinated by the agency Puertos del Estado, part of the Ministry of Public Works and Transport. These ports are managed by 28 Port Authorities. Although the duties of the Port Authorities are listed in the Consolidated Text of the State Ports and Merchant Navy Act, the Act 14/2014 on Maritime Navigation dated July 24 includes a new responsibility [18]. This is to prevent and control pollution incidents, performing

the cleaning if necessary, in the port area where the Port Authorities provide services.

This complex network has been put together in the National Response System for Marine Pollution, approved by the Royal Decree 1695/2012 of December 21 [1], meeting the requirements of the OPRC Convention and OPRC-HNS Protocol. Before, a National Contingency Plan for accidental marine pollution issued in 2001 as an Order by the Ministry of Public Works and Transport organised the various bodies involved in the response and even included guidelines to develop the local and territorial plans. But a new and broader approach was needed. The actual response system puts in place the different plans and covers the overall organisation and coordination for responding to marine pollution incidents. The system consists of a multilayered regulatory framework and establishes two subsystems depending on the affected area: the marine waters and the coastline.

At the bottom layer of the marine water subsystem, interior plans of ports, terminals, platforms and installations are in place in order to be activated if necessary. At the top layer is the National Maritime Plan for pollution response, established by Order FOM/1793/2014, of September 22 [19], ensuring that national resources will be available for emergencies beyond the capabilities of port and industry responders.

At the bottom layer of the coastline subsystem, local plans may be activated, followed by territorial plans of the coastal autonomous communities and cities in case their coastline may be affected by the pollution. And finally, at the top layer the State Plan for Coastline Protection Against Pollution (Plan Ribera), established by Order AAA/702/2014, of April 28 [20], ensures that national resources will be available for emergencies beyond the capabilities of local and autonomous communities' responders.

In case plans from both subsystems are activated (level 1 or 2), a coordination body will command the incident. If level 3 is activated, the Ministry of Public Works and Transport will command the incident or the Ministry of Interior if there are threats for the population and the emergency is declared of national interest.

International cooperation will be demanded in case a neighbour country is affected by the pollution or extra resources are needed. To this end, Spain has in place bilateral agreements which cover SAR and pollution incidents with annexes containing practical and operational information: the Lion Plan (cooperation agreement between the Spanish Maritime Safety and Rescue Agency and the French Prefecture Maritime of the Méditerranée) since 2002 and the Biscay Plan (cooperation agreement between the Spanish Maritime Safety Agency and the French Prefecture Maritime of the Atlantic) since 1999. Spain has signed also the SARMED Plan (SAR and Maritime Pollution Cooperation Plan) with Morocco and Algeria. The Lisbon Agreement signed with France, Portugal, Morocco and the European Economic Community came into force in 2014.

On a daily basis, the 20 Maritime Rescue Coordination Centres (MRCCs) from SASEMAR, located along the coastline, are responsible for the operational coordination of marine pollution incidents. The MRCC operators, available 24 h a day, 7 days a week, follow the established procedures, contact the responsible party, mobilise the resources if necessary and log the information. The Emergency Director is the Harbour Master, who represents the Maritime Authority in the different areas and works side by side to the MRCC Chief.

Before the Act 14/2014 on Maritime Navigation [18], the Harbour Master was responsible for managing pollution incidents and the Port Authority collaborated. But since the forenamed act, the Port Authorities respond with their own resources, and if these are not enough the Maritime Administration will step in. Actually some Port Authorities have signed contracts with SASEMAR to cover the services of traffic control and pollution response. This is the case for Tarragona, La Coruña, Bilbao, Cartagena, Castellón, Cádiz, Huelva, Ría de Marín, Villagarcía de Arousa, Ferrol and Gijón.

The different authorities are therefore prepared to give a quick response until the polluter, either the shipowner or the industry, gets its own resources ready or in case these are not enough. A plan may be necessary in important spills or when there is a high pollution risk and must be accepted by the Maritime Authority. If the polluter fails to respond in time or according to the Maritime Authority demands, SASEMAR will respond. In any case, monitoring will be carried out to control the operations and minimise the damage.

The Maritime Authority is responsible for taking the decision to accommodate ships in need of assistance in a Spanish place of refuge as established by the Royal Decree 1593/2010, November 26 [21]. The pollution risks will be considered in this decision-making process, in which a technical committee will advise if necessary and a specific tool will be used to help in the overall evaluation.

Monitoring measures are the basis of the national approach when dealing with marine pollution. Nevertheless, the main response strategy is to ensure safety of human lives on response units, vessels in distress, offshore installations and mainland. Never forgetting this goal, all pollution incidents are monitored using maritime and aerial units together with satellite services. The drift of the spillage can be studied and predicted through the use of models and drifting buoys.

The experience gained in pollution incidents in the past years has determined the Spanish level of preparedness as well as its response strategy. In one hand, the *Prestige* (Galicia 2002), together with other pollution incidents in which heavy oils were involved, such as *Don Pedro* (Ibiza 2007) and *Oleg Naydenov* (Gran Canaria 2015), has led Spain to focus in the mechanical recovery as the first response option. In this way, the necessary equipment like sweeping arms, booms and skimmers are used by the maritime units to contain the oil and to recover it from the sea surface and store it in the oil recovery operation (ORO) tanks of the oil response vessels or in fast tanks located in towing rescue vessels.

Additionally, there has been a considerable amount of subaquatic operations undertaken where oil has had to be removed from sunken vessels in past years, for example, the *Woodford* operation in 2012, and this has enabled Spain to be prepared to recover oil from sunken vessels. Two small remotely operated vehicles (ROVs) are available to conduct underwater inspections up to 150 m depth, one bigger ROV can work at 1,000 m depth, two wet diving bells may take divers safely until 90 m depth and one closed bell for saturation can dive up to 200 m depth. A total of 450 m³ were removed from the vessel *Woodford* at 80 m depth 40 miles off the coast of Castellón.

In Spain, dispersants can be used under the approval of the local Maritime Authority on a case-by-case basis. Although some steps have been taken to push forward this option, especially after the *Deepwater Horizon* incident and European Maritime Safety Agency (EMSA)'s support, Spain is still not prepared to use dispersants as an effective response measure. Standards were published in 2014 for the efficiency, toxicity and biodegradability tests, but an updated regulation is needed to establish the national policy for the use of dispersants. Although this regulation is being drafted, from the operational point of view, no stockpiles or application equipment from maritime or aerial units are available, and no field training is being delivered. Nevertheless, Spain has an aircraft dispersant application capability to be provided by OSRL due to SASEMAR's associate member condition. On the other hand, EMSA's services will provide by 2016 200 tonnes of dispersant stockpile in Canary Islands to be applied by the vessel M/T MENCEY.

Spain's response strategy aims to reduce shoreline pollution by recovering at sea as much as possible and by protecting sensitive areas with booms and sorbents. Depending on the type of coastline and taking into account environmental analysis, different response options will be considered. Through aerial and satellite surveillance, pollution incidents are monitored allowing the coastline responders to get prepared in case the oil may wash ashore. If the oil reaches the coastline, cleaning operations will be done by trained professionals. In case volunteers are demanded, they must also have a minimum training to be able to participate in the cleaning operations.

The polluter must face the costs of the operations carried out by the different parties involved in the response, according to the polluter pays principle. From the very beginning, the polluter is reached and the EU Guidelines on Claims Management are followed in the process. The staff fills out daily log sheets including working hours, deployed equipment and work progress. And the necessary evidences of the pollution are collected during the response operations. The Ministerial Order 1634/2013 of August 30 [22] establishes the SASEMAR operations' fares for staff, maritime and aerial units and equipment deployed.

4.2 Resources

The actual capacity in Spain to respond to pollution incidents is a result of the strategic preparedness defined in the specific investment action plans approved by the state. These plans are not only for pollution response but also for search and rescue and maritime traffic control. This makes sense as most of the resources are used for the different tasks assigned to SASEMAR. The evolution of the pollution policies and resources can be followed throughout these investment plans: I (1989–1993), II (1994–1997), III (1998–2001), IV (2002–2005), Bridge Plan, and V (2006–2009). The fifth plan was the most ambitious and 50% of the expenditure was spent on new investments. It was then when the multipurpose vessels and the surveillance airplanes came into operation. Today, an 8-year investment plan under the name of the National Rescue and Pollution Response (NRPR) Investment Plan 2010–2018 [23] is in place and covers an efficient use of the available capabilities.

SASEMAR owns an important maritime and aerial fleet (Fig. 6). The maritime fleet includes 73 vessels, permanently on stand by or on duty. The geographical distribution of these vessels can vary depending on season and specific needs. The aerial fleet consists of 3 aircrafts and 11 helicopters. All the maritime units and the helicopters have sampling kits to take samples from the sea surface.

The maritime units are necessary to perform the mechanical recovery of oil in the sea surface. Fourteen vessels are especially prepared for towing (emergency towing vessels, ETVs), search and rescue (SAR) and oil spill response purposes. They all have self-operating cranes to load and unload equipment and oil booms and skimmers ready to load. Four of them are multipurpose vessels equipped with

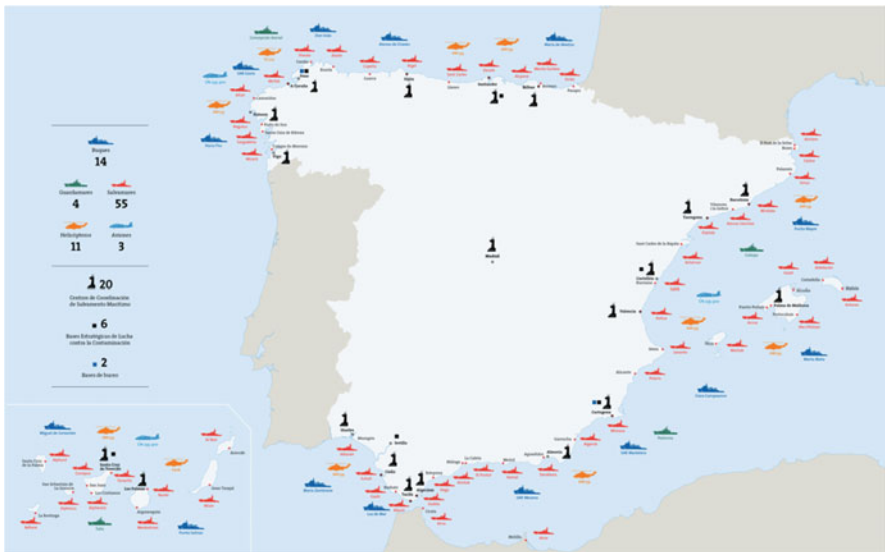


Fig. 6 Maritime and aerial resources for responding to pollution and rescue incidents

sweeping arms, oil recovery operation (ORO) tanks that may be heated, dynamic positioning systems and FLIR cameras. Luz de Mar and Miguel de Cervantes are 56 m long with 128-tonne bollard pull and a recovery capacity of 290 m³. Clara Campoamor and Miguel de Cervantes are 80 m long with 228-tonne bollard pull and a recovery capacity of 1,750 m³. The vessel Clara Campoamor is additionally prepared to act as a support platform for subaquatic operations. The vessels Alonso de Chaves and Punta Salinas also have ORO tanks, increasing the total capacity for oil recovery up to 4,430 m³.

The maritime fleet also includes 55 fast response vessels of a smaller size (15 and 21 m length) and four patrol boats (32 m length) positioned along the coastline for SAR and pollution activities. They are currently used as auxiliary units to tender booms and help the vessel tugs in response operations.

The aerial surveillance of pollution incidents is key to locate and evaluate the slicks and to guide the maritime units by night. Three CASA CN235-300 planes, fully equipped, patrol the Spanish waters. They cover the Mediterranean Sea, the Spanish North Atlantic Coast and the Canary Islands. A smaller plane replaces the owned aircrafts when they are out of service.

The aircrafts are fitted with specific antipollution sensors, SLAR, IR/UV, MWR and LFS, and with other equipment: FLIR/CALI, video recorder, digital photo camera, AIS and data link, managed by two operators placed in the mission consoles. The operators evaluate the data from the sensors, the information is analysed at the Mission Support Centre and finally a technical report is written.

The helicopters can support the marine pollution aerial surveillance in pollution incidents, and they can take samples of slicks located far away from the coast. SASEMAR operates eleven helicopter bases with nine medium-size helicopters and two heavy helicopters equipped with FLIR, video recorder and digital photo camera. Four of the helicopter bases cover the North Atlantic coast, two the Canary Islands, four the Mediterranean Coast and one the Strait of Gibraltar.

The pollution response equipment of SASEMAR is stored in six stockpiles known as strategic bases and located along the Spanish coastline: Santander, A Coruña, Sevilla, Cartagena, Castellón and Tenerife. A total of 60 km of oil booms, 46 skimmers, 40 fast tanks of 10 m³ capacity, 18 portable tanks of 7.5 m³ and other additional equipment are stored, maintained and repaired. Additionally, there are two bases for underwater operations, with diving equipment and intervention teams.

Five stockpiles from the Ministry of Agriculture, Food and Environment with counter pollution material for shoreline response are also located along the coastline: Pontevedra, Jerez de la Frontera, Tarragona, Las Palmas in Canary Islands and Palma in Balearic Islands.

4.3 Surveillance

Today, Spain has a solid system to prevent illegal pollution based on regulation and enforcement through aerial surveillance, inspections and sanctions. The fixed-wing crafts were delivered in 2007 enhancing the national capacity to prevent and combat marine pollution. In one hand, they could be used for monitoring operations in pollution incidents and, on the other, could patrol the Spanish waters so that surveillance is ensured. These aircrafts perform 4 h missions searching for illegal discharges, travelling at 165 knots and covering 20 nautical miles with the SLAR sensor, sweeping approximately 10,000 km² per hour. SASEMAR planes patrol approximately 1,200 h per year for pollution control. Around 50% of the surveillance is performed by night. Each aircraft monitors approximately 1,800 vessels in navigation in the Mediterranean Sea, 1,600 in the North Atlantic and 600 in the Canary Islands every 100 flight hours. These figures are dependent on the traffic of the covered areas. A general overview of the aerial surveillance results is shown in Table 2.

Coordination is essential among the different stakeholders that take part in the prevention system, in order to detect the pollution and the polluter, to collect the evidences and to prove the offence. There are procedures in place that establish the operational methodology, the data collection and the notification and reporting process. SASEMAR performs the surveillance operations. Two operators with experience collect and document the evidences. If the polluter calls in a Spanish port, the Harbour Master's office performs the vessel inspections. In any case, the Maritime Authority notifies the pollution incident and may even reroute the vessel to a Spanish port.

The Maritime Authority conducts the administrative procedures according to the criteria established by the Environmental Public Prosecutor 2011. Considering the sea polluted, the distance to coast and the area of the spill, the enforcement process will follow an administrative or a criminal procedure. Ship-source pollution crimes in the Mediterranean Sea in which polluted areas are over 2 km² and located within 12 miles off the coastline and those in which polluted areas are over 3 km² and located beyond 12 miles off the coastline can follow the criminal proceedings. The same happens for ship-source pollution crimes in the Atlantic Ocean when polluted areas are over 5 km² and located within 12 miles off the coastline and those in which polluted areas are over 10 km² and located beyond 12 miles off the coastline. These crimes will be dealt by the Public Prosecutor as offences against natural resources or the environment, covered in the Organic Law 10/1995, of November 23 of the Spanish Criminal Code.

However, most of the ship-source illegal pollution will be dealt by the Maritime Administration as MARPOL offences. The sanctioning procedure is covered in the Consolidated Text of the Spanish Law for State Ports and the Merchant Marine, approved by Royal Decree 2/2011 of September 5 [17], and follows the regulatory standards of the administrative system. The penalties established are up to €60,000 for minor offences, up to €601,000 for neglect discharges considered as serious

offences and up to €3,005,000 for intentional discharges classified as very serious offences. Additional penalties can be imposed concerning the necessary measures to return things to its original state and to claim for damage compensation.

But the prevention air surveillance system as a whole has long-term outcomes. Once the sanctioning procedure is solved by the Maritime Authority, the responsible party may appeal and contentious administrative proceedings must be followed, increasing the duration of the process. As an example, a red-handed vessel detected in 2008 was finally solved in 2013. The plane SASEMAR 102 detected by night on September 2008 at 120 nautical miles off Cabo Ortegal, in the Galician coast, a pollution spill from a red-handed vessel. The discharge of 21 km long was connected to the wake of the vessel, being clean the surrounding area. The vessel was a product tanker with Panamanian flag coming from Denmark and heading to Las Palmas Port. The vessel denied the discharge when interrogated. An inspection was carried out in Las Palmas and oil was found in the discharge line of the oily water separator. The polluter appealed the administrative decision. And finally in January 2013, the decision of the High Court of Justice dismissed the appeal.

The creation of the European Maritime Safety Agency (EMSA) in 2002 has contributed significantly to the enhancement of the overall prevention system. The CleanSeaNet system, developed in 2006 and based on remote sensing surveillance, is progressively providing a clearer picture of the position on both accidental and illegal pollution, and potential slicks are spotted on a daily basis. Satellites cover a great area, being a powerful surveillance tool. During 2015, the satellite Sentinel was already in operation providing images with very high resolution. Spain gives feedback to EMSA for the satellite detections by sending an aerial or maritime unit.

Figure 7 shows the spills detected by aerial and satellite surveillance in Spanish waters. Table 2 shows the decreasing trend for both spills and red-handed vessels detected in the last 5 years. The deterrence effect is clear. Ten years ago, the vessels coming from northern Europe were waiting to reach Spanish waters to discharge bilge waters, and today they will give it a thought.

5 Operational Forecasting and Source Identification of Oil Spills

Oil spill forecasting together with oil spill identification are the main scientific and technical keys for a good management in a pollution incident in order to minimise the impact in the marine environment. This was highlighted during the *Prestige*, in which from the first stages of the accident, different Spanish institutions and public agencies started to work on both aspects.

A system (Fig. 8), composed of three main interconnected modules addressing different capabilities, was proposed: (1) an operational circulation subsystem that includes nested models at different scales, data collection with near real-time assimilation, new tools for initialisation or assimilation based on genetic algorithms

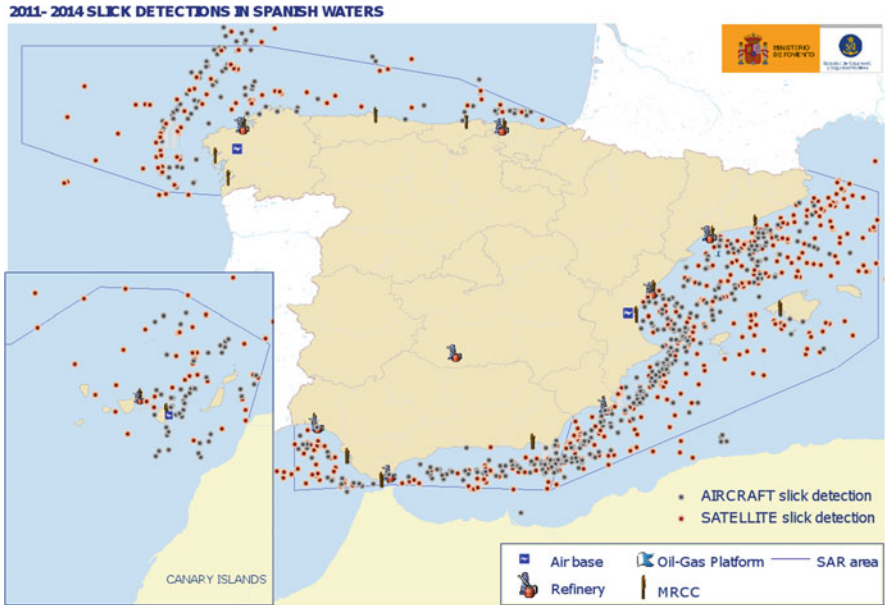


Fig. 7 Aircraft and satellite slick detections in Spanish waters 2011–2014

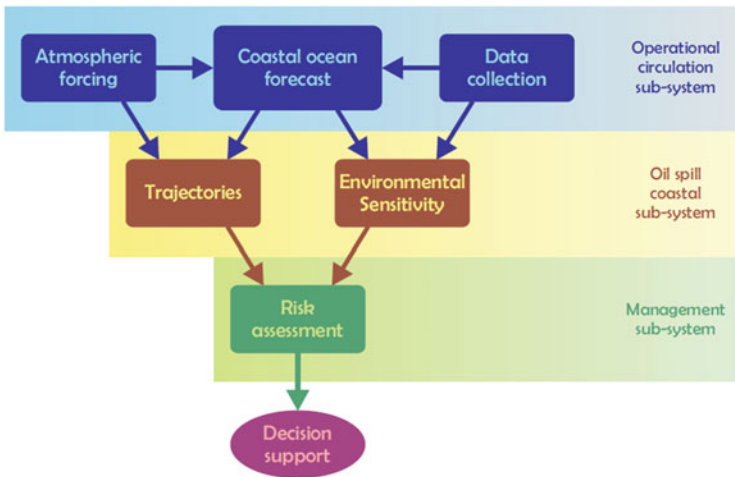


Fig. 8 Structure of the hybrid forecasting system for oil spill or search and rescue operations [24]

and feature-oriented strategic sampling; (2) an oil spill coastal subsystem that allows simulation of the trajectories and fate of spilled oil together with evaluation of coastal zone vulnerability using environmental sensitivity indexes; and (3) a risk management subsystem for decision support based on GIS technology.

The operational system was complemented with a monitoring component to feedback the whole system, validating the forecasting assumptions. Today, the satellite and aerial surveillance, the historical data from past incidents, the use of drifting buoys and sampling results are part of this monitoring element. But also oil spill forecasting and identification may be essential as evidences in the enforcement process to prove the polluter offence.

5.1 Oil Spill Forecasting

The Spanish Maritime Safety and Rescue Agency uses marine meteorological and oceanographic data to feed the pollution models. An Environmental Data Server (EDS) connects to the different data providers and manages the information. The EDS allows storing, analysing and displaying the environmental data. The system collects the information in different formats and makes it available to the operators at the MRCCs. The wind data is provided by AEMET (State Meteorology Agency), MeteoGalicia and NOAA. The current data is delivered by Puertos de Estado, Copernicus and local sources such as MeteoGalicia, SOCIB, AZTI and the Universities of Cadiz and Vigo. All the information is stored daily for environmental studies and currently there is historical data since 2013.

The 2D OILMAP model is used by SASEMAR to predict the drift of the oil. The MRCC operators receive a training course, and they are prepared to run the model for slicks detected in the sea in order to plan the response. And they can also perform a backtracking analysis to identify suspected vessels, by using Automatic Identification System (AIS) data. Of course this is a very difficult task especially in areas where there is a high traffic density, but a suspect can be identified and an inspection at port can be carried out by the Maritime Authority.

Drifting buoys are used in exercises and in real incidents. In small drills, the buoys are deployed to analyse the spill modelling. In larger exercises, feedback is given to Puertos del Estado and to scientific and research organisations. In real incidents, drifting buoys are key in supporting the model predictions.

The historical data obtained from real oil spill incidents which have been analysed are really important to feedback the models and to validate the operational system.

All started in 2002, when there was a need to establish an operational oceanography in order to monitor and forecast the oil spill from the *Prestige*. Several operational forecast systems were built in different regions with a common objective of helping to manage the crisis [25, 26].

The experience gained with the *Prestige* pre-operational systems and the funding opportunity provided by the Spanish Ministry of Education and Science

gave birth to a 3-year project (2004–2006), the ESEOO (Implementation of a Spanish Operational Oceanography System (www.esooo.org)). The ESEOO partners constituted a multidisciplinary team coordinated by Puertos del Estado with the basic objective of developing operational oceanography at the national level by creating new tools and by improving the inter-institutional and international coordination. Nowadays, the ESEOO modelling products are integrated into the Spanish Maritime Safety and Rescue Agency (SASEMAR) procedures, being used to provide forecasts of drifting persons and objects as well as providing basic tools for dealing with accidental marine pollution [27].

In order to test the accuracy of the prediction tools, a periodical comparison between ground truth information and numerical predicted paths was carried out. The model parameters were corrected by means of a trial-and-error procedure. Specifically, in Cantabria, a study on the relative importance of the different forcing (wind, wave, currents) was undertaken as part of the calibration process. This study found that although wind drift and surface currents were the major advective transport mechanisms, wave-induced Stokes drift could not be discarded and, on several occasions, wave-driven transport became the most important factor in the transport of the floating oil slicks.

Another way of testing the performance of the numerical models consisted of a continuous oil slick tracking. To this end, the overflight information from aircrafts was one of the main components of the forecasting system. Another valuable source of information was provided by satellite-tracked Lagrangian buoys.

The buoy data is particularly useful to calibrate the oil spill dispersion models. These tools were extensively used during the *Prestige* oil spill [28] and also during a recent spill originated by the grounding of the vessel *Oleg Naydenov*, 15 miles south of Gran Canaria Island, after towing it away from the port when a fire was declared on board (April 14, 2015). The oil slick position charts are elaborated and provided daily to the response team. The information obtained during the first week after the spill is shown in Fig. 9.

5.2 Source Identification

Efficient analytical methods for the unambiguous characterisation of oil spillages are needed from the standpoint of the enforcement of the pollution control laws, designed to protect the public health and the environment. Chemical analytical results are thus used to attach responsibilities, assess penalties and help recover clean-up costs incurred during an incident.

In Spain, the implementation of a solid source identification mechanism started just after the *Prestige* accident (2002) and was completed in 2012 with the accreditation of the official laboratory (Fig. 10). The laboratory has been actively participating in the annual Bonn-OSINet (oil spill identification network of experts within the Bonn Agreement) round-robin tests for enhancing knowledge and experience [29].

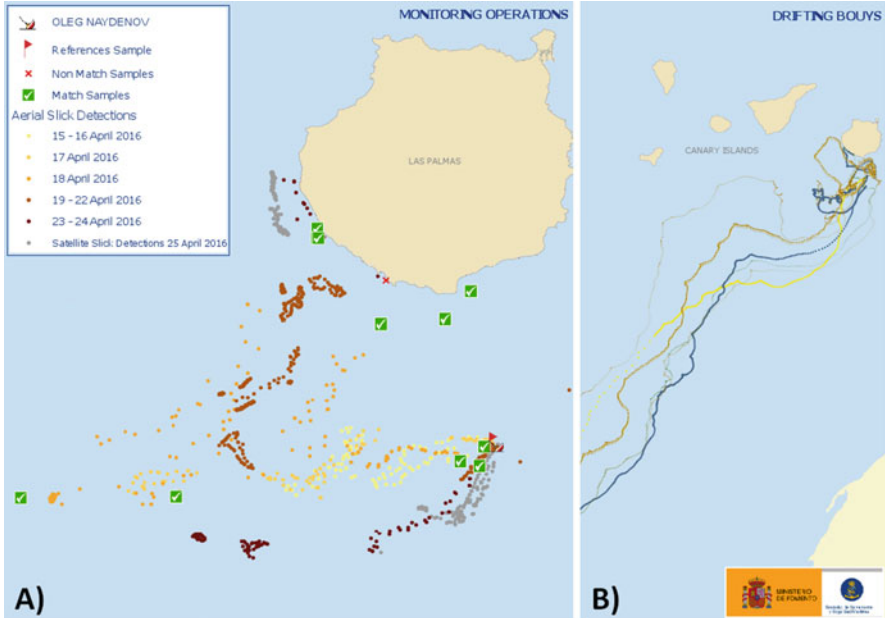


Fig. 9 Monitoring operations of the *Oleg Naydenov* spill (a) and buoy trajectory evolution during the study period (b)

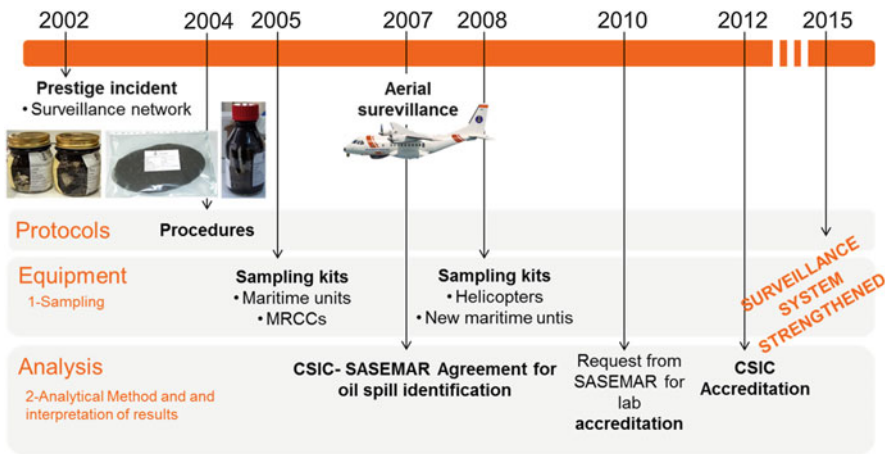


Fig. 10 Implementation of the Spanish surveillance system

The methodology used in the laboratory for oil spill monitoring and the prosecution of infringers is the one established in 2002 by the European Committee for Standardisation (CEN) [30], encompassing two guidelines:



Fig. 11 Sampling kit for oil spills

Part I: Oil spill identification – Waterborne petroleum and petroleum products. Sampling (CEN/TR 15522-1; 2006)

Part II: Oil spill identification – Waterborne petroleum and petroleum products. Analytical methodology and interpretation of results (CEN/TR 15522-2; 2012)

Sampling is the first step in the process of defensibly determining the source or impact of an oil spill. Designing a comprehensive oil source sampling plan is fundamental in the investigative efforts of an oil spill, and collection of oil from both the spill and the suspected source(s) is crucial to any forensic investigation.

In the sea, samples are collected using the devices described in the guideline (Part I), according to the type of sample, a Teflon net for thin oil films (slicks or sheens) and a polyethylene cornet for floating oil. A sampling suitcase with all necessary equipment has been designed and placed on board of the response vessels and helicopters (Fig. 11).

Special attention is paid to secure the representativeness of the collected samples, both at sea and from the vessel tanks. If the spill response operation continues for more than 1 day, samples are taken every day to make it possible to determine the degree of weathering of the oil as well as a possible contamination by other oils and as evidences in the claims management process. Together with the samples, all relevant information is recorded, e.g. the sampling conditions, the sample location (e.g. latitude-longitude-depth), the potential spill transport pathways, etc. These documents are also important for warranting the chain of custody of the samples.

Once in the laboratory, samples are analysed by gas chromatography-flame ionisation detector (GC-FID) and gas chromatography-mass spectrometry (GC-MS) and compared using a suite of diagnostic ratios of selected compounds (molecular markers) which constitute the fingerprint of the oil [31]. The selection of these series of compounds lies on the combination of their source specificity and

their lower susceptibility to weathering. Any differences of compound ratios, not influenced by weathering, are only relevant if a difference is larger than the variability of the method itself.

The application of these concepts and methods is illustrated in the following case studies. They offer important examples of how to identify the oil spill source, if unknown, and additionally monitor changes in oil samples due to weathering in the longer term.

5.3 Case Studies

The CEN methodology was extensively used during the *Prestige oil spill* (November 13, 2002). Following the accident, an extensive survey was carried out by SASEMAR at the northern coast of Spain, to obtain a comprehensive picture of the fate of the spill in the marine environment and, indirectly, identify the possible occurrence of illegal discharges in the area after the spill. More than 200 oil samples were collected in the region (at sea, at the continental shelf and stranded on the coast) between December 2002 and December 2003 and characterised by chemical fingerprinting (Fig. 12).

From the total samples analysed during this period, 17% of them did not match the *Prestige* oil, and most of these (52%) were found off La Coruña where the city harbour and a refinery support an intense maritime traffic. This demonstrates the continued occurrence of oil discharges at sea and the need for a more strict surveillance of the areas holding heavy tanker traffic.

During that survey, the *Prestige* oil was drifting on the seawater surface for almost 1 year, and thus it was highly exposed to major weathering processes

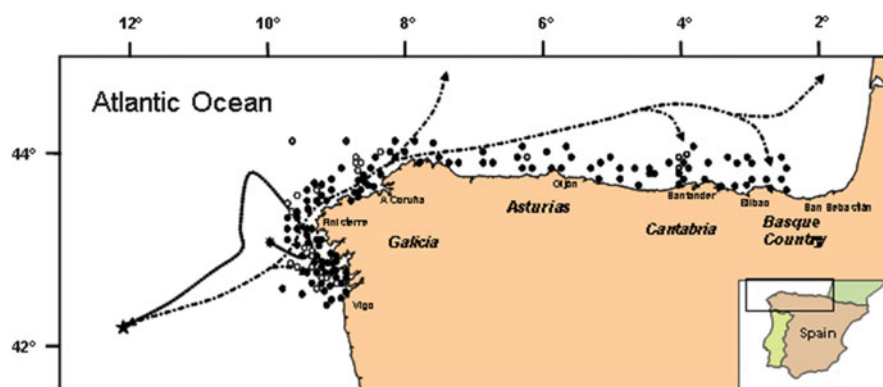


Fig. 12 Sample locations along the northern Spanish coast with indication of the main oil trajectories. *Solid arrow*, tanker towing route. *Filled star*, shipwreck position. *Dotted arrow*, oil trajectories. Oil samples (*full and empty circles* correspond to *Prestige* and non-*Prestige* samples, respectively). Reprinted from [32], with permission from the American Chemical Society

(e.g. emulsification, evaporation, dissolution, photo-oxidation and biodegradation). Thus, a good opportunity to monitor the resulting compositional changes for assessing the molecular indicators to be used for oil source recognition was presented [32]. Evaporation of the lower fractions (<n-C20 range) and dissolution (low-molecular-weight aromatic hydrocarbons) were the most apparent processes, which accounted for a 5% and 2% of oil loss, respectively. In summary, the data showed the high persistence of the spilled heavy oil at sea, 1 year after the accident, with very low incidence of the natural weathering processes, thus stressing the need for mechanical removal from the sea surface and the coastal areas.

However, 9 years after the accident, oil from the *Prestige* was still recurrently arriving to some beaches [33]. It was found that the morphodynamics of high-energy beaches favoured a cyclic burying of the oil, down to 4 m depth, and resurfacing, and its transport from the subtidal area to the intertidal area and vice versa. During this process, a clear biodegradation signal was observed within the aliphatic and aromatic fractions. *n*-Alkanes were totally depleted and the C1–C2 alkylphenanthrenes and dibenzothiophenes, proposed for source recognition and weathering assessment of spilled oils, exhibited an interesting sequence of events of increasing biodegradation, as shown in Fig. 13 and discussed elsewhere [34]. The

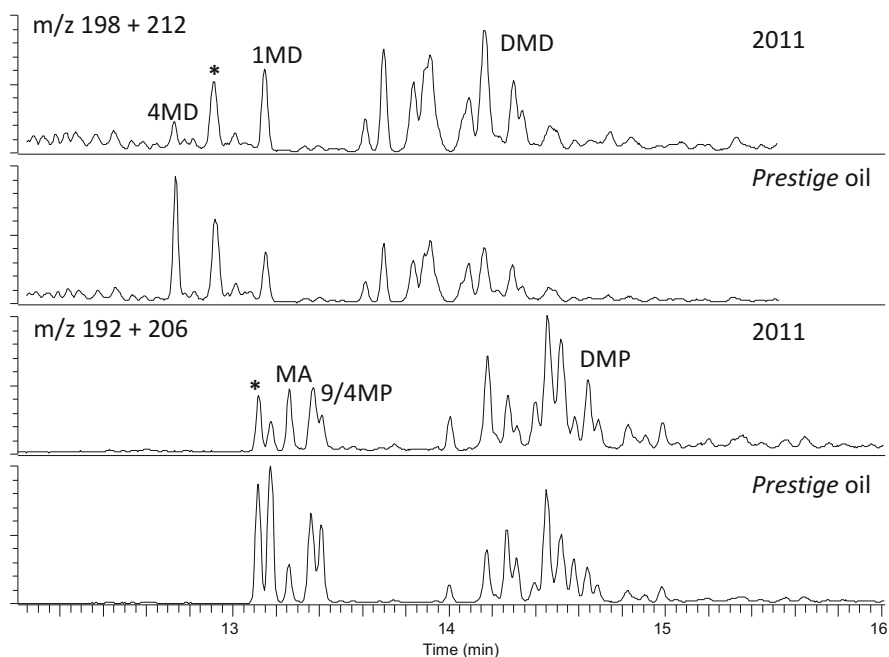


Fig. 13 Ion chromatograms of methyl- and dimethylphenanthrenes (m/z 192 and 206) and dibenzothiophenes (m/z 198 and 212) of the oil samples and *Prestige* oil. MA methylanthracene, MP methylphenanthrene, MD methyl-dibenzothiophene. *2-/3-methylphenanthrene and dibenzothiophene

more recalcitrant triterpene and sterane compounds provided the clue for source recognition.

All these findings were integrated in the strategy design of the *Prestige* oil spill assessment and hence the remedial treatment of oiled beaches.

More recently, on the morning of April 15, 2015, the Russian flag fishing vessel *Oleg Naydenov* sank 15 miles south of Punta Maspalomas, at a depth of 2,700 m. On April 11, the ship, with 1,400 tonnes of fuel, 30 of diesel and 70 of lubricating oil, was ready to leave the Port of Las Palmas (Gran Canaria Island) when a fire was declared on board. Due to the risk posed by the ship afire for the population and the environment, it was towed offshore, where it finally sank.

Since its downfall, a surveillance programme and monitoring pollution was established. Following the aerial surveillance (Fig. 9), around 30 sets of samples were collected from April 15 to May 15, 2015, which were sent to the laboratory for identification.

As in the *Prestige* case, the main aim of the monitoring was to obtain a comprehensive picture of the spreading of the spill in the marine environment and, indirectly, to identify the possible occurrence of illegal discharges in the area after the spill. However, the problem here was the mixing of the different products carried by the vessel during the spill. This is illustrated in the representative profiles displayed in Fig. 14.

The GC profiles of different samples show the characteristics of a heavy fuel oil with different proportions of lubricating oil (in grey). The matching of the fuel oil in all samples was confirmed by the coincidence of the mid-range profiles (e.g. C1-pyrenes and C4-phenanthrenes) and the associated diagnostic indices, whereas the contribution of different proportions of lubricating oil was evidenced by the differences in the characteristic sterane and triterpane profiles and the corresponding indices, as illustrated in Fig. 15. The profiles of C4-phenanthrenes (m/z 234) exhibit a full overlay, whereas the differences between the $\beta\beta$ -sterane distributions (m/z 218) are consistent with the increasing proportion of lube oil.

These features are common in spills of waste oils (e.g. bilge residues, sludge, slops) where different mixtures can be found in different tanks and samples. These differences should be considered in the assessment of diagnostic ratios in comparing the samples.

An operational incident occurred in May 22, 2013, when the captain of a container carrier communicated to the maritime authorities an accidental spill of fuel oil offshore Valencia. Spill samples were collected in the vicinity of the vessel and also from the suspected tank the same day of the accident, but some days later (from May 31 to June 15), new oil slicks appeared on the sea. At the same time, almost 1 month later, from July 6 to July 14, oil residues were widely spread on some Valencia and Castellón beaches. The question was to identify the source of these samples and, particularly, if they were related to the aforementioned spill.

The comparison of the diagnostic ratios of all collected samples at sea confirmed their coincidence with the reference sample from the vessel tank. Most of the ratios of the samples collected on the beaches allowed to conclude also a match. However, some ratios exhibited an increasing deviation with time (Fig. 16). These ratios were

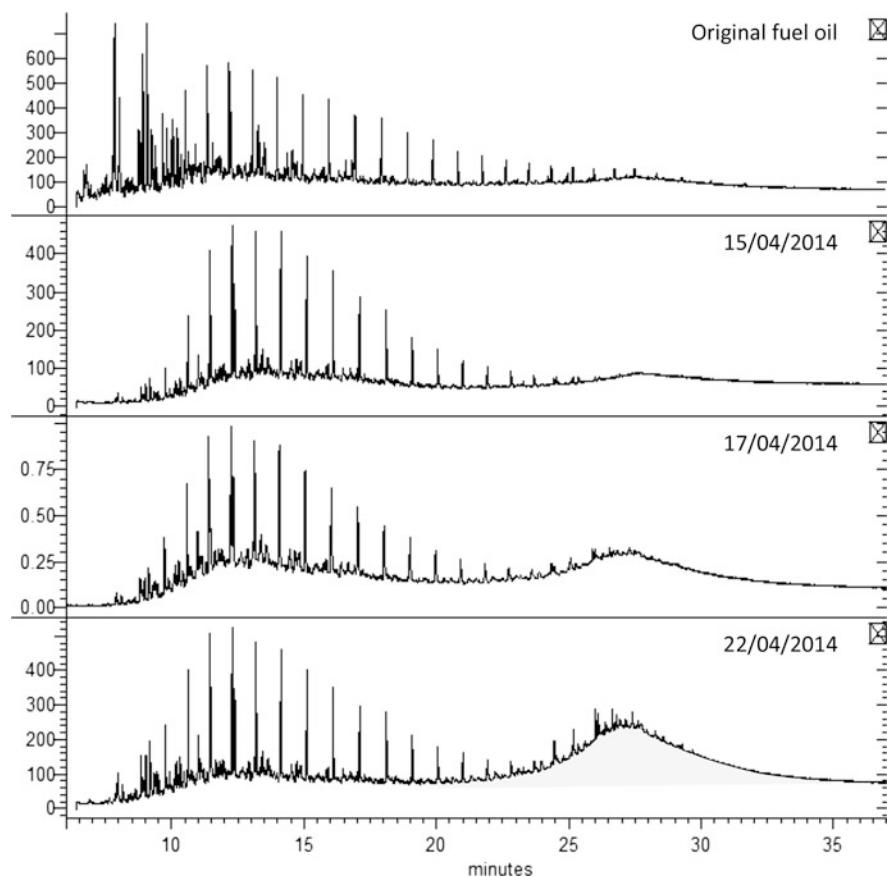


Fig. 14 Gas chromatographic profiles of the *Oleg Naydenov* fuel and samples collected at sea

those involving the fluorenes and benzofluorenes (2MF/4-Mpy, B(a)F/4-Mpy) and benzonapthothiophenes (BNT/T-M-phen), which is known to be affected by photo-oxidation [35]. This is a rather fast process in low-latitude areas, whereas sunny conditions predominate, as it was the case in the present incident that, in addition, occurred in summer.

A practical way to quantitatively illustrate these compositional changes in weathered samples is by the so-called ‘percentage weathering’ plots (PW plots) [30]. They can be obtained when the individual compounds of the original and weathered sample are normalised to the 17 α (H),21 β (H)-hopane (C30-hopane), highly refractory to weathering. Next, the calculated remaining percentage of the compounds in the weathered sample relative to the original oil is plotted against the retention time, linked with the boiling point of the corresponding compounds. If the samples are identical (e.g. a duplicate analysis), the result will be a straight line at

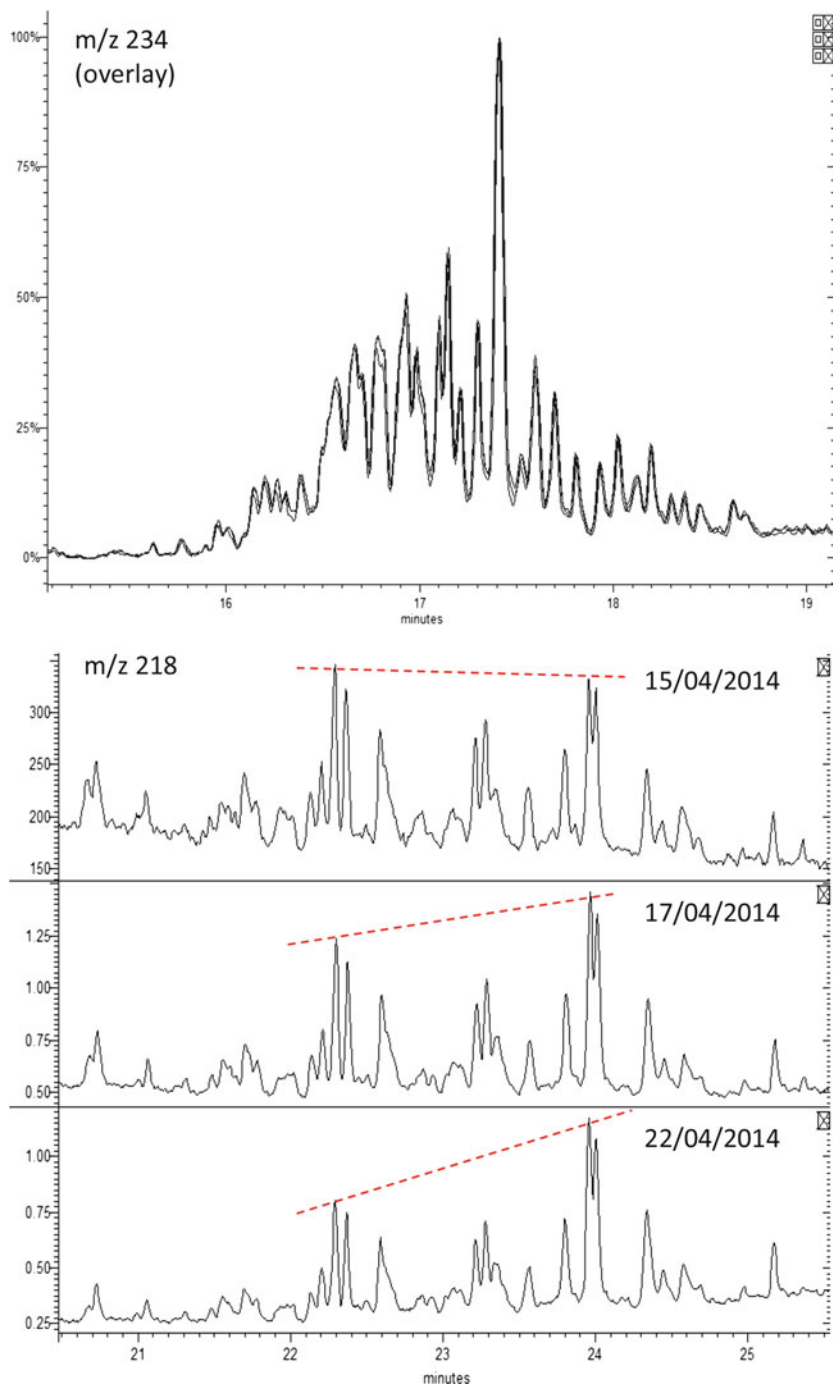
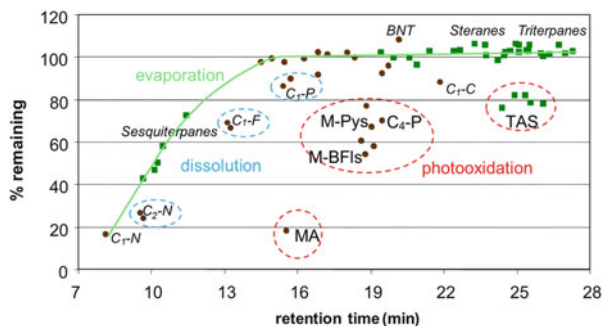


Fig. 15 Ion chromatograms of C4-methylphenanthrenes (m/z 234) and β -steranes (m/z 218) of *Oleg Naydenov* samples collected during April 2014

Fig. 17 Percentage of PAHs (*circles*) and biomarkers (*squares*) of the *Prestige* sample after simulated photo-oxidation in the laboratory [34]



100%. The loss of certain compound by weathering will be reflected by a decrease in the plot.

A summary of the effect of different environmental processes on the oil comparison is shown in Fig. 17, which reveals a significant depletion of compounds with low retention times (volatile) due to evaporation. At the same time, the effect of other processes, such as i.e. dissolution, may explain the loss of C1- and C2-naphthalenes (C1-N) and fluorenes (C1-F). Finally, the significant reduction of MA (80%), M-BFIs (40%) and M-Pys (20–40%), C4-Ps (30%) and TAS (20%) can be attributed to photo-oxidation, as it has recently been demonstrated through laboratory and field tests [35].

When the effects of weathering on a spilled oil are understood, any affected ratio can be eliminated or cautiously considered when comparing a weathered spill sample with an unweathered source sample.

6 Conclusion

Throughout history, large incidents have allowed countries to move forward on oil spill preparedness and response. This happened to Spain in 2002 when the Maritime Authority had to face the *Prestige* spill. At that moment, a national system for oil pollution was being set up, but of course it was not enough to cope with such a major accident. Lessons were learnt at a national and international level. Due to the *Prestige* incident, important investments were made in Spain, greatly increasing its resources. Oil spill response equipment was acquired; and multipurpose vessels and fixed-wing aircrafts became new units in the Spanish fleet. But also scientific and technical research was supported, providing interesting results. All these resources, developments and innovations have been integrated into the national system.

Today, Spain has a solid system for oil pollution prevention and response. Policies have been established to implement the international and European regulation, to ensure coordination and cooperation at a national and international level and to make an efficient use of the resources. The regulatory framework includes a National Maritime Plan and a Coastline Protection Plan as well as the coordination

mechanisms between them. The operative plans established with neighbouring coastal states are also part of the system. Through investment action plans, the pollution strategies have been defined covering preparedness, prevention and response. Aerial and satellite surveillance together with oil forecasting and sampling are strengths of this system, providing a reliable monitoring of the Spanish waters. These monitoring tools are key in the enforcement processes to prove the pollution offences in case of illegal discharges. But they are also essential to provide an effective response in oil spill incident's management.

Although a large incident has not occurred since 2002, Spanish authorities have dealt with medium and small oil spills, in which the whole system has been tested. Learning from these past incidents and keeping updated with international experiences and developments is crucial. Also, measures have been taken to enhance maritime safety in order to reduce the shipping accidents, with a special interest in being at the forefront of technology. And never forgetting preparedness, prevention and response for hazardous and noxious substance incidents, a major challenge in which a great effort needs to be done perhaps with a European coordinated approach.

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