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Remediation strategies and management of oil spill hazard along the Emilia-Romagna coast (Italy)

Thesis in: Integrated Coastal Zone Management

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Abstract

In the Adriatic Sea, large vessel traffic is dense, and accordingly there is a great deal of operational pollution along with the constant threat of accidents and incidents. The Emilia-Romagna region does not have any planning documents for managing the oil spill risk. The aim of the thesis is to propose strategies for a management plan (not currently available) and intervention strategies of coastal protection from oil spill events utilizing models (simulations) of potential scenarios which could happen near the Emiglia-Romagna coast, and how it should be the proper reaction due to this possible accidents, in a way to build preparedness and improve the efficiency regarding to the response, raising the level of safety and marine security security towards those events that can impact not only environmental units, but also other society development pillars as economy and health.

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1 Introduction

Oil spills are a threat to coasts worldwide, being one of the main sources of water pollution, this type of disposal carries lots of different consequences to the environment, public health and to the economy, affecting and disturbing biodiversity, impacting littoral communities and providing major losses to the natural aquatic environment (Singh et al., 2020). According to ITOPF,2018 as cited in Singh et al. (2020) in an interval of 47 years(1970-2017) more than 5.7 million tonnes of crude oil were spilled into the oceans, those numbers serve as an introduction regarding to the size of the issue, dealing with spills is a global coastal communities problem, and in every part of the globe that faces these transition environments needs to be prepared for eventual accidents and situations that could cause significantly or even irreversible short, medium and long term damage. The Adriatic Sea is one of the main maritime roads for global maritime trade holding around 30 per cent of it, and one of the goods that are commercialized in a big scale through the sea is oil in its different forms, putting the local coastal communities and habitats at risk (Thana & Patuzi, 2013).

The Emilia-Romagna coast in Italy is one of the areas plated by the Adriatic waters having 130 km of flat alluvial sandy system, in which contains varieties of river mouths, channels and lagoons, holding a long time economical, cultural and environmental value (Airoldi et al., 2016).From Beaches that drives tourism and leisure activities to the area, to industrial and port activities, being the coast the host of one of the most important ports in Italy, the Ravenna port, which was established thousand years ago and held a very strategic position that was very valued for the Roman Empire, not even fading away after the fall of the Western Empire, going along with the Byzantine dominion, until today. It provides the transport and handling of varieties of cargo throughout Italy, from raw materials, ceramic, grains, containers and other good to gas, refined product and crude oil as liquid bulks (Airoldi et al., 2016). These intense port activities raises the amount of circulation of vessels and with that the raise of risk regarding to accidents not only for the Ravenna area, but also for neighbor coastal cities. In need to protect such a important and valorous zone, plans and strategies are needed to be developed and applied following trends already done by current "colleague Adriatic countries" (Croatia and Albania for example) and also Emilia-Romagna neighbor region Marche, that according to HAZADR (2015) exercises of oil spill monitoring, response and mitigation techniques were applied as drills, aiming the rise of the level of coastal protection and safety of it's resources, preparing administrations beforehand for accidental spills improving one of the main aspects for an effective response to those events which is the time of action (Lauro et al.(2015); IPIECA-OGP(2014)).Despite of the existence of the Italian plan for containment of hydrocarbons and other toxic substances (PCN, 2010), a specific and directed approach is needed to guarantee an efficient and more cost beneficial response, as Italy is a big country facing different types of environmental structures, weather and realities.

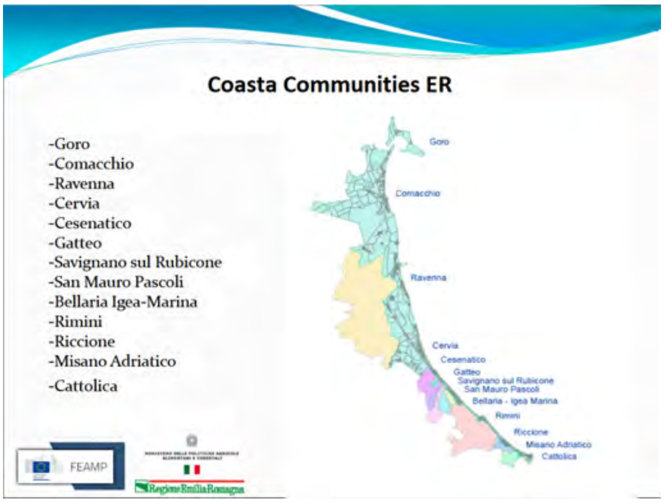

Figure 1: Emilia-Romagna Coast and administrative divisions. (https://www.flag-costaemiliaromagna.it)

This work has the objective to focuses on the region Emilia-Romagna and work within its boundaries, directing the studies of how the coast could be affected by accidental spills, possible events and outcomes, and what would be the options and actions that could be used to defend and save not only natural coast resources, but also reduce collateral damages, utilizing integrated coastal zone management approach as a tool for a better understanding and resolution for complex coastal problems.

1.1 Towards an Oil spill, the five questions.

According to NOAA (2015), there are 5 questions that needs to be brought up when facing an oil spill accident for a more efficient impact reduction: 1 - What happened? (causes, motivation, origin of the pollutant) 2 - Where could it go? (trajectory of the pollution) 3 - What could it affect? (impacts on society and environment) 4 - What harm could it cause? (toxicity and lethally of the contaminant) 5 - What can be done to help (remediation, monitoring, strategies to fight the spill) The aim of this work is to support the resolution of the questions number 2, 3 and 5.

1.2 Oil spill and Impacts

Accidental oil spills represent a complex problem because it gathers different consequence in different sector of nature and society. According to Cirer-costa (2015) and Nelson et al (2018) cited in Singh et al.(2020), the oceans since the 40s has suffered 25 critical oil spills, the transit of this substances in nearshore waters provokes a negative impact on leisure aquatic activities, water sports and tourism related to ecosystems such as beaches, wetlands and mangroves (Singh et al., 2020). The mixture of different substances that may contain in those spills as PHCs (petroleum hydrocarbons) VOCs (volatile organic compounds), PAHs (poly-aromatic hydrocarbons) and other products, has been proved to be dangerous to marine and organism affecting it's development and livability, furthermore, the contact with those substances can also develop health conditions in humans such as asthma, inflammations, irritations, liver damage, cardiovascular diseases, deformities and more as stated by Eykelbosh, 2014 in Singh et al.(2020). In addition of the health and environmental effects, those events can be very harsh for economies that depends from the coastal resources, as found in Pena et al.(2020); regarding to consequences of the biggest oil spill that happened at the Brazilian coast in 2019, estimations of 360,000 artisans fishers were affected by the loss of income and mental health impacts that came along with it. Approximately the oil compromised 724 fishing and shellfish areas impacting families that were entire generations born and raised with duties related to the extraction and use of the coastal resources.

For a better monetary comprehension of impacts of an oil spill, it can be brought into the spotlight, one of the biggest accidents that happened in western Europe, which was the Prestige spill (77,000 tons of oil) at the Galician coast (Spain) in 2002, according to Wirtz(2006) this accident costs were: 750 million euros for environmental damages, 500 to 2000 million euros for socio-economic damages, plus the costs for the clean up that goes around 600 millions to 2500 millions (Wirtz & Liu, 2006). Those data values can be obtained by the use of different models that try to interpolate the coastal units values with monetary values, transforming it in a type of product, in another words, aggregated values. One example of this kind of modelling regarding to this relation was developed by Wirtz(2009) as they simulate an event in Germany and determine values to different coastal units (biotic and abiotic) and main activities that would have been impacted by an oil spill, see Figure 2.

Parameter	Description	Value
$f(t)$	Time-dependent recovery function	A S-shaped smooth transition ranging from 0% to 100%
M_i	Monetary value per unit resource i and year	[a]M_{beach} = €379200/km^2/year [a]M_{water} = €26100/km^2/year [b]M_{duck} = €62.5/bird
yr_i	Yearly revenue for economic sector I	[c]$yr_{fishery}$ = €568.8 Millions/year [d]$yr_{tourism}$ = €2250 Millions/year
up_i	Price of using facility i per hour	[e]i = {combat vessel | Neuwerk, Mellum, Eversand, ..., Knechtsand, Marcus}; up_i ranges from €300/h to€ 1618/h

[a] Costanz et al. (1997).
[b] Frech-McCay (2004).
[c] Germany fishery products annual (Lieberz, S. M. and Ramos, K., 2003).
[d] The economic productivity at the German coast (Hagner, 2003).
[e] Water and ship management, Federal Ministry of Transport, Building and City Development, Germany. http://www.wsv.de.

Figure 2: Parameters utilized to run their spill cost model, based on values written below regarding to the north sea cost of Germany.
(Wirtz & Liu, 2009)

At the Figure 2 it is possible to see that not only the resources (tourism, beach, water, fisheries, etc...) were taking into account, but also the facilities used to "fight" the spill (combat boats) and their rent per hour. It is important to say that in this modelling it was also determined the time of recovery of the oil and weathering processes, sedimentation of the oil, evaporation, submersion etc. In that model 72 scenarios were run in order to simulate a range from 7 to 2200 tons of spills at Germany north sea area, as results expenses would vary from 1.28 million to 41.27 million euros, quantities that by the time (2006) represented 0.0021% of German GDP. So if this quantity is applied to a more fragile economic country and also add variables of size of spill and ecological and economical value of the affected area, numbers can be even higher according to Wirtz(2009). This gives a perspective of how this type of accidents are costly to administrations and can be an important challenge for coastal managers all around the word that, not only face environmental depredation and damage problems, but also, a chain of issues that are interconnected in between all society factors (economic activities, public health, etc...) which turns an oil spill into a very complex and critical situation.

1.2.1 Concept of oil and its interaction with human organisms

Oil or it's most general term, "crude oil", is a mixture of different compounds that have toxic substances and are mainly composed by VOCs (volatile organic compounds), PAHs (polycyclic aromatic carbons), Hydrogen sulfide and heavy metals (Pena et al., 2020). Humans can interact with those dangerous materials in different forms, as its generally presents in a dark dense liquid, crude oil can be inhaled, ingested primarily or secondary contact (through a contaminated animal) and absorbed through the skin (Pena et al., 2020).Toxicological risks are severe, PAHs contaminated water bodies can be a great source of cancer development, affecting children and adults acting silent through skin absorption (Howard et al., 2021). Also, these substances can impact the human organisms altering and deforming reproductive systems of male and female individuals (Pena et al., 2020), not only chronic health issues are provided by those compounds, also acute effects have been found, aromatic compounds also present in some toxic fractions of petroleum can induce death by poisoning, VOCs have been associated to hematologic and immunologic disorders, hepatic and hormonal alterations, mental disorders and even genotoxic damages (DNA damage) (Aguilera et al., 2010) (Pena et al., 2020).

Furthermore, heavy metals found in crude oil composition as cadmium, arsenic, chromium, manganese, copper, vanadium, nickel and lead are responsible for different diseases such as renal injuries, neurotoxicity, carcinogenicity and immunotoxicity (Pena et al., 2020). According to Howard(2021), Pena et al.(2020) and Aguilera et al.(2010), the degrees and type of damage related to crude oil exposure depends of its composition and amount of contact, but it is concordant that it is a hazardous material with numerous acute physical, psychological, genotoxic and endocrine effects, that can be life-threatening.

1.3 Oil spill remediation techniques

For the containment and mitigation of the impacts of oil spills, several numbers of remediation techniques were developed to attend different scenarios and strategies, with the aim to provide alternatives that could fit in diverse administrations budgets, nature of the material that forms the leaked crude oil, characteristics of the environment that will receive this material and in general, the interaction in between the oil, sediments and water column (Singh et al., 2020).

1.3.1 Mechanical or Physical techniques

-Booms-

Those materials consists in large floating devices that are dragged on the surface of water bodies by boats,they are made up of polyurethane, polystyrene, bubble rap or cork.They provide a kind of incarceration of the spill forming a floating barrier, that has the objective to not let the material spread and reach nearby ecosystems as beaches, wetlands, etc... They can also be effect not only to stop the evolution of a spill but also can diverge the trajectory of it, directing the oil away from critical and sensitive areas (Dave & Ghaly, 2011) (Singh et al., 2020). According to Potter and Morrison, 2008 in Dave & Ghaly(2011) there are 3 different types of booms; curtain booms, fence booms and fire-resistant booms.

Table 1: Boom type and main advantages

Boom type	**Curtain**	**Fence**	**Fire-Resistant**
Every Type of oil	X	X	X
Easy Handling		X	
Easy Towing	X		
Easy storage and cleaning		X	
Resists abrasion	X	X	
Fire protection			X
Oil recovery	X	X	

Table 2: Boom type and main disadvantages

Boom type	**Curtain**	**Fence**	**Fire-Resistant**
Expensive	X	X	X X
Intensive labor	X	X	X
Hard towing		X	
Needs other technologies	X	X	
Complex	X	X	
Not effective in high waves	X		X
Difficult handling	X	X	X

-Skimmers-

According to Dave & Ghaly(2011) , skimmers are devices that can be used with the booms to help on the process of recovery of oil from the water surface, this instrument can have different forms, belts, drums, disks and brushes. Skimmers can be operated from vessels and also used from shore or automatic by a before hand program, its efficiency depends of the type of the spill, the water and weather conditions. They can be divided in three categories; weir, oleophilic or suction.

Table 3: Skimmer type and main advantages

Skimmer type	**Weir**	**Oleophilic**	**Suction**
Flexible with different oils		X	X
Oil recovery	X	X	X
Work with debris and/or ice		X	
Stability in rough conditions	X	X	

Table 4: Skimmer type and main disadvantages

Skimmer type	**Weir**	**Oleophilic**	**Suction**
Expensive	X	X	X
Intensive labor	X	X	X
Complex	X	X	X
Easy to jam or clogg	X X	X	
Cannot work with mixed material		X	
Cannot stand rough conditions			X

-Absorbent materials-

This type of technology is mainly constituted of hydrophobic sorbents, that generally follows the skimming processes in a determined oil stain, cleaning up the oil that remained at the contained (or not) area, they facilitate the separation in between the liquid and semisolid phases of the spill. (Adebajo et al., 2003; OSS, 2010) in (Dave & Ghaly, 2011). They can be divided in three different types; natural organics (Peat moss, saw dust, vegetable fibers...), natural inorganic (Clay, glass, wool...) and synthetic materials (polyester foam and polystyrene) (Karakasi and Moutsatsou, 2005 and (Holakoo, 2001) in (Dave & Ghaly, 2011).

Table 5: Absorbent material and main advantages

Absorbent Material	**Natural organic**	**Natural inorganic**	**Synthetic**
Flexibility with oil type	X	X	X
High absorbing rate	X	XX	
Easy to handle			X
Can be reused			X
Environmental friendly	X	X	
Absorbs ONLY oil			X

Table 6: Absorbent material and main disadvantages

Absorbent Material	Natural organic	Natural inorganic	Synthetic
Intensive Labour	X	X	
Expensive			X
Health risks		X	
Non biodegradable			X
Difficult handling	X	X	

1.3.2 Chemical techniques

Chemical remediation techniques are another type of spill combatant that is generally used within mechanical techniques to improve the efficiency of the cleaning, but also can be applied alone (Lessard & Demarco, 2000) (Dave & Ghaly, 2011). The materials used are called dispersants and solidifiers, each one interacting in different ways with the oil, depending from the environmental setting and strategies regarding to the accident scenario. Dispersants consists in reagents (surfactants), solvents or a stabilizers (Singh et al., 2020), being designed with lipophilic and hydrophilic affinity they act dispersing the slick by diffusion into the water column, reducing it's concentration in order to accelerate the degradation of the oil by natural process (Lessard & Demarco, 2000).

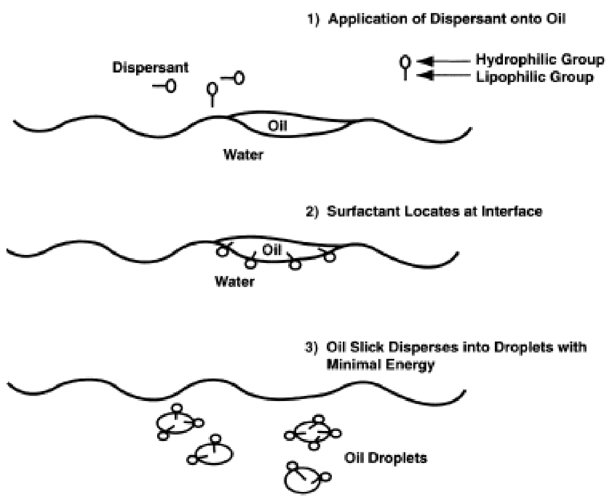

Figure 3: Scheme showing how the Dispersants works when in contact with the oil.
(Lessard & Demarco, 2000)

Dispersants are efficient to avoid the arrival of the spill into sensitive habitats and shorelines removing the content from surface waters, are also usable in rough weather conditions (e.g, storms, currents...) whereas a mechanical technique appliance maybe can be difficult to perform, furthermore, large areas can be easily treated because of the possibility of aircraft appliance (spraying the material from above) and it's appliance can provide more time window to the response (Lessard & Demarco, 2000). Those products have limitations regarding to timing of appliance, as the dispersants needs to be applied in a certain time-frame in between the beginning of the spill and the time when the oil gets too viscous to be dispersed (Lessard & Demarco, 2000), adding a factor of dispersant effectiveness, and how this factor x toxicity towards the environment relates. According to Almeda et al.(2014) despite of the decrease on the toxicity levels of recent dispersants (e.g Corexit 9500), the wide spread use of this material to fight spills, can represent a significant threat for marine plankton organisms. Almeda et al.(2014) in his studies, reached a conclusion that the Corexit 9500 is highly toxic to micro planktonic organisms and can impact directly on the functions and structures on its communities. Solidifiers (gelators), the other chemical alternative technology for an oil spill cleaning, is generally composed by hydrophobic materials that react with oils to change its physical state into a solid rubber like state, which facilitates it's physical removal (Singh et al., 2020). According to Motta et al.(2018) gelators can be divided into two categories; polymeric gelators (PGs) and low-molecular-weight gelators (LMWGs), they can be naturally (e.g gelatin) or synthetic (e.g poly acrylic acid). Generally, this technology works better when dealing with small spills and can act not only on the water surface, but also in the water column "lifting" the sunken oil in the water column and delaying the spread of the spill (Hum and Hamza, 2016) in (Motta et al., 2018). But also, solidifiers tend to be complex to handle and implement. Variables such; temperature, oil composition, viscosity, surface area, mechanical agitation and other factors have a huge impact on the gelator performance (Motta et al., 2018). But the products, can be an inexpensive, green and fast-effective method when used with proper previous research towards the spill's nature and environment conditions (Motta et al., 2018).

1.3.3 Magnetic nano-materials techniques

Magnetic nano-materials (MNM's) is a type of technology that is being used now to various purposes in the field of wastewater reuse, as the magnetic particles (1-100nm) can interact by affinity with the pollutants being separated from from the water later by magnetic fields, and for oil is not different (Kumar et al., 2015).One example of successful oil "combat" nano-structures is the beta-cyclodextrin that has been proven to be a green, recyclable and efficient material (see fig 4) (Kumar et al., 2015). The nano-particles can avoid fouling and blocking providing more durable and reliable equipment (Shah et al., 2018), however, those particles may represent significant threat to human health if absorbed, inhaled or ingested (Shah et al., 2018).

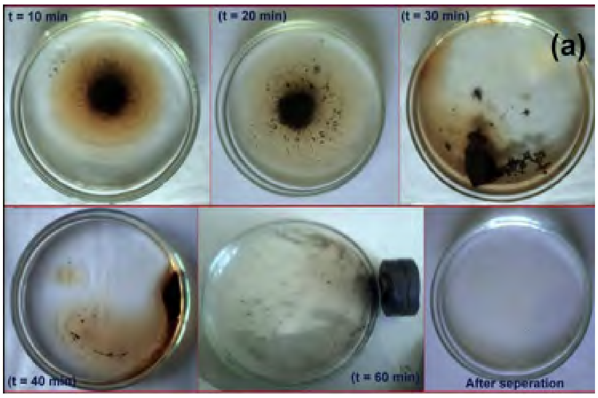

Figure 4: Photos of the interaction and separation of oil, utilizing SPION/beta-cyclodextrin, the oil is "attached" to the nano particles and them separated by a magnet.

(Kumar et al., 2015)

MNM's can also constitute "regular tools" used in oil spill remediation techniques, being the materials in booms, absorbents, skimmers, etc... but also new tools are coming to improve the use of this technology and turn it into a more sophisticated and efficient alternative. One example is the use of propelled autonomous robots. They can hover around the surface of the spill pumping up the oil mixed with water and separating it with the help of nano-particles installed inside it's storage and finally pumping down only water (Shah et al., 2018). This kind of device is also equipped with GPS and solar energy in order to provide a better autonomy and also emits acoustic waves in order to keep the marine animals away (Shah et al., 2018).Being this technology a tool that avoids possible accidental contacts in between humans and nano-particles.

1.3.4 Biological Remediation

Biological remediation techniques consists in the use of microorganisms (overcoming the limiting natural factors), adding exogenous microbial populations or stimulating native ones, in order to accelerate the process of bio-degradation of the hydrocarbons presents in petroleum, crude oil and similar pollutants.The technique also contributes to the area, by providing products of the bio-degradation (nutrients) that could be used by the local organisms, improving local food chain (Atlas, 1995). The efficiency of this technique depends of the bio-availability of nutrients, concentration of oil and area extension which the biodegradation has already started naturally, as the microorganisms tend to compete for the material slowing down the process (Dave & Ghaly, 2011)(Atlas, 1995). Bioremediation when compared to other techniques, presents a significantly economical advantage, with lower costs to be implemented (Atlas, 1995), but still, the nutrient limitations, biodegradators limits for dealing with the oil. Local microbial structures and the oil composition itself, creates a shade towards this remediation technique efficiency (Swannell et al., 1996) in (Dave & Ghaly, 2011).

1.4 The Emilia-Romagna coast.

The Emilia-Romagna coast is located in the northwestern part of the Adriatic Sea, the shoreline is divided into two sectors, northern and southern (being the city of Cervia the boundary), it has 130 km of length and it is developed along the Po plain, being limited northerly by the Po river delta and southerly by the Apennines (Perini et al., 2017). The coastline is composed by low-elevation sandy beaches ridges, with a variety of ecosystems such as wetlands, lagoons and river mouths (Perini et al., 2017). The shoreline has suffered along the years lots of changes and is full of coastal flood defences, human settlements and nourished beaches, being a very artificial shoreline (Perini et al., 2017).

Figure 5: Especial protected zones located at the Emilia-Romagna coast.
(Portale minERva D.G. Cura del Territorio e dell'Ambiente)

According to (Regione Emilia-Romagna, 2010a) cited in Sekovski et al.(2015), there is an environmental difference in between the sectors of the coast, regarding to coastal features, being the north typically a deltaic environment, with reclaimed lowlands, wetlands and brackish water lagoons. Different to a more urbanized south, full of structures built to improve tourism conditions in the area (Sekovski et al., 2015). Apart from tourism, another great factor that increased the human pressure along the E.R coast was the industry development around the city of Ravenna harbour, mainly oil and chemical industries are now spread all along it's surrounding's (Sekovski et al., 2015). In Figure 5 it is possible to see that there is a highest presence of Sites of Community Importance (Council of European Union, 1992) and Special Protection Areas (Council of European Union, 2009) located on the northern part of the coast. The dissipative beaches of the coast are generally constituted by fine-to-medium sand with low elevations and suffers from a chronic erosion issue, caused mainly by reduced sediment supply, dune destruction, and disruption of sediments by human buildings (Preciso et al., 2012)(Teatini et al., 2005) in (Sekovski et al., 2015). Being around 57% of the coastline protected by artificial structures and having beach nourishment's as a common procedure to hold the shoreline. (Armaroli et al., 2009) at (Sekovski et al., 2015).

1.4.1 Waves

The E.R coast has a low energy wave climate, with around 60% of significant wave height (Hs) being less than 1m (Idroser 1996 e Ciavola et al.2007) at (SGSS, 2020), according to (Idroser, 1996) with a prevalent direction of 60º to 120º (SGSS, 2020).The waves of less energy being in the SE quadrant derived by the Sirocco winds and the most energetic ones from E-NE originated from Bora winds (SGSS, 2020).

Table 7: Distribution of wave frequency and direction according to the season (Rapporto Mare, (2021)).

Direction	**Autumn-Winter/Frequency**	**Spring-Summer/Frequency**
E	33.58%	29.28%
NEE	>13.38% < 20.19%	>11.77% < 17.61%
NE	>6.8% < 13.38%	11.77%
NNE	>6.8% < 13.38%	>5.94% < 11.77%
N	<6.8%	<5.94%
SEE	>6.8% < 13.38%	>17.61% < 23.44%

See Appendix A and figure 52 for a more detailed scheme of wave climate.

The waves originated from E, NE and NEE are the ones reaching the highest altitude, from 1.55 to 2.05 meters. On Spring-Summer 91% of the waves are less than 1 meter height, having a slightly difference on Winter-Autumn, where 88% are less than 1 meter height.((ARPAE), 2021)

1.4.2 Currents

The ocean currents in the Adriatic sea are composed by the interactions of tidal currents, bathymetric features, winds and density gradients, in which are mostly influenced by river inputs principally the Po river which is the major fresh water resource of the Adriatic(Orlić et al., 1992) and heat exchange (Bolaños et al., 2014). The general surface circulation of the sea can be described as a large-scale cyclonic meander, with a northerly flow along the eastern coast and a southerly return flow along the western coast, having during winter a more eastern current strengthen and western in summer (Orlić et al., 1992). (Zore-Armanda, 1969 b) in Orlić et al.(1992) States that during summer the North Adriatic water is warmer and less saline than the water mass in the Middle Adriatic which is the main explanation of the southerly flow during summer along the west coast. furthermore the influence of the Sirocco wind appears to be the driven of the eastern flow in winter. The average velocity of the currents are around 10cm/s (Orlić et al., 1992). Also Bora events can also alter the circulation dynamics following a trend of "reversing" the circulation during autumn - winter periods (Bolaños et al., 2014).

1.4.3 Winds

The region is main affected by two winds, Bora and Sirocco, and their dynamics are main drivers regarding to weather, waves and current conditions along the Adriatic coast (Orlić et al., 1994). The Bora wind being a cold and katabatic wind which blows from the northeast and forces highly productive waters from the Po river-mouth into the Adriatic shelf (Orlić et al., 1994). In the other hand Sirocco blows from the southeast bringing warm Mediterranean air and is responsible for piling up water in the North Adriatic occasioning the birth of storm surges along the north coast (Orlić et al., 1994).

1.5 Main events of accidental oil spills

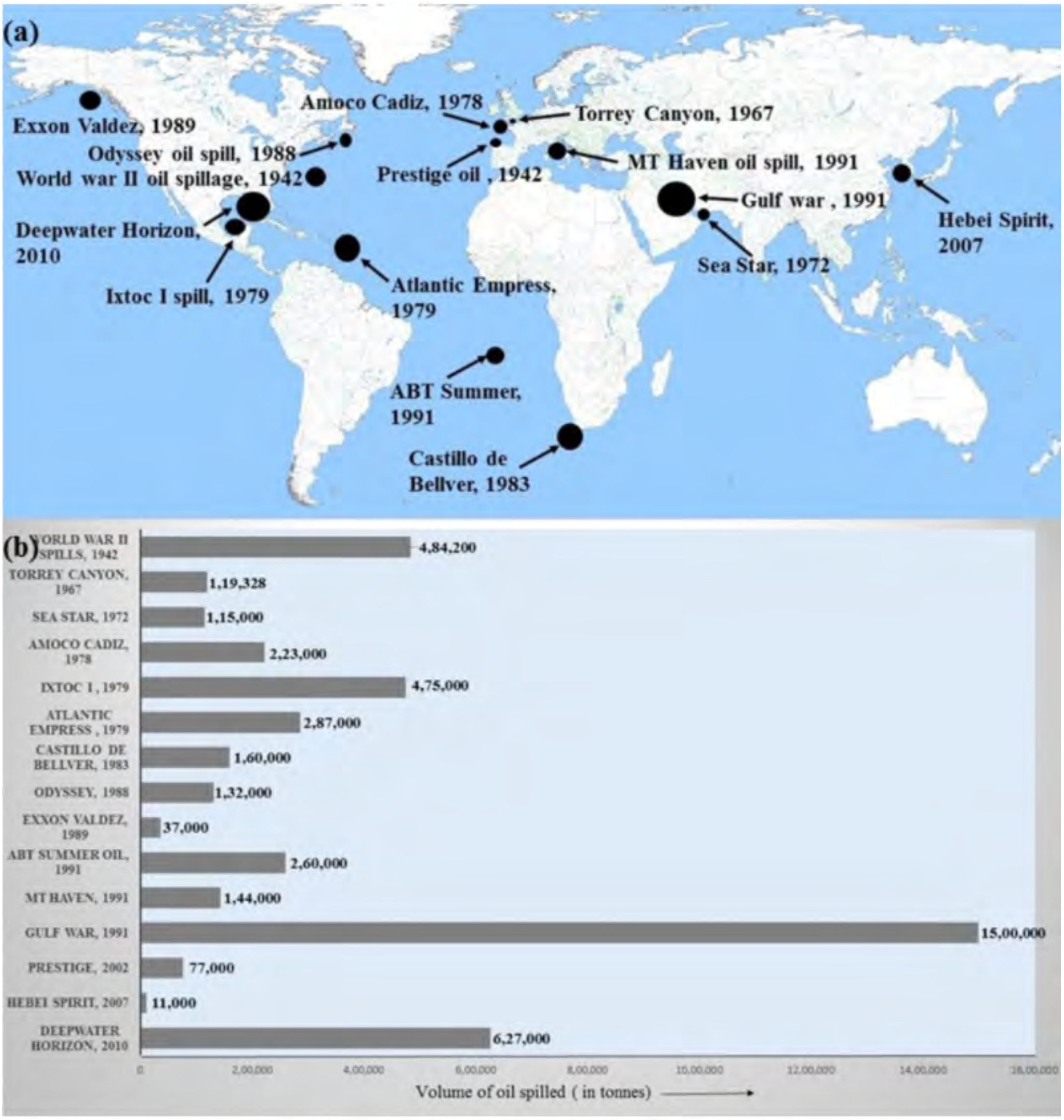

Figure 6: Location of main oil spills since 1942 until 2010, a) shows the locations and b) the volume amount for each accident.
(Singh et al., 2020)

Since 1942 because of the tragic events that followed the world war II, an Atlantic incident marks the beginning of the big oil spill era, although the variety of location that those unfortunate events happened, it is notable as seen in figure 6, that the major spills are mainly concentrated in the northern hemisphere and in the Atlantic Ocean (Singh et al., 2020). South Atlantic incidents, as the "ABT summer" (1991) and "Castillo de Bellver" (1983) in South Africa, were the main threat to Africa and South America coasts in matters of spill size, but, not the only accidents that happened. In 2019 a major oil spill along the Brazillian northeast coastline was determined as the worst spill that happened along the Brazillian coast (Pena et al., 2020). Despite of its importance, it is not displayed on figure 6, because the size threshold of spills were set from 10.000 tons to above (Singh et al., 2020). The Indian-Australian oceanic area are the most oil-safe coasts, without having records of huge spills. What takes different ways when talking about the North-America historical data, which concentrates the highest number of incidents (Singh et al., 2020). European coasts also faced some difficult scenarios, principally Spanish coasts, that held 2 major accidents. Located in the North-Atlantic, the "Prestige" (2002) that happened in the northern part of the coastline along the Galician autonomous community and "Amoco Cadiz" (1978) which happened at the opposite part at the Andalucian autonomous community (Singh et al., 2020).Also, Italian Ligurian coast faced a major event in 1991 "MT Haven", the biggest one that happened in the Mediterranean sea (Singh et al., 2020). By far, the war influenced spills lead on the catastrophic ranks, with more than 4 millions of tonnes spilled, being the gulf war (1991) the highest number, reaching 15 millions of tonnes. The only events that reached closer levels of hazard were the "Ixtoc I spill" (1979), with more than 4.5 tonnes spilled and "Deepwater Horizon"(2010) with more than 6 million tonnes, both located around the Mexico Gulf (Singh et al., 2020). According to ITOPF(2021), fortunately the trends of accidental spills are lowering throughout the decades, with a major reduction from past average of 24.5 spills per year during the 70s to 1.8 spills per year on 2010's.

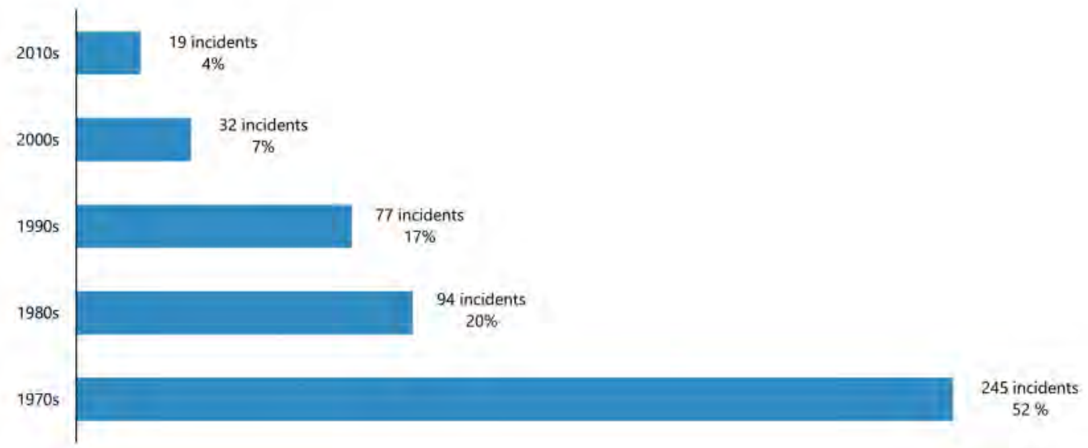

Figure 7: Large spills >700 tonnes, recorded for decades from the 1970's - 2010's, excluding 2020.

(ITOPF, 2021)

According to figure 7 from the 70s to nowadays there was a significant reduction of accidental spills, the advance regarding to raising of awareness, control and security regarding to vessel transit has been fundamental to improve marine safety among a every day denser cargo movement along worlds oceans, government and industries collaboration brought very optimistic number for the sector, as now more than 99.99% arrives safely at its destination (ITOPF, 2021). it is important to say that those numbers are regarding to total events, not only regarding to spills that had a major impact at the coast, as some past spills did not hold potential damage and could be managed with almost none to none intervention.

1.5.1 Oil spills in the Adriatic, historical events

The Adriatic sea faces problems regarding to pollution discharge from a long time, even with efforts to operate surveillance systems (satellite and aerial) by Adriatic nations, the practice of illegal discharging by commercial vessels is common and holds outstanding numbers, as the amount of accidental oil spills that happen in Adriatic waters are estimated to be around five times higher than the world average (Carpenter & Kostianoy, 2018a). Despite of the non-presence of a major worldwide scale oil spill as shown in figure 6, from 1995 until 2005 it was registered 174 occurrences in Adriatic waters, mostly not reaching a pollution area of 10 m^3 by the oil "stain", only 8 events surpassed this mark, being the largest one the "MT Baba Gurgur" spill that happened on the territory of Bakar,Croatia in February 1989, that reached an area of pollution of around 100 m^3 (Carpenter & Kostianoy, 2018a). The heavy marine traffic in the Adriatic, which has an estimated value of 100 to 200 commercial vessels transit at any time, holds a pollution index of 7 to 10 out of total, it is saying that almost 1% of those ships pollutes in any kinda of way, and it could include oil spilling (Carpenter & Kostianoy, 2018a). More than 1000 possible spills were identified at the Adriatic sea in between 1999 until 2004, and for more recent numbers, according to the EMSA (European Maritime Safety Agency) from 2011 to 2015 there were a confirmation of 250 probable spills in the Adriatic (Carpenter & Kostianoy, 2018a). Assessing the data provided on Carpenter & Kostianoy(2018a) of satellite data covering 1,520 square degrees of the Adriatic, It is shown possible oil spills identified, as show on the table below:

Table 8: Possible oil spills in the Adriatic on early 2000's

Year	**Number of events**
1999	223
2000	217
2001	168
2002	210
2003	104
2004	127
Total in 5 years	1049
(Carpenter & Kostianoy, 2018a)	

Most recently, the European Maritime Safety Agency (2007) established a real-time space borne system that supports aerial surveillance on oil spill pollution detection. The platform is know by CleanSeaNet (CSN) and has its data build on satellite data, more specifically; Synthetic Aperture Radar (SAR) images. The CSN has identified in a period from 2011 until 2015, 593 possible slicks, comparing the decade data interval (5 years observations of 1999-2004 and 2011-2015), it is possible to notice a reduction of almost 50% of the total possible events (Carpenter & Kostianoy, 2018a). Furthermore, is important to highlight that, the Emilia-Romagna coast it is not a hot spot of accidental or operational spills, as they were mainly identified on the middle-lower part of the Adriatic sea, having this region the most "accident prone" concentration (Carpenter & Kostianoy, 2018a). But as this work deals with catastrophic situations, past events just serve as an identifier of probable areas and routes, that can be representative for the risk management.

1.5.2 International institutions,plans and cooperation

Since the first big spills in Mediterranean waters caused by the "Haven" and "Jiyeh Power Plant", the countries from the region realized that any of them were prepared to handle alone a huge spill (more than 10,000 tons), and cooperation was needed for not only provide a better prevention for the accidents but also from the operational spills (Carpenter & Kostianoy, 2018b). In order to fulfill this need of cooperation, couple plans were developed in between the states:

- "The Mediterranean Blue Plan" implemented since the 70s has the purpose to finding environmental problems and allow a more sustainable development through different sets of tools; Development of databases related to environment, economy and society; Analysis of the major geographical and ecological issues using systemic methods; Publication of studies; Development of experts networks along the Mediterranean countries;Support the reviews of the Review of the Mediterranean Strategy for Sustainable Development and the Operation of the Mediterranean Information System on Environment and Development (Carpenter & Kostianoy, 2018b).

- "The Regional Marine Pollution Emergency Response Centre" (REMPEC), was founded in 1989 and carried out some structures from its predecessor the 1976 "Regional Oil Combating Centre", in order to facilitate the cooperation among the countries towards oil pollution, establishing a regional information system and developing each members national capacities, mainly focusing on preparedness and prevention of spills (Carpenter & Kostianoy, 2018b). REMPEC is managed by the International Marine Organization (IMO) in a co-lab with the Mediterranean Action plan under the United Nations Environmental Program (UNEP) Mediterranean Action Plan (MAP)(Carpenter & Kostianoy, 2018b).

-"The EuroMed Partneship", this partnership despite of the name, does not only assesses European countries, but, 28 EU Member States and more 15 non-European countries. It was established based on past "Barcelona agreements" and other new agreements, aiming economic integration, environmental actions, energy supply, health, migration and culture (Carpenter & Kostianoy, 2018b). The main priorities are; A clean Mediterranean Sea; Creation of maritime and coastal fast tracks;A common civil protection program for response and preparedness to catastrophes; The development of alternative energy sources; An Euro-Mediterranean university (inaugurated in Slovenia in 2008) and a support program for the development of small companies that wants to carry on their activities on Mediterranean waters (Carpenter & Kostianoy, 2018b).

Also it is important to mention the EMSA (European Maritime Safety Agency.) which acts monitoring all European maritime areas, and also, offers support regarding to oil spills, furthermore the specific Adriatic plan HAZADR, a cross-border initiative that gathers different tools, guidelines and even provided drills, for the development of combating spills efficiency (Lauro et al., 2015).

1.6 Oil spill governance: Management and institutions in charge of oil spill at international and national level

1.6.1 Governance and designations in Italy

- Decree on sea protection (Ministerio della marina mercantile, 1982)

The first Italian Law created to regulate marine pollution was approved in 1921 (Carpenter & Kostianoy, 2018a) for regulating industrial waste, nowadays it is the Law 979/82 (1982) that was crafted by the regent Minister of the Merchant Navy at the time, in order to protect Italian seas from harmful substances and pollution for preservation of the marine resources. Basically this was the first regulation that could be applied to oil spill accidents and it is the benchmark for the development of the subsequent regulations.

Governance regarding of oil spill response in Italy is divided in three levels; strategic decisions, which is carried by the Ministry of Environment; the operational responsibility, designated to the Coast Guard and if the size of the accident reach a catastrophic event, the issue is taken by the Civil Protection which is linked directly with the Prime Minister (Carpenter & Kostianoy, 2018a). The national plan, elaborated and operated by the Civil Protection is the most complex plan and involves a emergency situation in a national level, its application gathers all the regional competent authorities whereas the spill is going to impact, from the environmental protection agencies to the territorial army corps, every institution is taken into account (PCN, 2010). This procedure follows the law 225/92 article 5, that attributes the responsibility of this decision to the minister's council consent, or it is straightly declared by the president of the council as determined by the law 286/02 article 3 (PCN, 2010). For the matter of facts, any other size of spills that are not declared as a national emergency, is fought by local administrations and/or the ministry of the environment, for a better illustration, operational levels can be separated and simplified by the table below:

Table 9: Operational Oil Spill levels

Level	Threat size and conditions
1	Small quantity and far from the coast/protected areas
2	Small or medium and dangerous to coast/protected areas
3	Large and exceptional resources required
(Carpenter & Kostianoy, 2018a)	

2 Material and Methods

In order to provide efficient and realistic oil spill prevention a set of tools need to be analysed and utilized aiming an integrated approach, as the issue is treated as a coastal management competence, which gathers multidisciplinary fields of science, from economical, tourism and social factors, until physical, biological and chemical. The work assesses core information from past oil spills at the region, critical high valued environmental areas, regent regulations, institutions and furthermore catastrophic scenarios simulated following local ship transit in order to provide a drill situation, in which integrated coastal management and oil spill remediation tools would help the mitigation of the impacts caused by an accidental spill event.

2.1 The precautionary principle

the development of a management plan for oil spill situations follows a concept that is well spread into environmental frameworks around the world, the Precautionary Principle (Persson, 2016). The main ideas of it enforces that where are threats of serious or irreversible damage, event without science confirmation or certainty, those events need to be anticipated without postponing and every measure should be taken to prevent environmental degradation (The United Nations Conference on Environment and Development, 1992) in (Persson, 2016). Roughly, lack of scientific proof cannot be an excuse for a well-know catastrophic risk situation and precautionary actions must be done foreseeing potential damages. That concept can be applied to the oil spill accidents reality, as the nature of the issue is mainly originated by well-know and controlled components (vessels) that are (in most cases) subjected to national regulations and legislation's, being an "easy monitoring" subject, which the science in-certainty component is not a problem. Although vessels can be monitored, still, they carry some aspects pointed by the precautionary principle, such as, the potential for causing irreversible impacts, not only for the environment,but also for human health.The value of human health and environment are generally targets of actual trade offs, which is one of the main challenges faced by the precautionary principle, as according to today's social structure, economical factors collide with health and environment, turning scenarios involving decision making very hard to reach a common ground. Those difficult connections in between different values develop a situation whereas a type of "war tow" is born, developing a cost-benefit analysis, raising discussions in between stakeholders regarding to if the precaution its worth it or not (Persson, 2016). For this work, oil spills follow the premise that those events need to be anticipated and be treated as a public health and environment catastrophic event, in which needs to be prioritised as one of the main threats faced by a coastal society having the potential to influence economical, sociological and health aspects.

2.2 Waste Management

This part of risk preparedness is one of the main aspects on a remediation plan for oil spill accidents, despite of the facts that waste treatment and regulations are already covered by EU legislation's Council Directive 91/689/EEC on Hazardous Waste by Directive 2008/98/EC, the Waste Framework Directive (IPIECA-OGP, 2014), it is important to identify and track solutions to store the waste, transport and treat it, along the local community in question in away to be less damage to the environment as possible and also providing safety for public health (IPIECA-OGP, 2014). In case of accidental oil spills there is a trend of "amplification" of pollution, it is saying that, the amount spilled tends to produce more waste than the volume that was leaked (IPIECA-OGP, 2014).

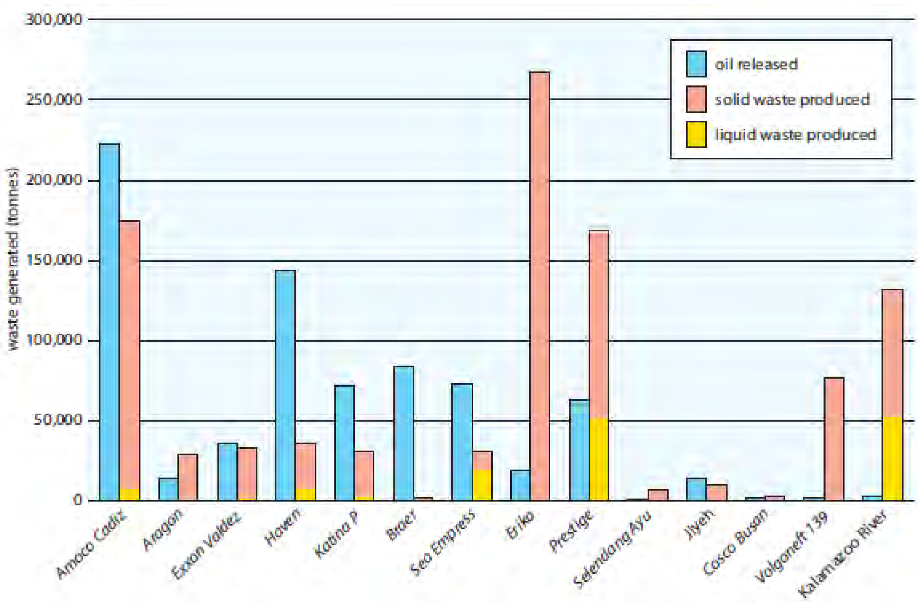

Figure 8: Amount of waste that historical data spills produced. (IPIECA-OGP, 2014)

To achieve a proper efficient waste management plan, some strategies were defined by (IPIECA-OGP, 2014): - Use licensed waste management companies near the area, that are reliable.

- Implement a data and record system.
- Ensure that the staff is trained and aware about regulatory requirements.
- Incorporate waste minimization and clean up techniques.
- Investigate and evaluate alternative landfill disposal.

So for the Emilia-Romagna coast the plan would have to comply with those strategies, adapted for its local reality. Also the place of storage of this waste should be assessed, according to some guidelines from (IPIECA-OGP, 2014):

Table 10: Waste storage location criteria

Criteria	**Storage**
Occupancy	0 - 1 years
Capacities	1,500 to 3000 m^2 surface area
Pits volume	100 to 200m^3
Distance from storage	$<$ 5 km from the coast up to 30 km
Access	Easy access by heavy transports
Land Conditions	Flat and graded
Hydro-geological factors	Avoid groundwater systems
Environmental conditions	Safe distance from populated areas $>$100m
Drainage	Rain runoff system and impermeable subsoil
Cultural heritage zones	Avoid them
(IPIECA-OGP, 2014)	

To obtain options for the completion of waste storage criteria, a GIS analysis of land use / protected areas plus the identification of waste treatment plants, can be used for trying to find desired locations that can comply with the conditions stated by (IPIECA-OGP, 2014).

2.3 Oil spill vulnerable areas at the Emilia-Romagna coast.

The HAZADR project was a cooperation of Adriatic nations to provide data and tools that could be used for the prevention, remediation and assessing of oil spill accidents (Lauro et al., 2015). Within this report a vulnerability map of the coast was built utilizing the PSCM (Point Count System Models) method which works as a Parameter Weighting and Rating that gathers information of important parameters that could be affected by an accidental spill, such as; ecological vulnerable zones, priority areas, economical important resources and its drivers (Lauro et al., 2015). The criteria of vulnerability divided the coastline in 4 main color indexes valued from 2 to 5: green, yellow, orange and red, being green (2) the less vulnerable and red(5) the most vulnerable area. To build the vulnerability criteria, environmental and socio-cultural structures from the Emilia-Romagna coast were evaluated regarding to it's response towards an oil spill impact. For example, regarding to environmental indexes, areas with higher natural value, particular biodiversity or special protection were considered higher vulnerability zones, while urbanized areas presented lower vulnerability values because of the lack of natural resources that could be affected. For the socio-economic aspects, the activities present on the cost were taking into account, for example, ports and offshore fish stokes were taken as low vulnerability factors, meanwhile,touristic areas, archaeological sites and shellfish cultivation and nursery were pointed as high vulnerability units (Lauro et al., 2015). To build the map, the value of each unit was also weighted into their resource group (see Table 11) and with that a development of 3 maps was possible: total, human and environmental vulnerability.For this study,the total vulnerability map was chosen in order to understand as a whole the main sensible areas and define priority zones, whereas the oil spill would be more hazardous and incorporate that in the risk management assessment. So, with the simulated scenarios, it would be able to see which coastal stretch would be more impacted, and based on different indicators (Environmental, socio-economical and cultural) try to quantify the impacts in order to estimate how badly a medium size oil spill could affect the ER coast.

Resources type	Resource category	Resource group	
ENVIRONMENT	Shoreline character	Exposed rocky headlands; Eroding wave-cut platforms; Fine-grained sand beaches; Course-grained beaches; Exposed compacted tidal flats;	Mixed sand & gravel beaches Gravel beaches Sheltered rocky coasts Sheltered tidal flats Salt marshes
	Plants & Animals	Plants – terrestrial, wetland and marine plants and algae Birds / Fishes Invertebrates Reptiles Mammals	
	Protected sites	International; Marine protected areas; Marine reserves; Wildlife Sanctuaries;	Scientific/nature reserve Wildlife refuge Wildlife Management reserves Scenic Reserves
HUMAN	Economic	Shipping/ports; Aquaculture; Tourism	Fishing Infrastructure/Coastal
	Cultural	Cultural, traditional Archeology	
	Social, Amenity & Recreation	Fishing; Diving; Shellfish harvesting	Boating Bathing waters

Figure 9: Table developed with the required parameters for the vulnerability assessing.

(Lauro et al., 2015)

As the data required was very large, a project called SHAPE (Shaping an Holistic approach to Protect the Adriatic Environment between coast and sea) funded by the IPA CBC Adriatic program, was also incorporated to the HAZ-ADR cluster, being essential for the development of multilevel and cross-sector governance system. For assessing effectively the coastal vulnerability, a holistic and integrated management approach was done fomenting data of natural resources, risk prevention and conflict resolution (Lauro et al., 2015). The mash up in between the two agreements was fundamental for the integration of the HAZ-ADR data collected by the diverse countries and also combined the SHAPE data with the vulnerability data requirements (Lauro et al., 2015), covering almost the whole Adriatic coast and making it possible the weighting of vulnerability of each group on the table (Lauro et al., 2015).

Table 11: Mapping criteria

Group	Units
Coastal Morphology	Shoreline type (grain, size, slope) Exposure to wave and tidal energy Biological productivity and sensitivity
Biodiversity vulnerable areas	Protected areas Diversity of coastal ecosystems and habitats Endangered species
Socio economic features	Fishing activities Aquaculture Water intakes Tourism and recreation areas Ports Industrial activities Oil facilities (transport, production and exploration) Cultural sites
(Lauro et al., 2015)	

The scale of the associated values were 0 - 10, being 10 the highest vulnerable (Lauro et al., 2015).Values were assigned taking assumptions. For example, ecosystems as wetlands are considered at more risk than rocky beaches as the oil when reach those kind of areas, are very difficult to clean and the assess/transportation to those zones are generally harder, and carry more biodiversity and has a less wave exposure. Following the trends of impact, shellfish aquaculture has higher vulnerability than offshore fish stokes ,as it is assumed that, shellfish aquaculture are largely important for economic reasons and depends more from an optimal water quality, as shellfish acts as filters being easily contaminated (Lauro et al., 2015). The Tables 12 and 13 shows some scores related to environmental and socio-cultural coastal activities:

Table 12: Example of associated values socio-economical

Human use	**Score**
Seaports	3
Tourism	8
Archeological sites	10
Commercial fisheries	**Score**
Offshore fish stokes	2
Fish breeding / nursery	7

Intertidal and shellfish aquaculture	10
(Lauro et al., 2015)	

Table 13: Example of associated values environmental

Protected area type	**Score**
Scenic reserves	2
Wildlife refuge	6
International	10
Coastal types	**Score**
Exposed rocky headlands	1
Exposed compact tidal flats	5
Salt marshes	10
(Lauro et al., 2015)	

So, relating to the Figure 10 the indexes would show according to its value and color, the degree of complexity towards the management of an oil spill on the desired area.

2.3.1 Map and vulnerability of coastal sections

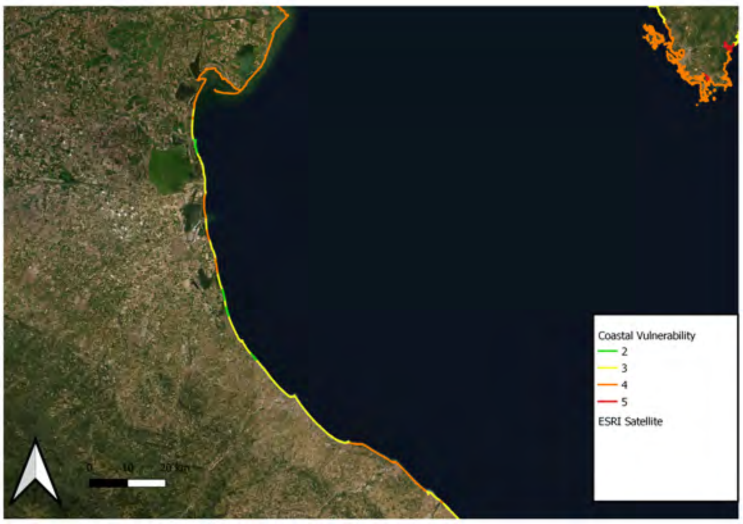

Figure 10: Vulnerability of the ER coast with the indexes.

Figure 11: Vulnerability distribution along the coastline.

2.4 Estimating the cost of impact

The methodology used to quantify the impacts is a modified version by the methodology utilized by Trang(2006) and developed by Etkin,2005, the figure below shows how the tools provided were integrated for the use of this work:

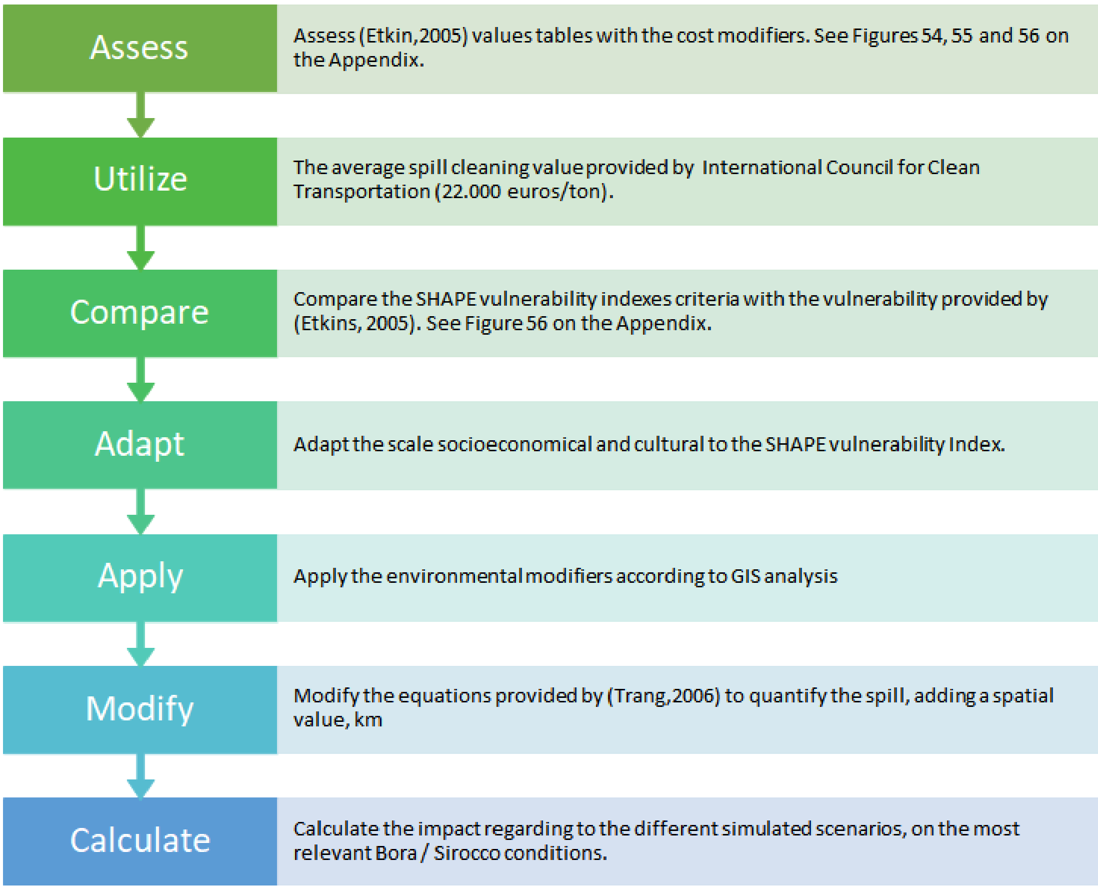

Figure 12: Workflow showing how the estimation of cost was carried on.

- Assessment of Etkin (2005) tables, through Trang (2006): The tables in question were developed by environmental consultants for EPA (Environmental Protection Agency, US) in order to model costs of oil spills, that's why the tables have the title BOSCEM, which stands for (Basic Oil Spill Cost Estimation Model). The tables were chosen because it was possible to find coastal environmental units that are present on the Emilia-Romagna coastline, Hence, the similarity with the holistic approaches done by SHAPE project on Lauro et al.(2015) regarding to the vulnerability of the coastline, were also a point considered. In a matter of fact, the two works approached the evaluation of the environments vulnerabilities and sensitivities with consonant patterns.

- Utilizing and modifying Trang(2006) equations: The equations were used according to Trang (2006) methods. Changes done for this work were the swap of units, gallons to tons, and the addition of a spatial feature, kilometers.

- Comparing and adapting the table values of 53 with the SHAPE vulnerability map, Figure 10: For the comparison of works, the indexes provided by the SHAPE project were mashed with the socio-economical cost modifier. The idea was to approximate the two factors, and translate the indexes from the map into the table 53. With that, the Table13 could be made, combining the indexes with the cost modifiers values.

- Applying the values on Tables 54 and 55 according to GIS analysis: GIS tool QGIS and the land use map (Fig14), were used for the identification of the coastal environmental units. After the identification of the units, the Tables 54 and 55 on Appendix A were assessed for the translation of the units into values.

- Calculating the spills:

2.4.1 Cost modifiers and vulnerabilities tables

On the Appendix A it is possible to assess the EPA BOSCEM tables presented on (Trang, 2006); Tables 54, 55, 53. The vulnerability provided by SHAPE on (Lauro et al., 2015), was than compared with the Table 53 for correlation of the values of vulnerability, scaling it accordingly, it is saying that, the green values corresponded to none to low risk values whilst the yellow the moderate / high risks and orange the very high and extreme risks. As the table presented on Trang (2006) had 6 classifications and the vulnerability indexes found on (Lauro et al., 2015) had 3, an adjustment was done to mash the cost modifiers simply taking the average scales of 2 subsequent values. For example; the mean of the modifier of no risk and the low risk corresponded to the green index of vulnerability, and the same procedure was taken for the other values, and when applied the values were determined on Figure 13.

Applying to the vulnerability:	
None and minimal values combined	0.2
High and moderate values combined	0.85
Very high and extreme values combined	1.85

Figure 13: Correlation in between the values from Etkin (2005) with the vulnerability provided by SHAPE on HAZADR (2015)

For the land use cost modifier the values found on the Appendix A on; 54 and 55 were determined to the current location whereas the oil arrived on the different simulations, for determining that a GIS and previous map check was done in order to find the most suitable criteria for the modifier.

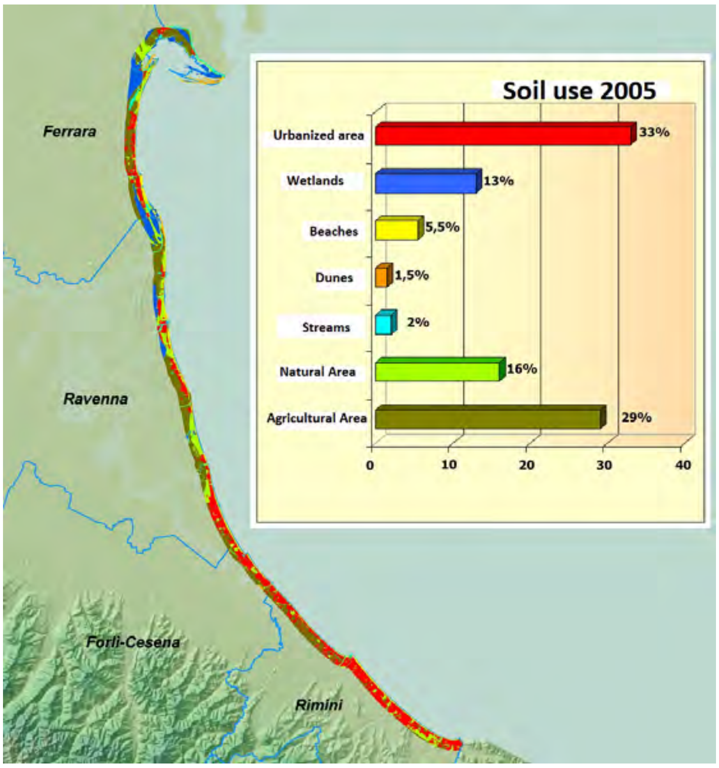

Figure 14: Map showing the land use of the ER coast. (https://ambiente.regione.emilia-romagna.it/it/geologia/geologia/costa/sistema-informativo-mare-costa)

2.4.2 Calculations of costs of impact

According to Trang(2006) it is possible to estimate the impacts of oil spills by utilizing simple equations evolving modelling values previous presented by Etkin (2005) and associating to the volume of the spill with the impact based on economic losses. (Trang, 2006) equations try to integrate the main factors that can modified the costs of a oil spill in order to make a closer approximation to reality, as modelling spill costs are a hard task that depends from various cross and not linear variables, as the clean up process it self can be held into different conditions and settings (Shahriari & Frost, 2008).

The equations provide by Trang(2006) are:

- Total socioeconomic damage cost = per-gallon socioeconomic cost x socioeconomic cost modifier x spill amount
- Total environmental damage cost = per-gallon environment cost x 0.5 (freshwater + wildlife modifier) x spill amount

The values utilized by Trang(2006) are on gallons, so, for adapting into a more European reality, the value that will be used for cost is the average cleaning cost value per ton determined by the International Council for Clean Transportation (2018), which is 24000 dollars per ton or at the time of conversion of this work, the equivalent of 22000 euros. Also one of the modifications for a better visualization of the impact cost is the adding of a spatial variable to the equations, to relate the damage cost per kilometers of coastline, when applicable. So the final equations after the modifications would be:

- Total socioeconomic damage cost = (per-ton average value x socioeconomic cost modifier x spill amount)/km of oil stain
- Total environmental damage cost = (per-ton average value x 0.5 (freshwater + wildlife modifier) x spill amount)/km of oil stain

2.5 HAZADR risk vessels observed along ER coast.

The risk vessels assessed were based in the COMADEX (Coastal Marche region Dangerousness Exposure) index, that was developed under HAZADR dispatching system scanning ships profiles in a way to track oil transporting vessels, monitoring and categorizing them according to their accident prone risk (Lauro et al., 2015). The parameters to obtain COMADEX are five:

Table 14: COMADEX parameters

Parameter	**Condition**

Type of ship	Passengers vessels represent less risk than cargo transport
Gross tonnage	The bigger the ship, the higher dangerous potential
Launched	The older the riskier: 6 < 20 years medium, >20 high
Flag	Ships from low detention rates states are safer
Register	Certified and recognized ships poses lower risks
(Lauro et al., 2015)	

Also on the COMADEX was added 2 extra parameters to be considered by the HAZADR partners which was the sea and weather conditions (Lauro et al., 2015). To incorporate that with the other parameters the Beaufort (wind conditions) and Douglas (waves conditions) scales were used (Lauro et al., 2015). For this work the sum of the COMADEX alert was used throughout the year, in order to identify along the ER coast and in it's proximity, the most dense alert areas, it is saying that, the COMADEX was used as a reference for geographic positioning of a possible oil spill catastrophe, that would be essential for the GNOME simulations.

2.6 Hazard risk density alerts and spill positions

Figure 15: COMADEX HAZADR alerts in one year sum (2019), brightest colors means more density of alerts.

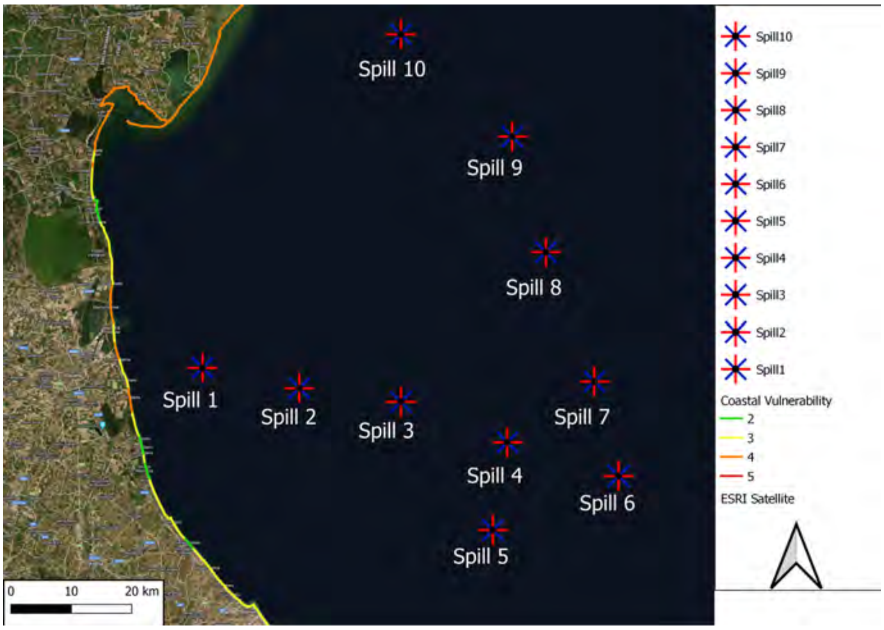

Figure 16: Positions of spills
(Author)

2.7 GNOME model and scenarios

GNOME (General NOAA Operational Modeling Environment) is a program used for modelling fate of pollutants, the product has different platforms and can be assessed on desktop or web, in the case of this work, the platform used was the WebGNOME, which comes integrated with the ADIOS (Automated Data Inquiry for Oil Spills) another tool that can provide the weathering of the oil and the balances of all the processes within (Sedimentation, Evaporation, Beached and floated). To set up the model conditions were chosen for the input based on 2 storms registered by ARPAE (Agenzia Prevenzione ambiente energia Emilia-Romagna), that happened in between the following dates; 04/12/2020 - 13/12/2020 and 22/03/2020 - 31/12/2020; being the first under Sirocco conditions and the second Bora conditions. The use of storm data is to try to reproduce worst case scenarios whereas the Beaufort and Douglas index were maximized (Stato di Mare), raising overall risk of accidents towards the vessels. Furthermore, simulations that the spill does not reach Emilia-Romagna coast domains are going to be excluded. The data of currents and winds during the events were acquired by netCDF files provided and generated by the ARPAE, utilizing DEXT3R (2022), which is the region's environmental agency free database, where it is possible to extract different variables related to meteorological data. The GNOME inputs are mainly related to the environment conditions where the spill happened, type of oil and it's properties and the timeline of the event:

Table 15: Gnome Inputs

Environmental input	**Settings**
Water property	Salinity, Temperature, sediment load and Wave height
Gridded winds	netCDF wind files
Currents	netCDF currents files
Horizontal Diffusion	Standard value provided by GNOME
Spill Input	**Settings**
Oil type	Defined by author
Spill type	Point or line release continuous or spatial
Amount	Defined by author
Release rate	Defined by author
Release duration	Defined by author
Position	Defined by author
Windage	Standard percentage by GNOME

-Water property: For this input there were four main variables to be fulfilled; Water temperature, Salinity, Sediment load and Wave height, according to Orlić et al.(1992) on winter months (period in which the simulations were run) the North Adriatic Water (NAW) has a temperature ranging the 11º celsius with a salinity of 38 PSU and the sediment loads are considerably high, possibly reaching some values higher than 1kg/m^3, as the GNOME model has 1kg/m^3 as the maximum value, this was the value chosen for the simulations based on the relevant influence of Po River discharge and the happening of high energy marine phenomena as strong waves that influence on higher numbers.

-Gridded winds: The Gridded winds were chosen according to periods in which a Sirocco and a Bora event were identified, so two grids were generated with its velocities, one from 22/03/2020 until 31/12/2020 (Bora event) and 04/12/2020 until 13/12/2020 (Sirocco event), the 2 files were extracted from the ARPAE database and only 7 days of data were use, in order to catch the proper event window where the winds characteristics are well defined.

-Currents: For the currents input, a netCDF file was provided by the ARPAE for the same interval as the gridded winds, as the model does not run if there is not a timeline match in between these two factors.

-Horizontal diffusion: This input was defined by the GNOME standard value for open waters.

-Oil Type: The oil type was selected by the location of its exporter and its presence on Adriatic / Mediterranean waters, so for that, the ADIOS database was used to export an Iranian crude oil labelled "ABOOZAR". The pollutant is has an API (American Petroleum Institute) of 27 (light oil) and it is mainly composed by saturated hydrocarbons, with a reference temperature of 15° Celsius and a density of 0.892 g/cm^3.

-Spill Type: To simulate a crash or an accident caused by a sudden damage nature, the point spill release with continuous volume was chosen, with the point of release being static.

-Amount: The amount of the input was 700 tonnes, this value was based on the medium highest tonnage of ships that transit on Adriatic, for example on Ravenna port, according to Carpenter & Kostianoy(2018a) it is common to have ships transporting liquid cargos from 10 to 700 tonnes, being 700 a medium size category. Also it is important to say that from 150 tonnes and above the ship is considered a potential risk cargo, at least on Ravenna port.

-Release rate: This input was chosen according to the release duration, it is saying that, the amount was calculated to be divided into equal interval of time from the release duration below.

-Release duration: The duration chosen was 2 hours, so for the input above "Release Rate" it was 350 tonnes per hour.

-Position: The positions were based on HAZADR(2015) density of alarm (risk vessels) and the input had the directions as shown on Figure 16.

-Windage: This input was also utilized on standard values provided by GNOME, assuming that the vessel had a minimum displacement regarding to the winds, values ranging for 1% to 4% during 15 minutes, assuming an almost static position.

3 Results

3.1 Overview of spills on 7 days of simulations

These primarily Results section shows the overall trajectory of the oil spill during the 7 days of simulation. The particles of the figures are categorized according to time (24 hours interval). The range goes from white (most recent particles of oil) related to the first hours of the simulation, until crimson (most older particles of oil) which represents the last hours of the simulation.

3.1.1 Spill simulation 7 days during Bora event window.

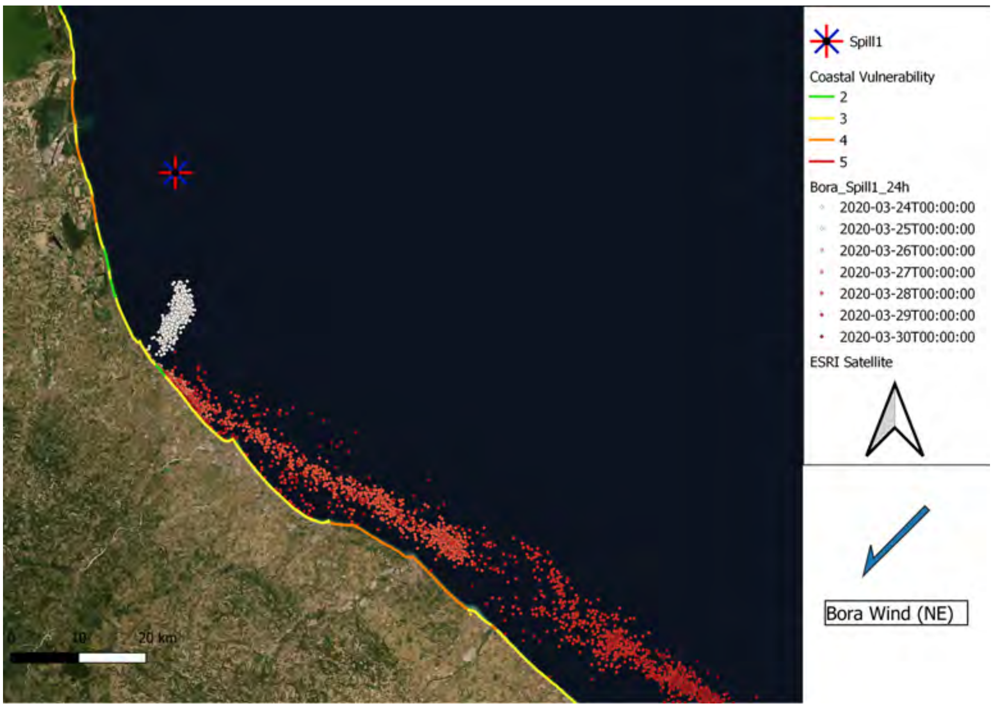

Figure 17: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 1 position.

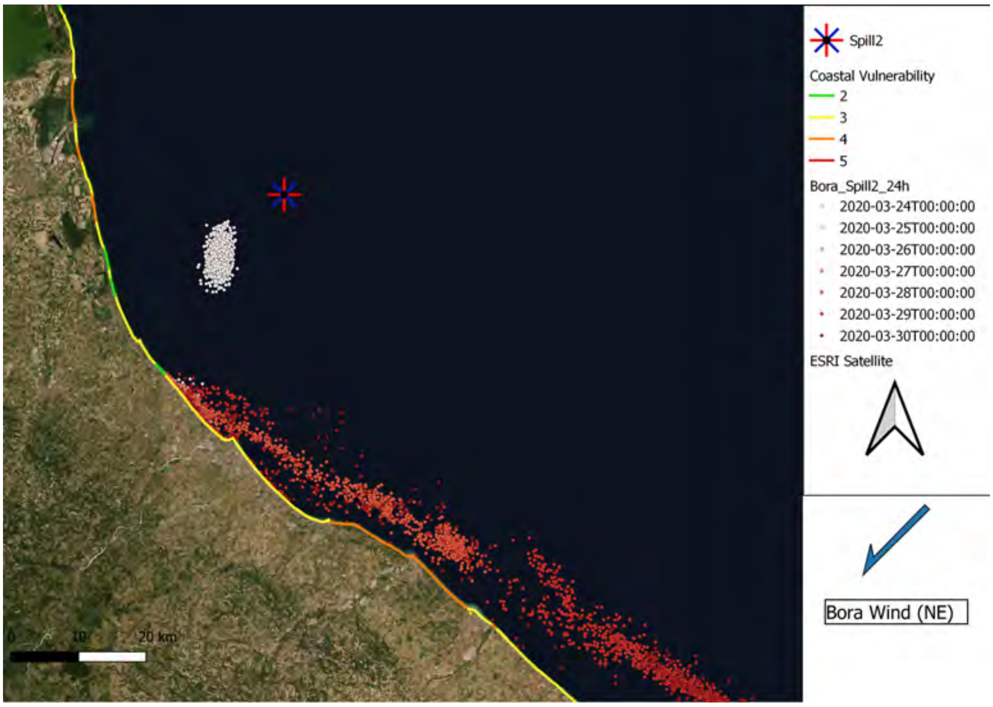

Figure 18: 7 days of spilling scenario under Bora event window (24 hour interval)at spill 2 position.

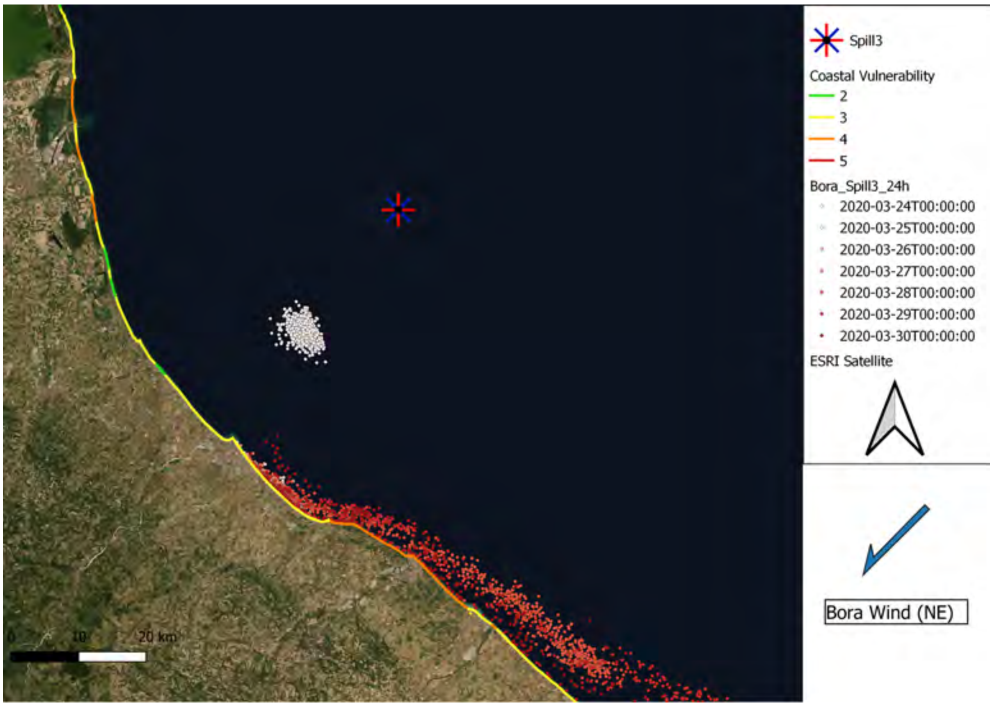

Figure 19: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 3 position.

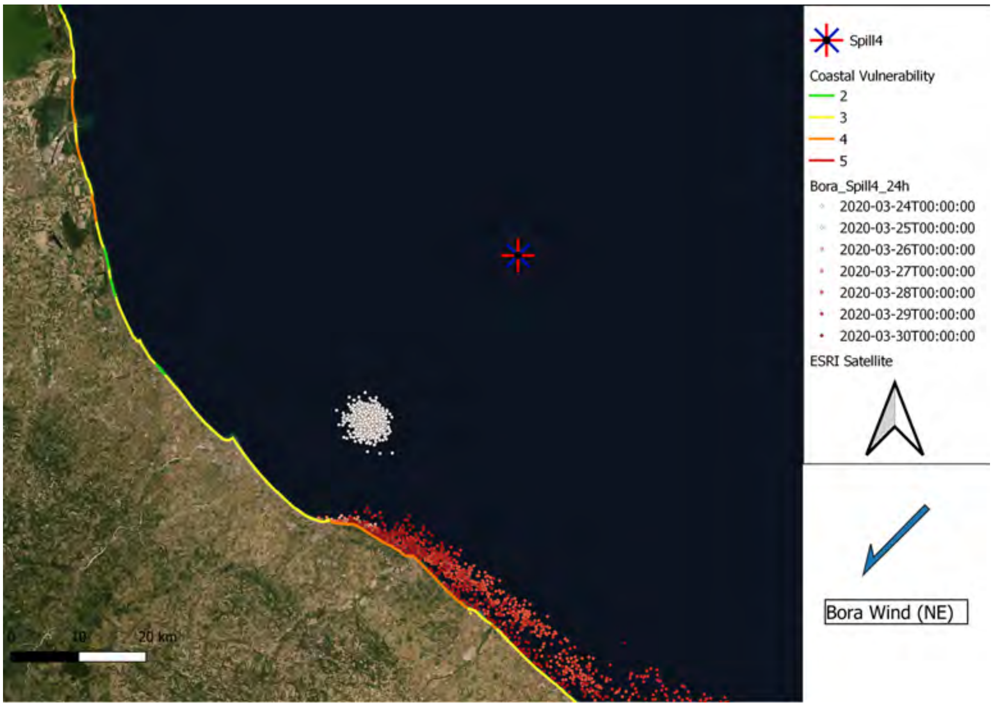

Figure 20: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 4 position.

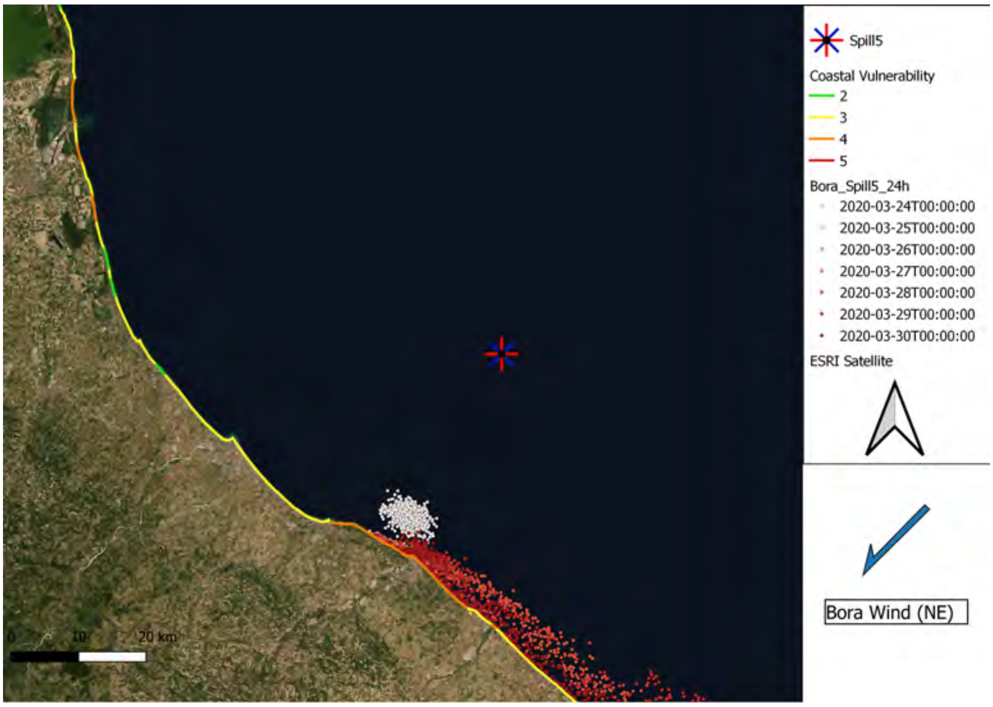

Figure 21: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 5 position.

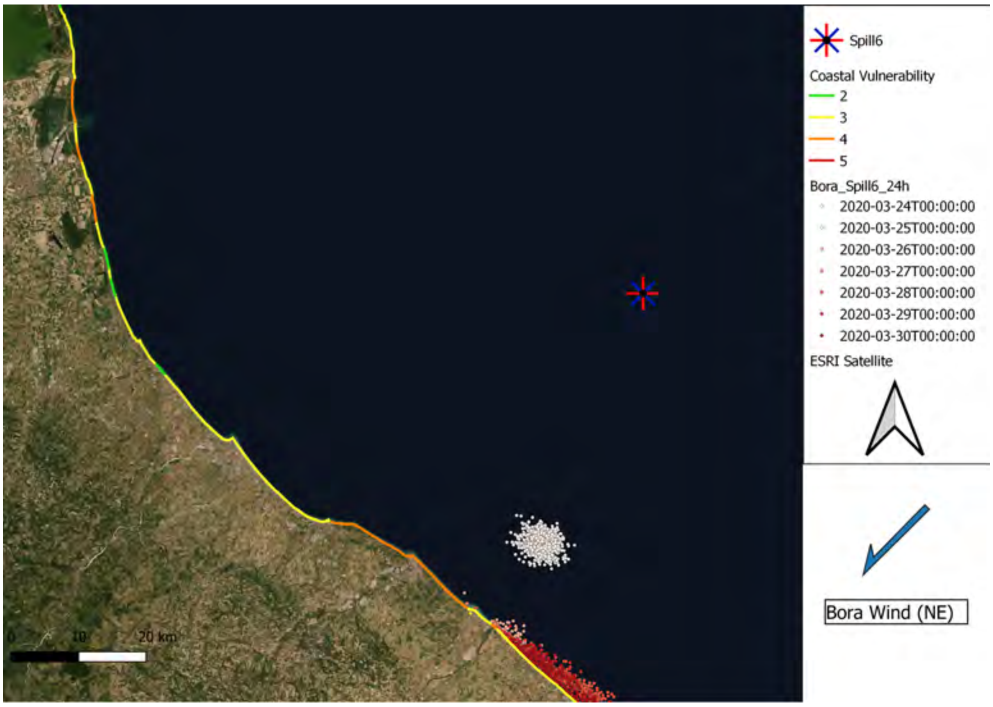

Figure 22: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 6 position.

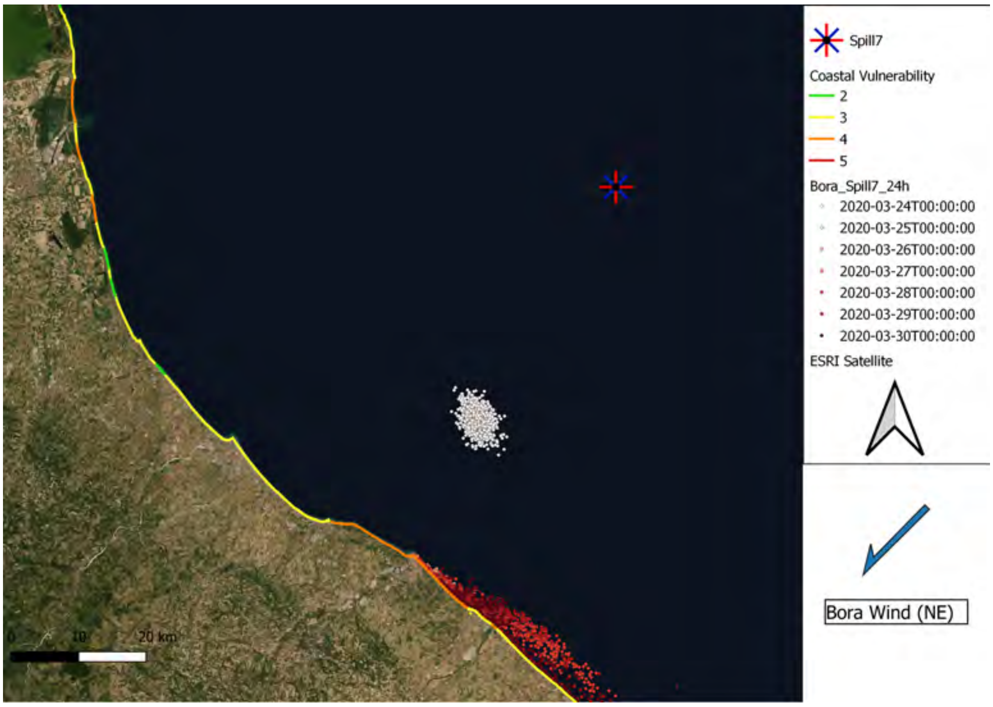

Figure 23: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 7 position.

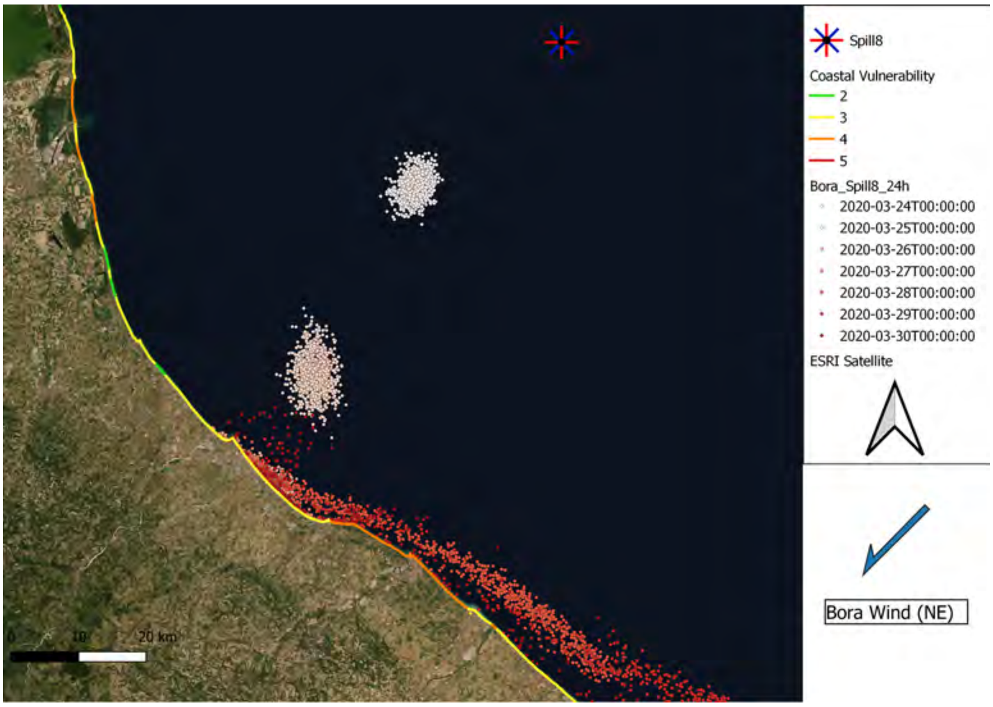

Figure 24: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 8 position.

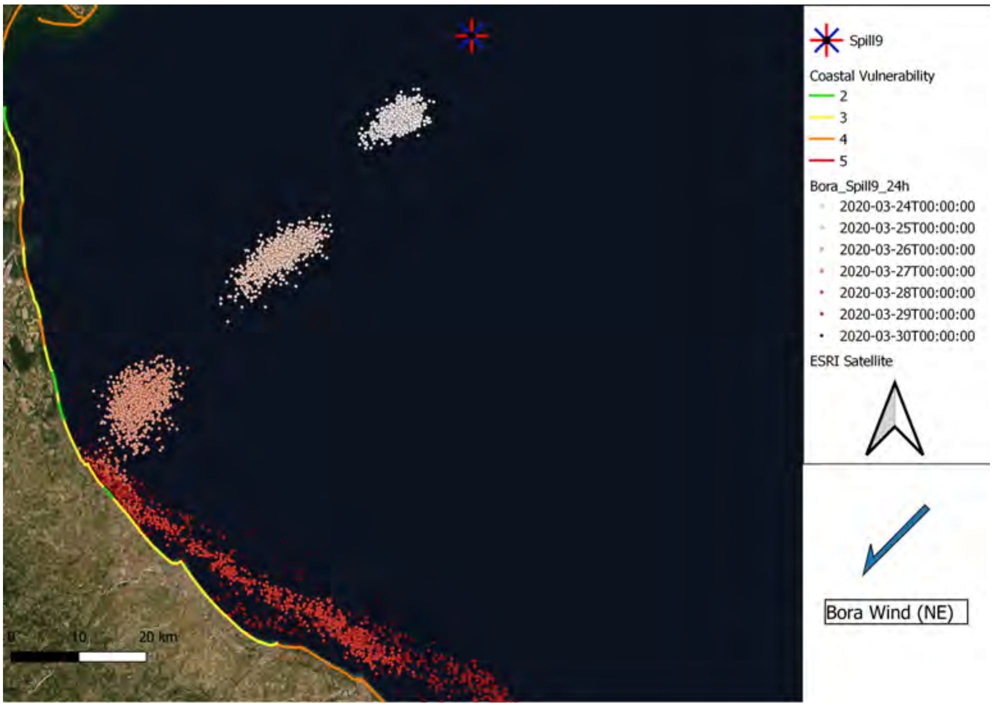

Figure 25: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 9 position.

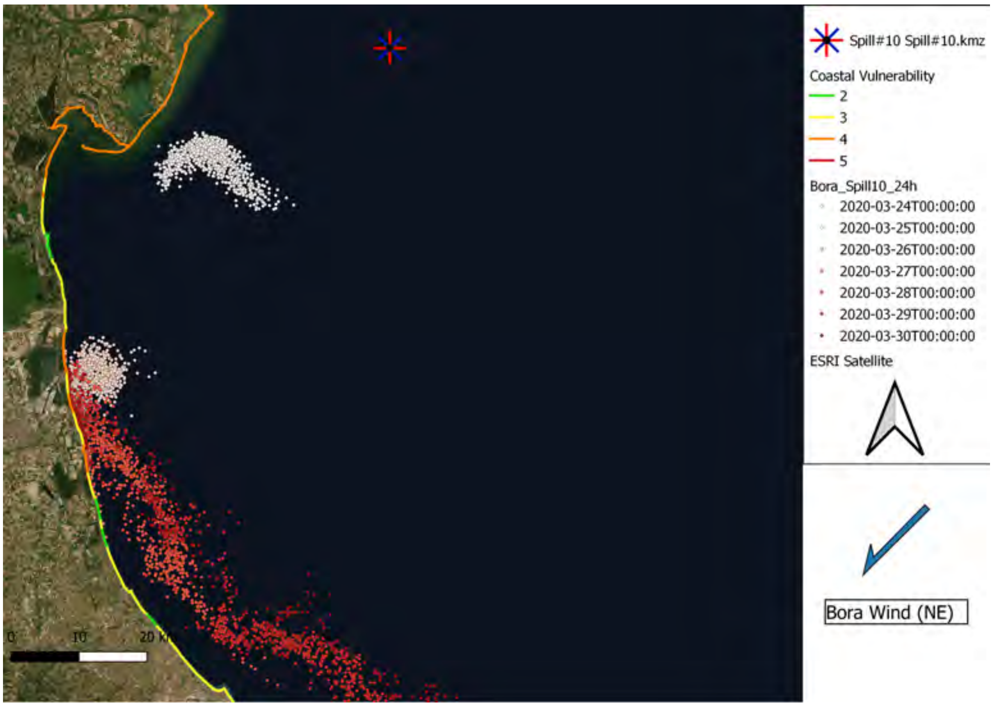

Figure 26: 7 days of spilling scenario under Bora event window (24 hour interval) at spill 10 position.

3.1.2 Spill simulation 7 days during Sirocco event window

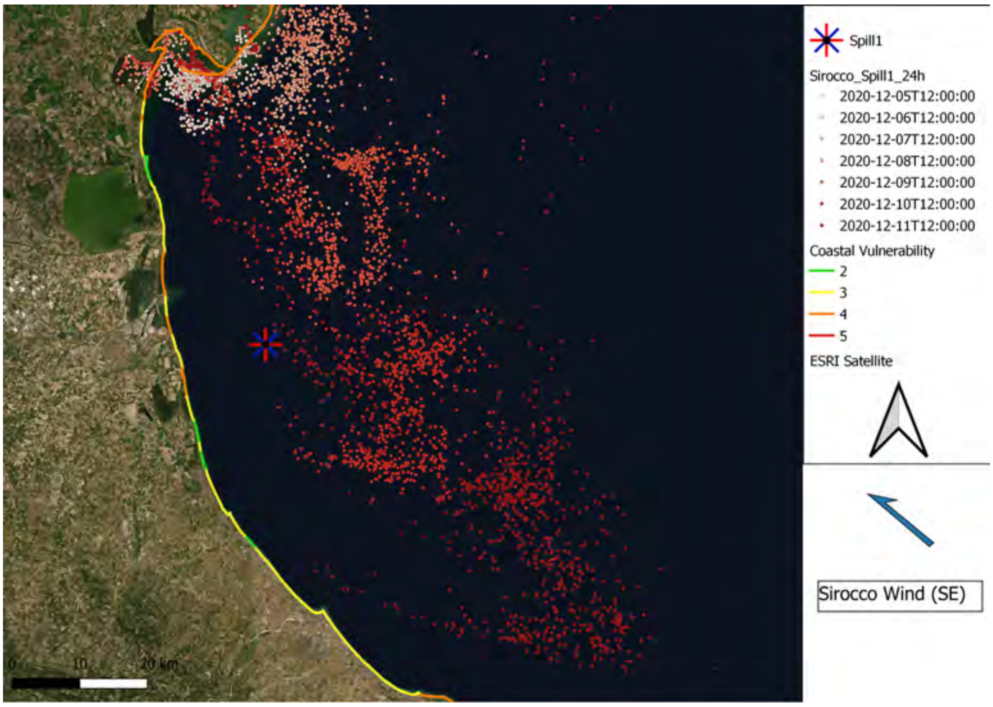

Figure 27: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 1 position.

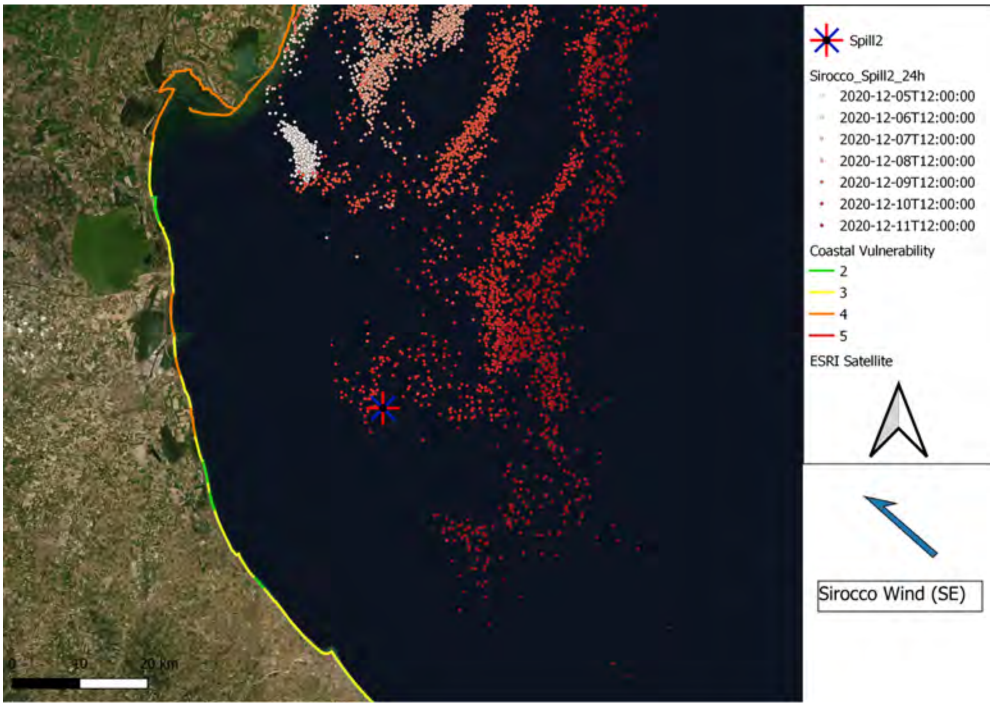

Figure 28: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 2 position.

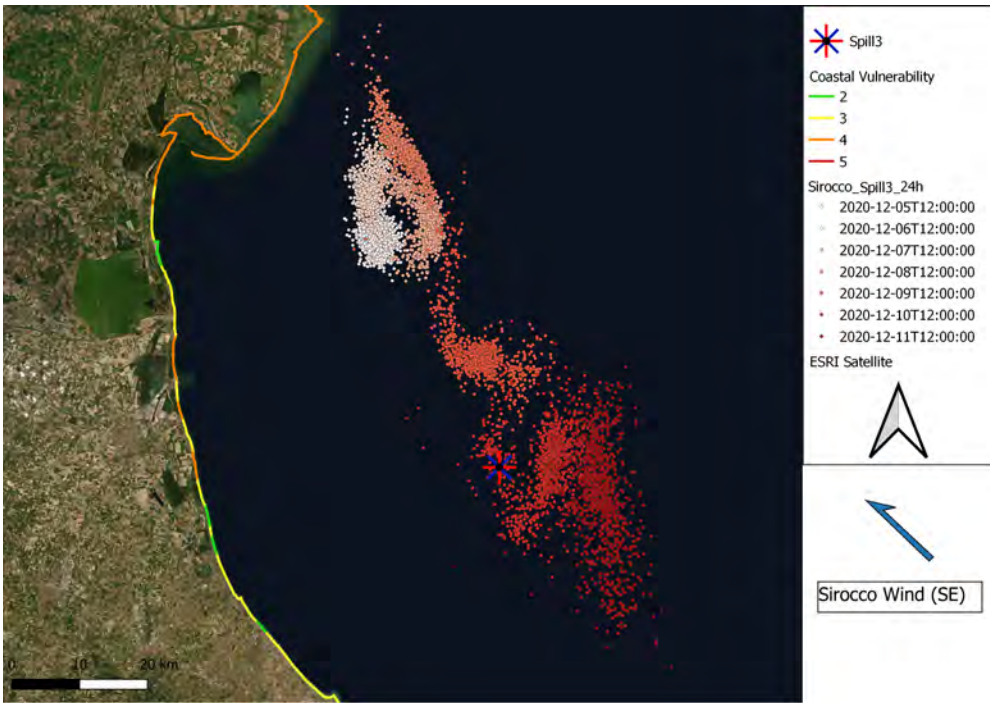

Figure 29: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 3 position.

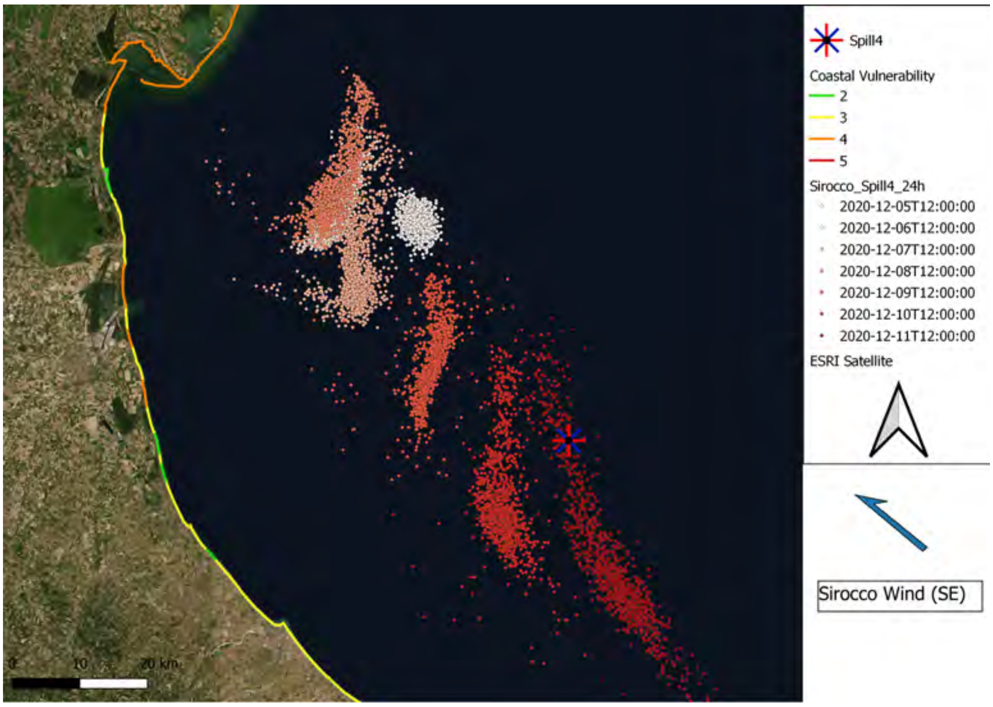

Figure 30: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 4 position.

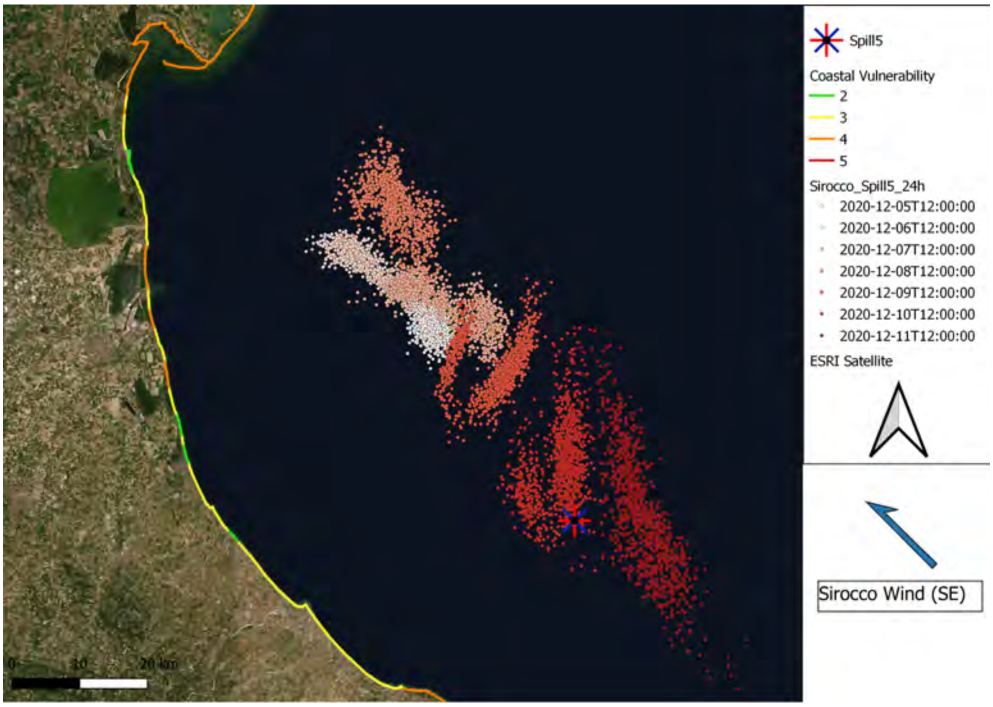

Figure 31: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 5 position.

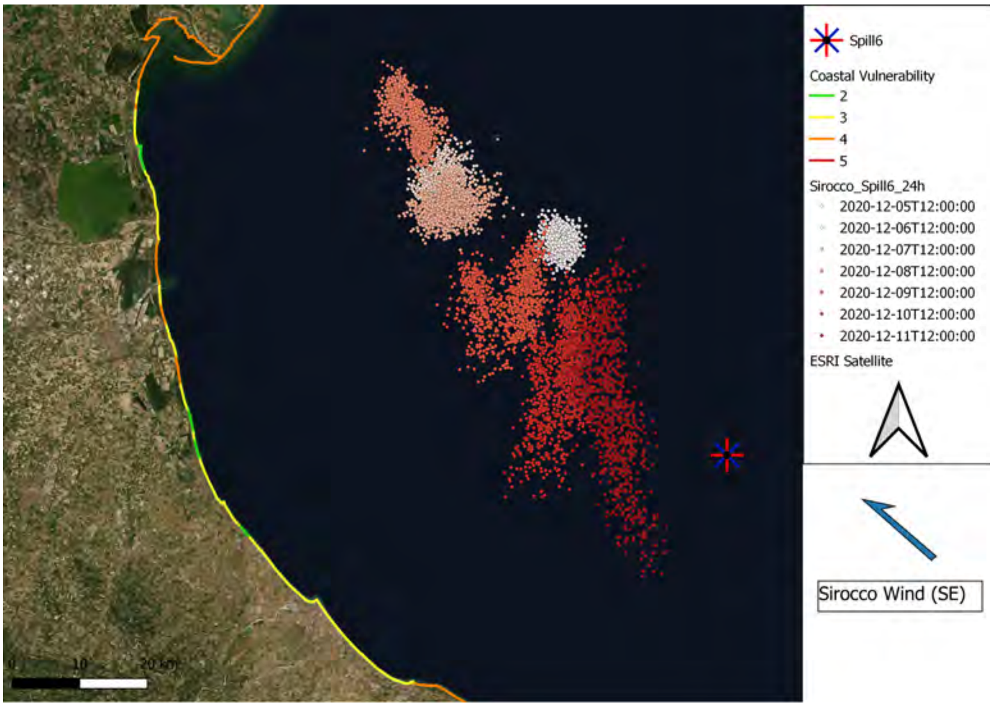

Figure 32: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 6 position.

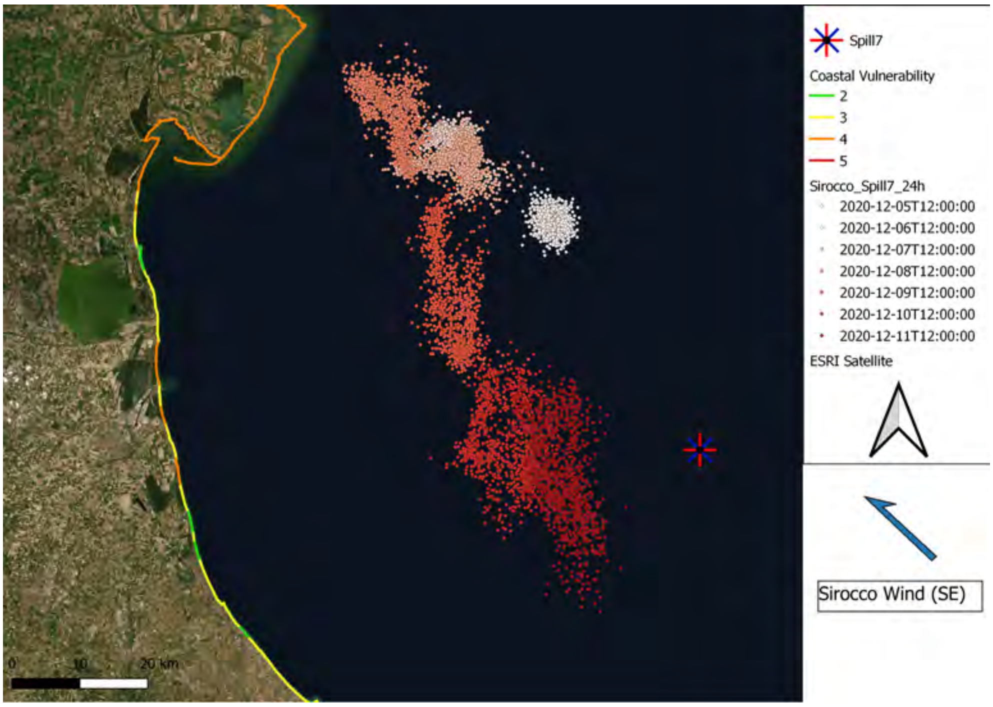

Figure 33: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 7 position.

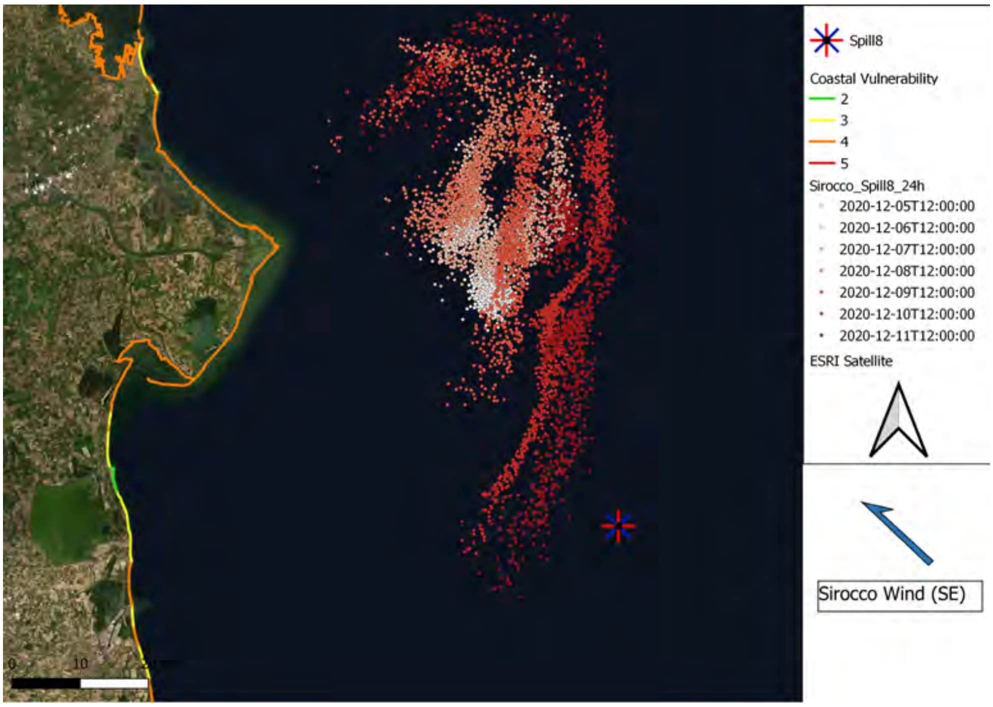

Figure 34: 7 days of spilling scenario under Sirocco event window (24 hour interval). at spill 8 position.

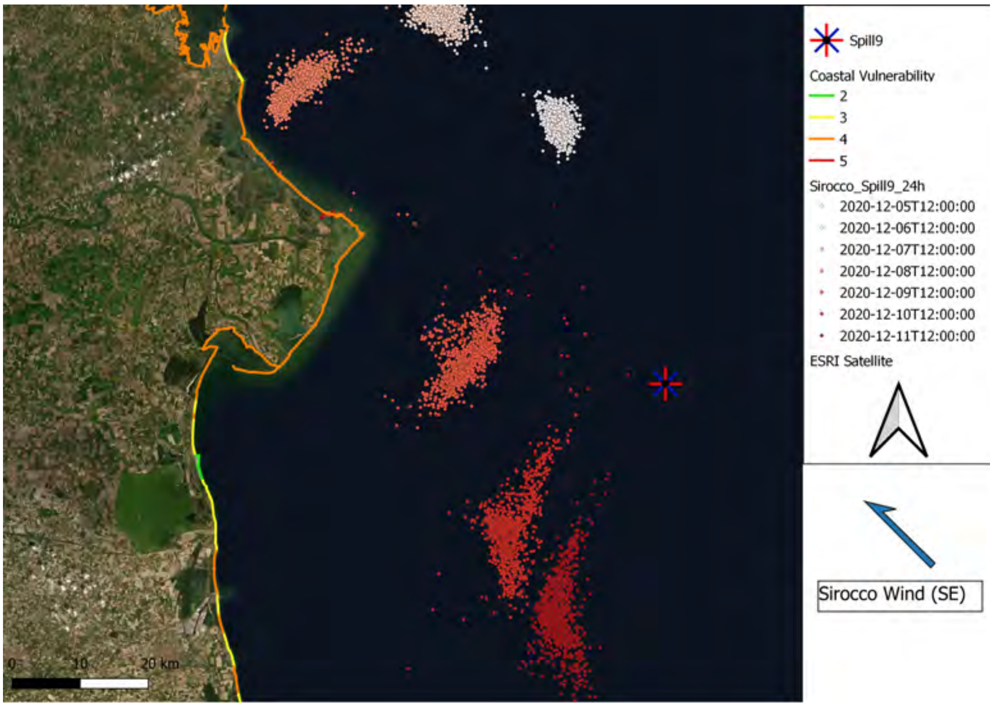

Figure 35: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 9 position.

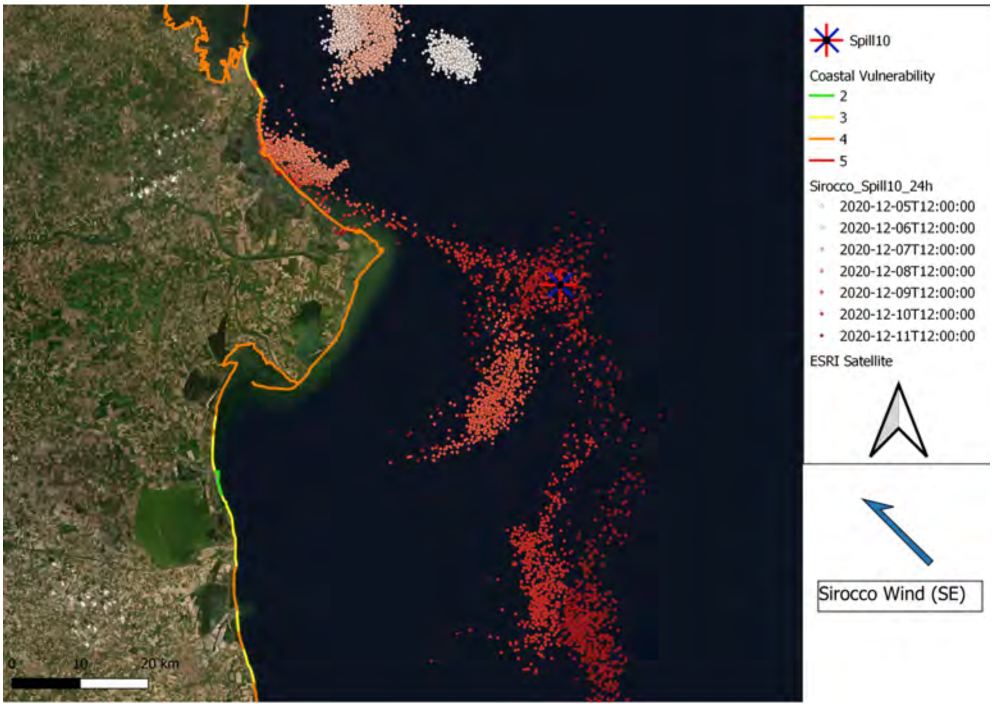

Figure 36: 7 days of spilling scenario under Sirocco event window (24 hour interval) at spill 10 position.

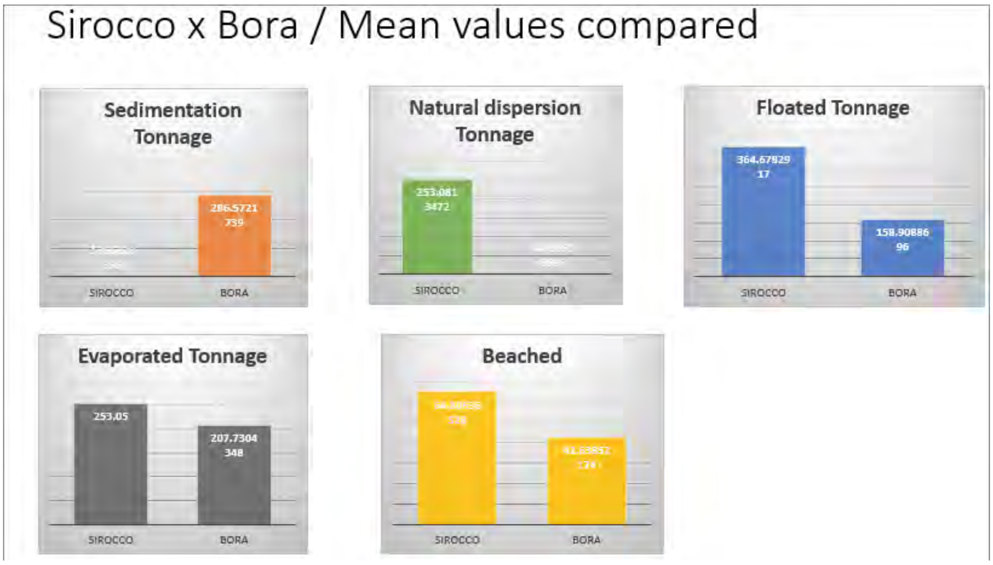

Figure 37: Fate of the oil along the 7 days of simulation, showing the weathering processes, compared in between all the Spills, Bora x Sirocco.

3.2 Impact and trajectory of spills that reached ER coast on only Bora and Sirocco conditions

On this section, the results are the actual spills that reached the ER coast and only in the time interval where the Sirocco and Bora events are well defined. Also there is the quantification of the spill, the amount of oil that reached the coast and in what sector. For the Bora events, the values are calculated from the day 23th until the day 27th of March, because after this day, the wind changes direction, dis-characterizing Bora conditions. For the Sirocco events the values were calculated from the 4th until the 8th of December. The values of the tonnage were calculated according to the shapefiles generated by GNOME, where each particle had a mass in kilograms, so every particle that reached near shore were counted and summed up. It is important to reinforce that, the spills simulated reached different sectors of the Italian coastline and probably would be propagated more without any action or intervention to break its spreading as seen on Figures provided on the previous sector, but, the purpose of this work is to focus on the accidents that could impact exclusively ER territory and under determined condition. The spills that reached ER coast were:

- Bora scenarios: Spill 1 / Spill 2/ Spill3 / Spill 4 / Spill 8 / Spill 9/ Spill 10

- Sirocco scenarios: Spill 1

Spill1		
index	Lenght(km)	Tonnage
	1.82	28.46
	13.38	195.54

Spill2		
index	Lenght(km)	Tonnage
	0.1	0.44
	13.3	170.56

Spill3		
index	Lenght(km)	Tonnage
	15.9	161

Spill4		
index	Lenght(km)	Tonnage
	1.65	0.69
	OUT	OUT

Spill8		
index	Lenght(km)	Tonnage
	23.3	175

Spill9		
index	Lenght(km)	Tonnage
	1.9	75.2
	15.3	102.8

Spill10		
index	Lenght(km)	Tonnage
	1.2	0.528
	12.4	173.5
	10	138.5

Figure 38: Amount of tonnage that arrived at the beach under Bora conditions from 23th until 27th of March. All spills.

-Spill 1-

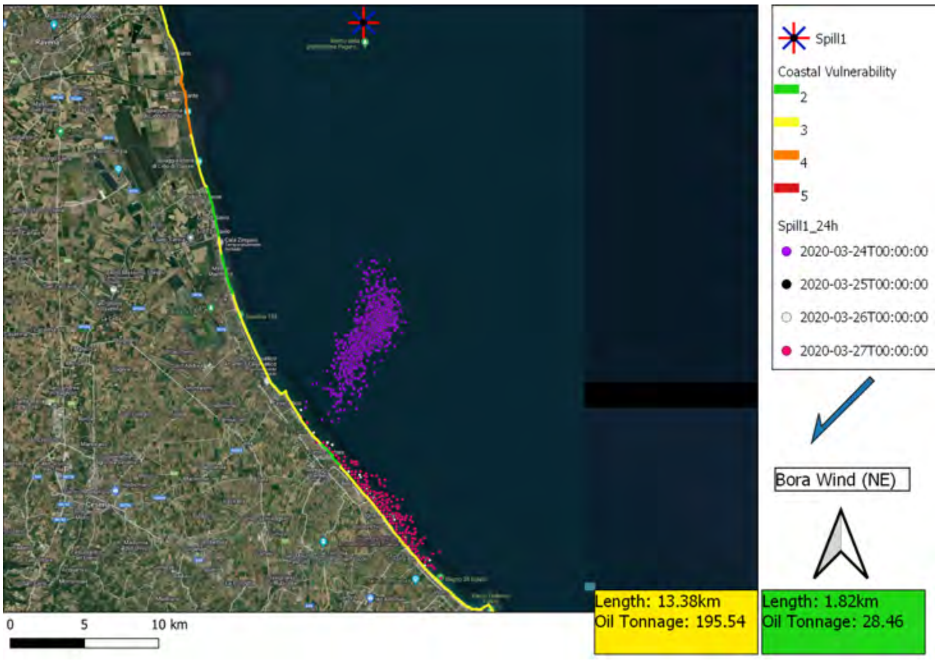

Figure 39: Simulation of Spill 1, only under Bora conditions from 23th until 27th of March.

-Spill 2-

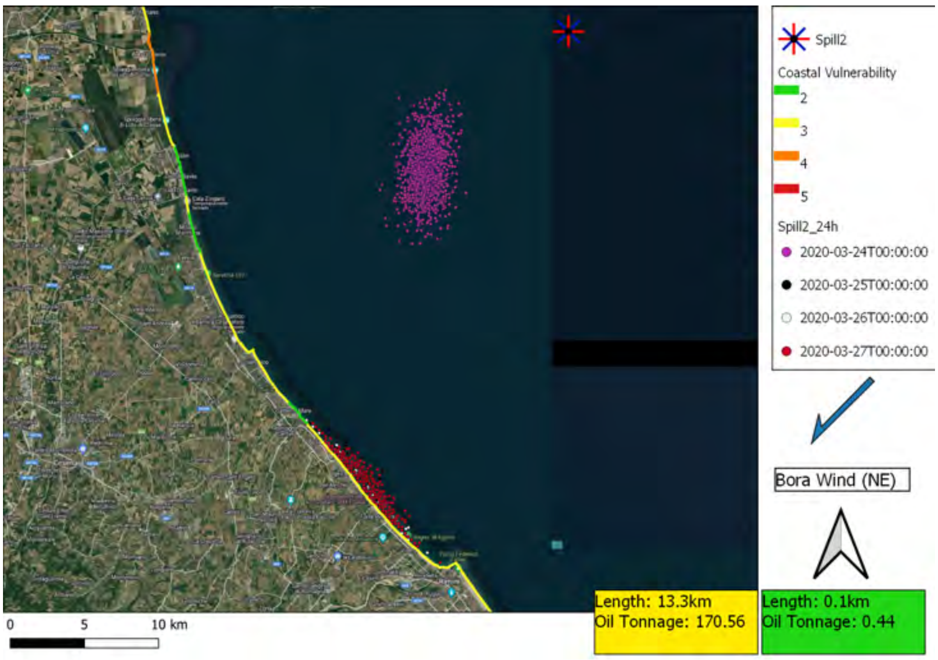

Figure 40: Simulation of Spill 2, only under Bora conditions from 23th until 27th of March.

-Spill 3-

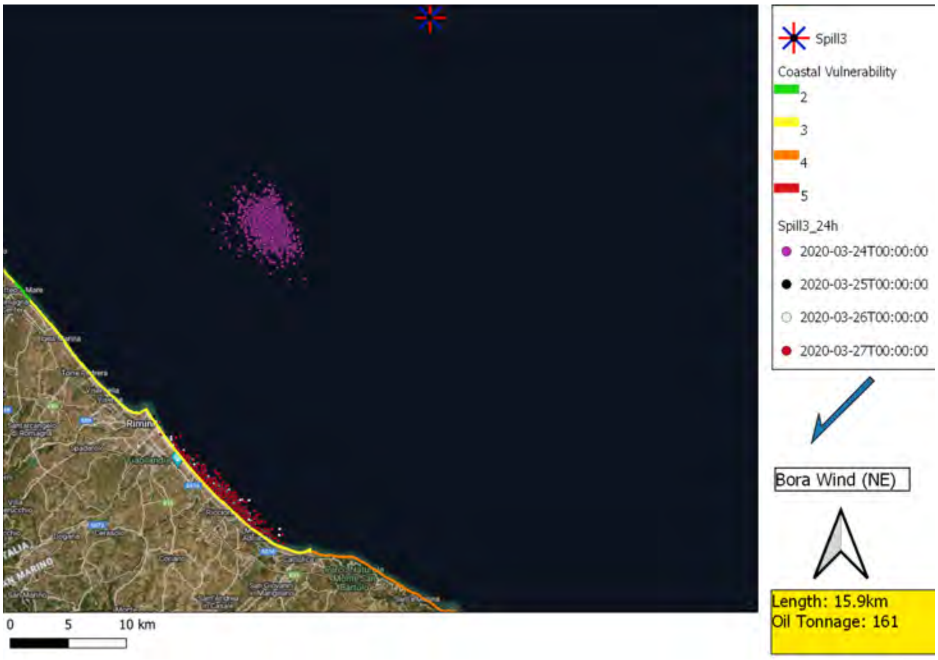

Figure 41: Simulation of Spill 3, only under Bora conditions from 23th until 27th of March.

-Spill 4-

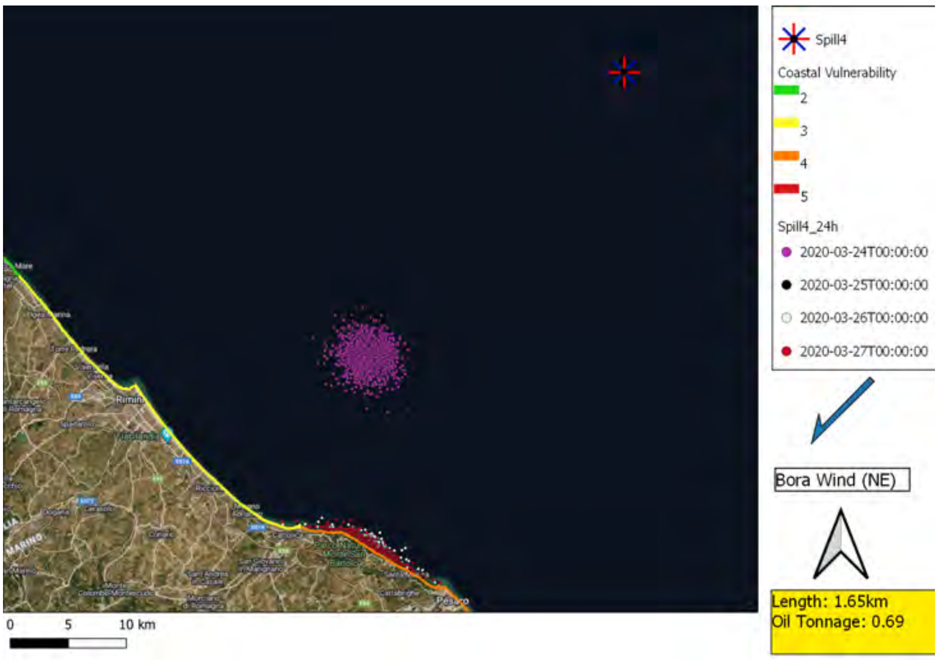

Figure 42: Simulation of Spill 4, only under Bora conditions from 23th until 27th of March.

-Spill8-

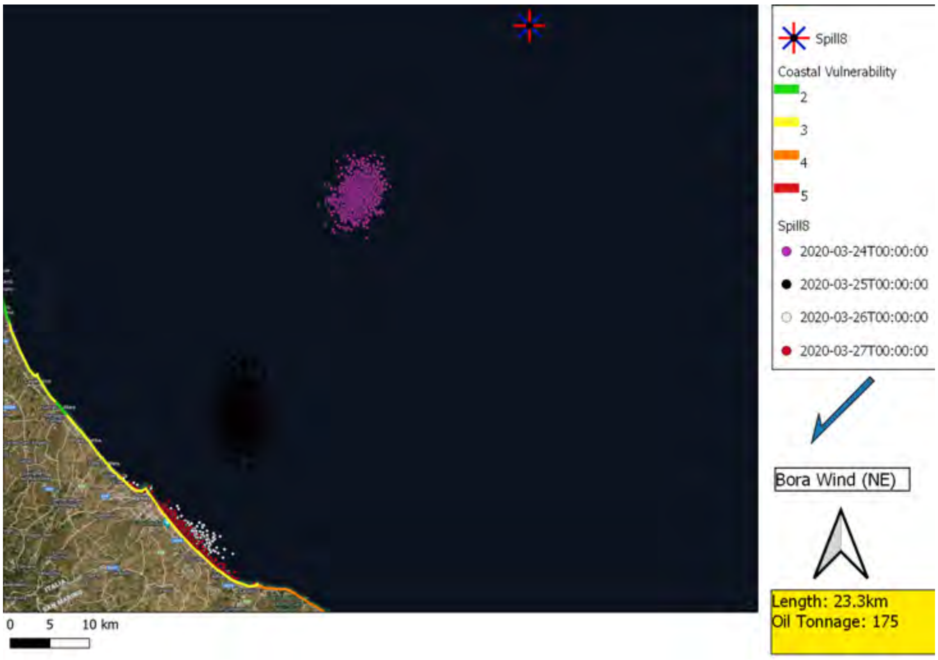

Figure 43: Simulation of Spill 8, only under Bora conditions from 23th until 27th of March.

-Spill 9-

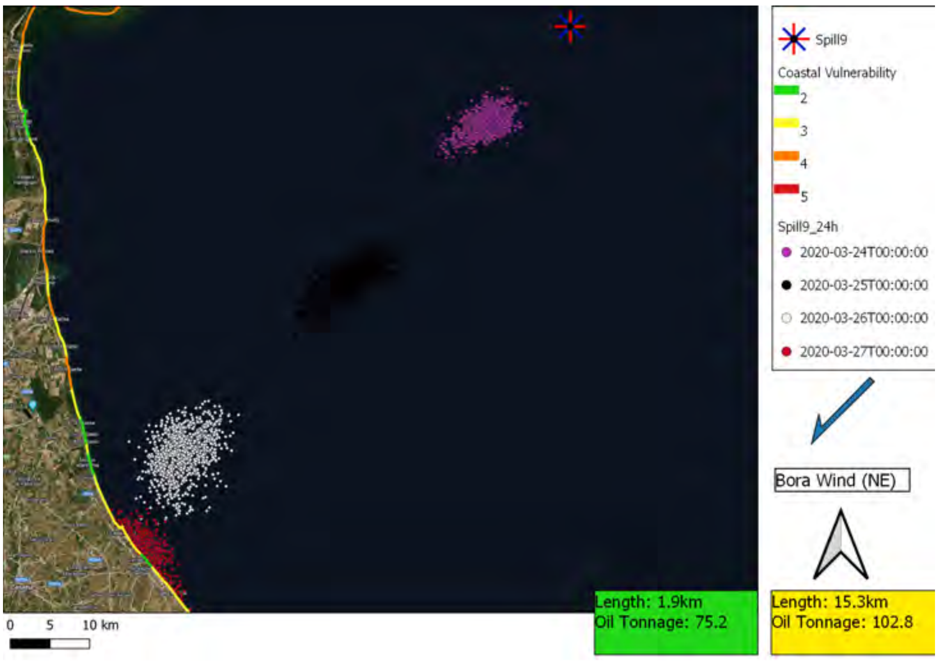

Figure 44: Simulation of Spill 9, only under Bora conditions from 23th until 27th of March.

-Spill 10-

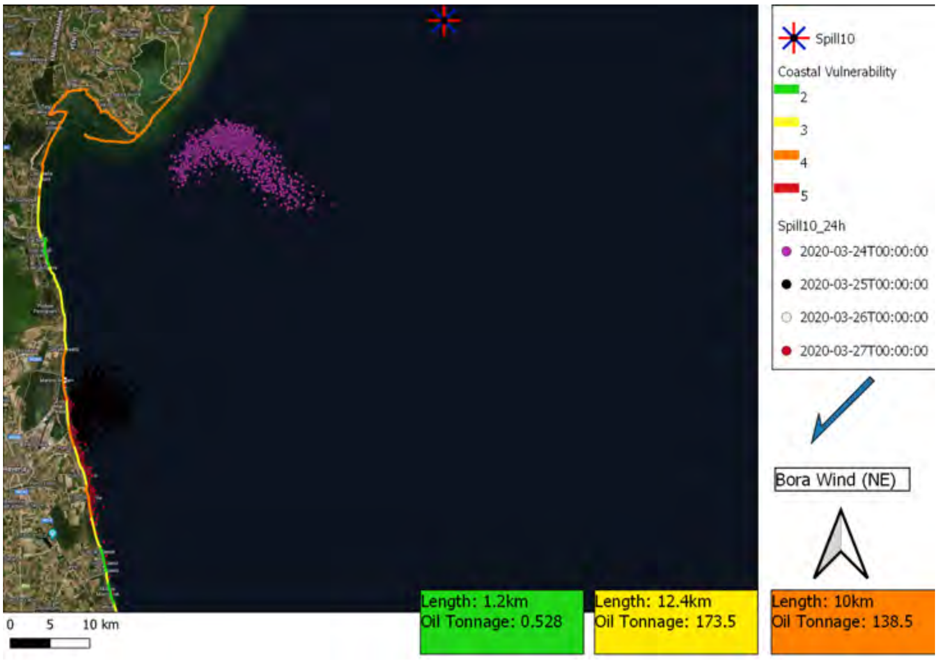

Figure 45: Simulation of Spill 10, only under Bora conditions from 23th until 27th of March.

Spill	Hours
Spill 1	30
Spill 1 (Sirocco)	20
Spill 2	42
Spill 3	48
Spill 4	42
Spill 8	72
Spill 9	98
Spill 10	48

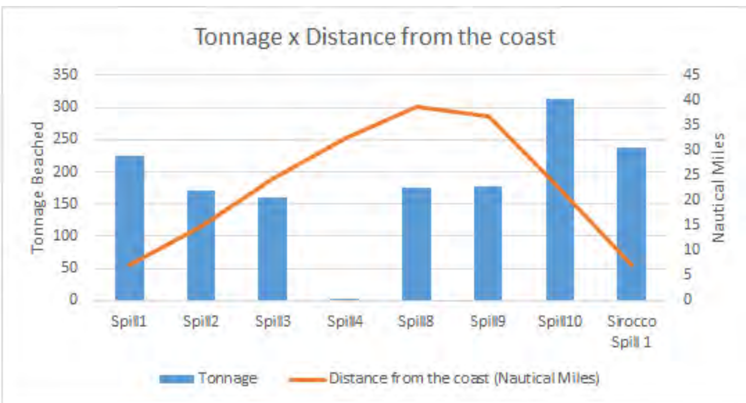

Figure 46: Amount of hours of the first arrival of the spill on the coastline; Relation in between the distance from the coast and oil arrived, with the Sirocco spill.

3.2.1 Costs of impact under Bora scenarios

The values of all costs were rounded for a matter of visualization.

- Spill 1 -

Green Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 28.46 tons)/1.82km

Environmental damage cost = ((22.000 * 0.5 * (1 + 0.4) * 28.46)/ 1.82

Environmental damage cost = 240.000 euros / km of coastline

Socio-economic damage cost = (22.000 * green index modifier * 28.46 tons) / 1.82 km

Socio-economic damage cost = (22.000 * 0.2 * 28.46) / 1.82

Socio-economic damage cost = 68.800 euros / km of coastline

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 195.54 tons)/13.38km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 195.54)/13.38

Environmental damage cost = 225.000 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 195.54 tons) / 13.38 km

Socio-economic damage cost = (22.000 * 0.85 * 195.54) / 13.38

Socio-economic damage cost = 273.300 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 240.000 + 68.800 = 309.000 euros / km of coastline

Total cost per km yellow section index = Environmental + Socio-Economic = 225.000 + 273.300 = 498.300 euros / km of coastline

- Spill 2 -

Green Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 0.44 tons)/0.1 km

Environmental damage cost = ((22.000 * 0.5 * (1 + 0.4) * 0.44)/ 0.1

Environmental damage cost = 67.760 euros / km of coastline

Socio-economic damage cost = (22.000 * green index modifier * 0.44 tons) / 0.1 km

Socio-economic damage cost = (22.000 * 0.2 * 0.44) / 0.1

Socio-economic damage cost = 19.360 euros / km of coastline

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 170.56 tons)/13.3km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 170.56)/13.3

Environmental damage cost = 197.490 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 170.56 tons) / 13.3 km

Socio-economic damage cost = (22.000 * 0.85 * 170.56) / 13.3

Socio-economic damage cost = 239.810 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 19.360 + 67.760 = 87.120 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 197.490 + 239.810 = 437.300 euros / km of coastline

- Spill 3 -

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 161 tons)/15.9km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 161)/15.9

Environmental damage cost = 155.937 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 161 tons) / 15.9 km

Socio-economic damage cost = (22.000 * 0.85 * 161) / 15.9

Socio-economic damage cost = 189.352 euros / km of coastline

Total cost per km yellow section index = Environmental + Socio-Economic = 155.937 + 189.352 = 345.289 euros / km of coastline

- Spill 4 -

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 0.69 tons)/1.65km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 0.69)/1.65

Environmental damage cost = 6.440 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 0.69 tons) / 1.65 km

Socio-economic damage cost = (22.000 * 0.85 * 0.69) / 1.65

Socio-economic damage cost = 7.820 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 6.440 + 7.820 = 14.260 euros / km of coastline

- Spill 8 -

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 175 tons)/23.3km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 175)/23.3

Environmental damage cost = 115.665 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 175 tons) / 23.3 km

Socio-economic damage cost = (22.000 * 0.85 * 175) / 23.3

Socio-economic damage cost = 140.450 euros / km of coastline

Total cost per km yellow section index = Environmental + Socio-Economic = 115.665 + 140.450 = 256.115 euros / km of coastline

- Spill 9 -

Green Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 75.2 tons)/1.9 km

Environmental damage cost = ((22.000 * 0.5 * (1 + 0.4) * 75.2)/ 1.9

Environmental damage cost = 609.515 euros / km of coastline

Socio-economic damage cost = (22.000 * green index modifier * 75.2 tons) / 1.9 km

Socio-economic damage cost = (22.000 * 0.2 * 75.2) / 1.9

Socio-economic damage cost = 174.147 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 609.515 + 174.147 = 783.662euros / km of coastline

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 102.8 tons)/15.3km

Environmental damage cost = (22.000 * 0.5 * (1.4) * 102.8)/15.3

Environmental damage cost = 103.471 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 102.8 tons) / 15.3 km

Socio-economic damage cost = (22.000 * 0.85 * 102.8) / 15.3

Socio-economic damage cost = 125.644 euros / km of coastline

Total cost per km yellow section index = Environmental + Socio-Economic = 103.471 + 125.644 = 229.116euros / km of coastline

- Spill 10 -

Green Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area) * 0.528 tons)/1.2 km

Environmental damage cost = ((22.000 * 0.5 * (1 + 0.4) * 0.528)/ 1.2

Environmental damage cost = 6.776 euros / km of coastline

Socio-economic damage cost = (22.000 * green index modifier * 0.528 tons) / 1.2 km

Socio-economic damage cost = (22.000 * 0.2 * 0.528) / 1.2

Socio-economic damage cost = 1.936 euros / km of coastline

Total cost per km green section index = Environmental + Socio-Economic = 6.776 + 1.936 = 8.712 euros / km of coastline

Yellow Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area + other sensitive areas (beach dunes reserve and green areas)) * 173.5 tons)/12.4km

Environmental damage cost = (22.000 * 0.5 * (4.6) * 173.5)/12.4

Environmental damage cost = 707.992 euros / km of coastline

Socio-economic damage cost = (22.000 * Yellow index modifier * 173.5 tons) / 12.4 km

Socio-economic damage cost = (22.000 * 0.85 * 173.5) / 12.4

Socio-economic damage cost = 258.995 euros / km of coastline

Total cost per km yellow section index = Environmental + Socio-Economic = 707.992 + 258.995 = 966.987 euros / km of coastline

Orange Index Section:

Environmental damage cost = (22.000 * 0.5 * (recreational water + urban area + other sensitive areas (beach dunes reserve and green areas)) * 138.5 tons)/10 km

Environmental damage cost = (22.000 * 0.5 * (4.6) * 138.5)/10

Environmental damage cost = 700.810 euros / km of coastline

Socio-economic damage cost = (22.000 * Orange index modifier * 138.5 tons) / 10 km

Socio-economic damage cost = (22.000 * 1.85 * 138.5) / 10

Socio-economic damage cost = 563.695 euros / km of coastline

Total cost per km Orange section index = Environmental + Socio-Economic = 700.810 + 563.695 = 1.264.505 euros / km of coastline

3.2.2 Total cost of oil beached under Bora simulations for each spill

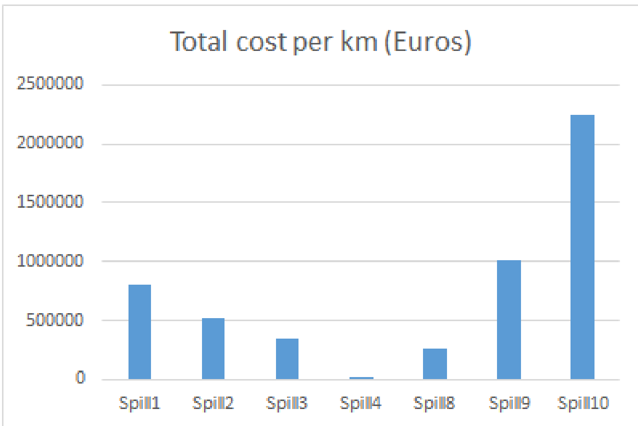

Figure 47: Total cost for every spill, obtained by the sum of the costs on the different indexes per kilometer of coastline.

3.2.3 Sirocco spills that reached ER coast tonnage x coastline length according to index

Spill1 index	Lenght(km)	Tonnage
	31.7	237.8

Figure 48: Amount of tonnage that arrived at the beach under Sirocco conditions from 4th until 8th of December.

-Spill 1-

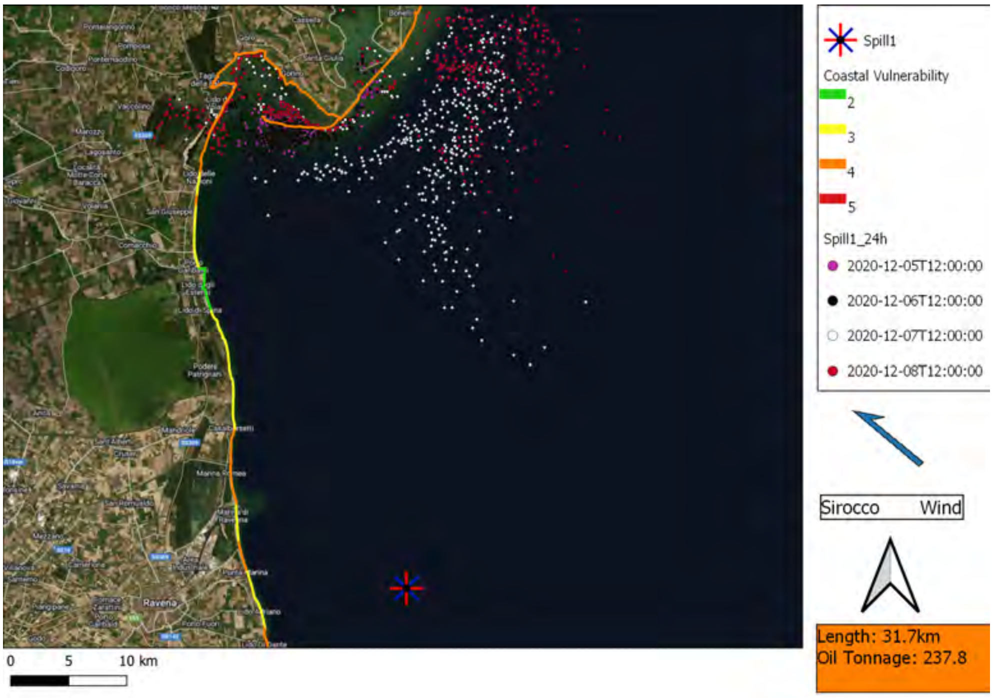

Figure 49: Simulation of Spill 1, only under Sirocco conditions from 4th until 8th of March.

3.2.4 Costs of impact under Sirocco scenario

- Spill 1 -

Orange Index Section:

Environmental damage cost = (22.000 * 0.5 * (Wildlife use + Wetlands + other sensitive areas (beach dunes reserve and green areas)) * 237.8 tons)/31.7 km

Environmental damage cost = (22.000 * 0.5 * (8.9) * 237.8)/31.7

Environmental damage cost = 734.404 euros / km of coastline

Socio-economic damage cost = (22.000 * Orange index modifier * 237.8 tons) / 31.7 km

Socio-economic damage cost = (22.000 * 1.85 * 237.8) / 31.7

Socio-economic damage cost = 305.314 euros / km of coastline

Total cost per km Orange section index = Environmental + Socio-Economic = 734.404 + 305.314 = 1.039.718 euros / km of coastline

3.2.5 Total cost of oil beached under Bora and Sirocco simulations for each spill

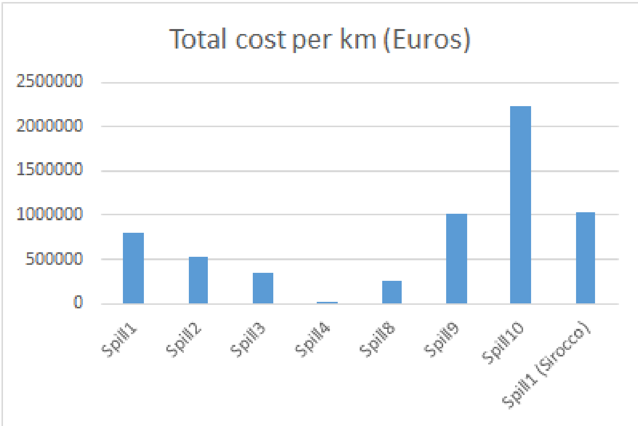

Figure 50: Total cost for every spill, obtained by the sum of the costs on the different indexes per kilometer of coastline.

4 Discussion

For a better understanding and development of the wide variety of results obtained, a discussion section structured on the review of each scenario that reached the ER coast has to be present. For that matter, this section of the work compiles the spills simulated and assess them in an integrated way, discussing outcomes and perspectives.

4.1 Analysis of Scenarios and Possible Responses

4.1.1 Scenario 1 : Bora Spill 1

The first scenario, nearest spill point, localized 7.2 nautical miles from the coast under Bora conditions settings, arrived at the coast in 30 hours with a bit more of 25% of its total volume of spill (700 tonnes) and mainly hitting yellow indexes stretches of coastline with a very short amount of green index, in an area mainly highly urbanized, having an impact that headed more towards the socio - economical spectrum, by that, the responses could be more flexible on this area as there is less need of environmental friendly techniques for mitigating the spills and the threatening to natural structures is small. The critical aspects of this simulation is the time of the arrival of the oil, as it is one of the fattest spills to reach the coastline. Based on that the response needs to attend some criteria to be successive:

- Easy to handle (preferential)
- Functionality under tough sea conditions
- Cheaper as possible because of the high value associated to the spill

Inside this criteria it is possible to highlight remediation techniques that would be preferable for using on this scenario and can be expressed on a table that has the reference attributes discussed on the section 1 (Introduction // Remediation Techniques) and create a table of favored techniques for the different scenarios with 2 main options, one being more resource-less or minimalistic and the other one being more resource-full and plural.

Table 16: Scenario 1 preferable responses

Option	**Technology**
1 Cheap and minimalist	Fence boom and Dispersant
2 Costly and plural	Fence boom and Oleophilic skimmer

Option 1: The use of fence booms comes as almost essential for every oil spill simulated on this work, firstly because the other types cannot handle well rough

sea conditions and it can stop the pro-gradation of the oil, stopping its beaching process, furthermore the use of dispersal's would accelerate the weathering of this material and as the trajectory of the spill does not reach mainly or sensitive environmental area, the main strategy would be "holding" this oil and accelerating its degradation.

Option 2: The main difference from this option to number 1, it would be the use of a skimmer to clean the oil, it is saying that, the oil would be contained while a skimmer "cleans" the water - oil area, whilst the degradation processes occurs, a more costly but a more fast "problem solving" option, that can allow the recovery of the oil in which would have to be stored later on (more costs), dispersants could be also added to this equation making it more expensive.

The main points that are critical for an efficient response on this Scenario 1, is to react fast to contain the oil transport, as the handling offshore can be done easily because of the lack of main natural structures on the spill trajectory.

4.1.2 Scenario 2 : Sirocco Spill 1

The second scenario, nearest spill point, localized 7.2 nautical miles from the coast under Sirocco conditions settings, arrived at the coast in 20 hours with more than 25% of its total volume of spill (700 tonnes) and mainly hitting Orange indexes stretches of coastline in an area mainly constituted of wet lands and beaches, having an impact that headed for both sides, natural and socio - economical, by that, the responses cannot be flexible on this area as there is a lot of concern of using environmental friendly techniques as this scenario represents a threat to a very sensible area. The critical aspects of this simulation are the time of the arrival of the oil (fastest from all scenarios) and the natural structures threatened. Based on that the response needs to attend some criteria to be successive:

- Easy to handle (preferential)
- Functionality under tough sea conditions
- Cheaper as possible because of the high value associated to the spill
- Environmental friendly techniques

Inside this criteria it is possible to highlight remediation techniques that would be preferable for using on this scenario and can be expressed on a table that has the reference attributes discussed on the section 1 (Introduction // Remediation Techniques) and create a table of favored techniques for the different scenarios with 2 main options, one being more resource-less or minimalistic and the other one being more resource-full and plural.

Table 17: Scenario 1 preferable responses

Option	Technology
1 Cheap and minimalist	Fence boom and Absorbent Material
2 Costly and plural	Fence boom + Oleophilic skimmer + Biological

Option 1: Again the use of fence booms comes as almost essential for every oil spill simulated on this work, because the other types cannot handle well rough sea conditions and it can stop the pro-gradation of the oil,but in this case another type of technology was elected to "clean" the oil as other options "chemical" or "magnetic" can offer danger to humans and other organisms that frequents the area, so the use of absorbent material with natural composition (saw dust, vegetal fiber...) would be an effective and environmental friendly technique with a low cost. Furthermore the absorbents materials needs to be collected and storage on waste containment's located near the area.

Option 2: As seen on Scenario 1, this option would also use of a skimmer to clean the oil, it is saying that, the oil would be contained by the fence booms, while a or more skimmers "cleans" the water + oil area, the main difference would be also adding micro-organisms to decompose the oil (biological remediation) for accelerating the oil degradation process making it the cleaning faster.

Different from the Scenario 1, apart of the time of action being also very short, or in this scenario case, 10 hours shorter, the trajectory of the spill not only can reach very sensitive natural areas, but also, passes by special protected zone "Adriatico settentrionale", which makes the handling of this spill more difficult, as there is no window for letting the oil mix or sediment and letting it float and evaporate gradually can impact local organisms, by that, the efforts to clean as fast as possible this spill would require more efficiency and environmental awareness.

4.1.3 Scenario 3: Bora Spills 2,3,8 and 9

On the third Scenario, it was chosen to gather 3 spills because of the similarities in between each other, regarding to the area of impact and indexes, as they are all spills that reaches highly urbanized areas and furthermore the total tonnage that arrives on the coastline, having the main difference the kilometers of coastline affected in which reflects on the cost per km diversion. On this case, Spill 2 is located 14.8 nautical miles from the coast, Spill 3 24.3 miles, Spill 8 38.7 miles and Spill 9 36.8 all of them under Bora conditions settings. The time of the oil arrival for the closest ones (2 and 3) 42 and 48 hours respectively and (8 and 9) 72 and 98 hours. For the spills on Scenario 3, the sense of urgency is less than the previous scenarios and the concern about sensitive areas on the trajectory are not present, so the response can be similar to the Scenario 1.

- Easy to handle (preferential)
- Functionality under tough sea conditions
- Cheaper as possible because of the high value associated to the spill

Inside this criteria it is possible to highlight remediation techniques that would be preferable for using on this scenario and can be expressed on a table that has the reference attributes discussed on the section 1 (Introduction // Remediation Techniques) and create a table of favored techniques for the different scenarios with 2 main options, one being more resource-less or minimalistic and the other one being more resource-full and plural.

Table 18: Scenario 2 preferable responses

Option	**Technology**
1 Cheap and minimalist	Fence boom and Dispersant
2 Costly and plural	Fence boom and Oleophilic skimmer

Option 1: Use of fence booms and dispersants to contain the oil and facilitate the process of degradation of the pollutant, same strategy as Scenario 1.

Option 2: Use of fence booms and skimmer to clean the oil, same strategy as Scenario 1.

The Scenario 3 illustrates a similar impact as Scenario 1, having differences more related to the area of the oil spread, than to volume arrived and the characteristics of the coastline that received it. The Spill 2 and 3 impacted in similar situations and time schedule acting more concentrated which lead to higher values of cost per km, principally because of the proximity to the coastline, being the Spill 8 and 9 a less dense incident as the oil travels a longer distance which spread the oil particles.

4.1.4 Scenario 4: Bora Spill 4

The fourth scenario holds a very specific outcome, as the oil that arrived on the ER coastline is less than 1 ton, and the costs related to the spill when simulated does not even reach the global average mean of cleaning (around 22000 euros per ton). By the lack of sensitive natural structures associated to the trajectory of the spill and small quantity of oil, In that case the response could be the beach cleaning of the oil when arriving at the beach.

4.1.5 Scenario 5: Bora Spill 10

The last Scenario, number 5 represented the most threatening situation for the coastline. The spill was located 22.3 miles from the coast, under Bora conditions, and arrived in 48 hours, which can be considered fast, comparing to spills 2 and 3 that were close to the coast with similar distances and time of arrival, and had an impact almost 50% less than the Spill 10, having Spill 2 and 3 a beached tonnage of 171 and 161 tonnes, and Spill 10 312.53 tons. Because of the distance from the ER coastline the spreading of the particles happened even more than the Scenario 3 (Spills 8 and 9) and different sections of the coasts were hit. Furthermore, in the trajectory of the Spill 10 the pollutant passes by the Special Protected Zone "Adriatico settentrionale", giving for this simulation another variable to consider about timing of intervention. For the response some criteria was determined for an efficient mitigation.

- Easy to handle (preferential)
- Functionality under tough sea conditions
- Cheaper as possible because of the high value associated to the spill
- Environmental friendly techniques

Inside this criteria it is possible to highlight remediation techniques that would be preferable for using on this scenario and can be expressed on a table that has the reference attributes discussed on the section 1 (Introduction // Remediation Techniques) and create a table of favored techniques for the different scenarios with 2 main options, one being more resource-less or minimalistic and the other one being more resource-full and plural.

Table 19: Scenario 2 preferable responses

Option	**Technology**
1 Cheap and minimalist	Fence boom and Absorbent material
2 Costly and plural	Fence boom + Oleophilic skimmer + Biological

The strategy adopted for that Scenario, follows the same line as Scenario 2 whereas the concern about the environmental sensitive areas adds a degree of urge to clean the spill, furthermore, in this simulation there was a diversity of impacts, it is saying that the oil had a very heterogeneous destination, from urbanized areas until wetlands and beaches, and all of the 3 risk indexes, that's why this spill had the most costly simulated values per km of coastline. This spill represents worst scenario from the simulations cause has the potential of two types of impact, floating and beaching, so it's containment must be done as fast as possible mainly on the first hours of the accident.

4.2 Value of the impacts and Response facilities along de ER coast

4.2.1 Value of the impacts

According to figure 50 it is possible to see the cost of every spill per km, but, that does not determine the most costly spills in total, as it is treated this way because of the variety of coastline characteristics as the coast is not homogeneous.That's why the use of the quantity per km, which allows a better visualization of how that costs would "weight" on the pockets of the local population, by correlating the value of the spill per km of coastline, to the working power per km^2 utilizing Emilia-Romagna GDP. According to (*AdminStat Italia Demography Emilia Romagna*, n.d.) the population density of Emilia-Romagna region is 197.4 inhabitants per km^2 and the GDP according to (*Invest in Emilia-Romagna Economy*, n.d.) is 36.247 euros, assuming that on the coastline the trend of demographic population continues, a km^2 holds a GDP of 7.155,1578 euros, the following table can be made using the total cost value of each spill:

Table 20: The value of the spills

Cost of spill (Euros)	**Percentage of GDP**
(1 Bora) 807.969	11.3%
(1 Sirocco) 1.039.718	14.5%
(2 Bora) 524.420	7.3%
(3 Bora) 345.289	4.8%
(4 Bora) 14.260	0.2%
(8 Bora) 256.115	3.6%
(9 Bora) 1.012.779	14.2%
(10 Bora) 2.240.203	31.3%

4.2.2 Response facilities

For the intervention of spills, according to (PCN, 2010) entities such as the coastal guard would be the vanguard followed by the civil protection, on operating mitigation procedures under 12 miles of Italian limits, taking this institution as the main active for response, and looking it's distribution along the coast, it is possible to discuss how the sector of the ER coastline are "covered" regarding to the Scenarios that reached the beach.

Figure 51: Coastal Guard (Guarda Costiera) facilities distribution along the ER coast.

(Google Earth)

On Figure 51 the coastal guard facilities are located from the middle to the south of the coastline, on the mainly urbanized areas from Ravenna until Cattolica, for the Bora scenarios the concentration of the facilities converge with the needs of intervention, as the spills mainly head on this direction of the coast, but under different circumstances as the Scenario 2, where the Sirocco winds prevail, the northern coast is the target, and it is the part which has less presence of the Coastal Guard, only holding one facility on Goro. So in a case where a spill would go towards this section of the coastline, responses can be have its logistics affected by the lack of presence of main intervention facilities on the north part of ER coastline.

4.3 The fate of the oil and the preparedness provided by the "Piano Nazionale"

The winds characterised by Orlić et al.(1992) were the main factor on determining the trajectory of the oil, but, not only beached oil could be a threat to the coastline. On the previous section regarding to the 7 days behaviour of the spills and it's fate, the simulations shows a more concentrated behaviour of oil spreading under Bora conditions and a more dissipated one for the Sirocco spills, apart of not reaching the territory of ER coast, on Figure 37 displays means that can be taken into consider as despite of the lack of incidence on the coastline, the Sirocco spills had a more chaotic behaviour and did not weathered as much as the Bora ones. On Piano Nazionale(2010) main factors that are taken into consideration to determine gravity of the spill does not focus on the sea conditions, taking more consideration the amount of spill, distance from the coast and the possibility to harm natural areas. The target areas represented the main cost big factor on the cost determination for the spills, despite of the difficulty to precisely model spill cost as mentioned by Shahriari & Frost(2008), trends can be noticed when comparing the natural diversity of the areas hit by the spill, related to their nature diversity, taking as the main example the Spill 10 on Figure 45, a fairly distant situation that provided huge outcomes, whereas other simulations nearest to the coast but mainly "urban damages" had a way lower cost of cleaning. The amount of oil is a variable that can be questioned on PianoNazionale(2010) for being a main factor, as the oil "generally" does not sink and gets exposed instantly, small spills or medium spills as the one simulated on this work, can represent a dangerously situation compared to a bigger one if the rate of spilling is high and the weather conditions are strong (winds and currents), even far from the coastline. PianoNazionale(2010) tackles mainly the vessel situation and potential damage, despite of the actual natural conditions. Interventions done only under Italian territory can be determinant for an efficient mitigation, as depending of the speed of oil arrival, a contingency plan has to be already settle even from "out of jurisdiction" zones, to avoid major damages. Distance from the coast can add a sense of safety but also can be a prejudice under the development of the response logistics as the transition of jurisdictions on an oil spill trajectory, can turn the management of the accident more complex, and as the simulations shows, the oil without proper early containment, can travel along different zones in a matter of days, sometimes hours, as seen on Figure 46.

4.4 SWOT analysis regarding to the integrated tools

A SWOT analysis was chosen to represent the main aspects of the risk assessment tools use, and evaluate them providing a simplified visualization:

STRENGTHS	WEAKNESSES
1. GNOME Scenarios 2. Waste deposition points 3. Vulnerability map 4. COMADEX points	1. GNOME Scenarios 2. Waste deposition points 3. Vulnerability map 4. COMADEX points
1. Forecast of oil arrival, including oil fate and weathering, showing quantities that beached, floated, evaporated, etc in a timeline, facilitating the intervation and dimension of impacts. 2. Pre-determined area with desired connections to important roads and safety location, saving time on decision making. 3. Provides a notion of which areas should prioritized for protection. 4. Gives information about zones whereas the risk was increased during different conditions and vessels, identifying main routes.	1. The scenarios depends of the sea conditions (currents, waves, winds and other variables.) So each spill should have a kind of variability even if they happen on the same position and have the same size. 2. The area needs to be negotiated with local communities as it would probably occupy someone's property. Also the land use GIS data provided is not updated and forces a more analogical and organic survey, taking time and efforts to do so. 3. Needs to be updated constantly to be effective. 4. Are a sum of at the moment data, which means, also depends of currently sea conditions and vessel conditions, being effective only for estimates and positioning representation.

OPPORTUNITIES	THREATS
1. GNOME Scenarios 2. Waste deposition points 3. Vulnerability map 4. COMADEX points	1. GNOME Scenarios 2. Waste deposition points 3. Vulnerability map 4. COMADEX points
1. Development of different simulations and gathering data for future threats in different conditions, building a database. 2. Determine points along the coast that could serve as waste deposit and it's fate. Not only for oil spills but also other pollutants. 3. Refine vulnerability map and develop a ER oil vulnerability atlas, with the activities held and the environmental units. 4. Repeat the monitoring each year, repeating the activity on year 2019.	1. Stagnation of the software upgrades and development. 2. Bureaucracy to obtain emergency terrains or use. 3. Stagnation on updates and lack of interest in develop the vulnerability map. 4. Lack of monitoring and database built, turning the system obsolete.

5 Conclusion

5.1 The oil behaviour along the coast

Throughout the simulations, the spills behaved differently, mainly because of the wind conditions ,but also, distance from the coast. Those differences, although offering diverse scenarios, provided a pattern, that could provide a basis for understanding possible future cases. Under Bora wind, the crude oil tended to impact the southern most part of the coast and arrived in a more concentrated structure to the shore, reaching shallower waters more frequently, as the wind tended to push the pollutant against the coastline, presenting a high mean average of sedimentation as its main weathering factor. On the Sirocco side, the pollutant followed the Sirocco's main wind direction, as the spills assumed a more northward than northeastern trajectory, behaving in a more dissipated way and covering more area offshore. Sirocco simulations showed that the pollutants stayed along deeper waters, with higher means of natural dispersion and floating, but, not strongly pushed away towards the main wind direction as its counterpart.

5.2 The use of ICZM general principles for helping the management of oil hazard on the Emilia-Romagna coastline

Applying the (Burbridge, 1999) Integrated Coastal Zone Management principles on the ER coast case in a way to provide ideas and actions for supporting on oil hazard.

5.2.1 Take a Wide-Ranging perspectives

Oil spills can happen in any place around the Adriatic coastline and can affect different countries at the same time. Building a common sense of awareness under international and national environment shareholders, can improve the security levels as different institutional agencies works for foreseen the same problem. One perfect example being the HAZADR (Lauro et al., 2015). ER could join similar cooperation's or initiatives, or develop it's on partnerships with neighbors.

5.2.2 Build on an Understanding of Specific Conditions in the Area of Interest

This type of study, simulating spills and assessing different aspects that could influence its outcomes, are one of the tools that contributes for this aspect for this ICZM topic. The local knowledge of economic activities, natural structures and human settling on the ER coast, helps settling the dimensions, calculate costs and determine priorities. On the ER, the north sector of coastline presents more fragile structures to deal with, whilst, the south is a mix in between different sectors, mainly directed to tourism and leisure. So, one action that could be implement for a oil hazard management, could be define priority and sacrifice area, it is saying that, utilize south coastal stretches that could be easily assessed and clean, or, the oil arrival and handling could be easily done, because of the easy assess, less vulnerable areas and reduced environmental sensitive areas eg. protected zones. That allows the develop of a buffer zone where this material could be directed or even constrained, which can turn the process of cleaning, removal and weathering less costly, more efficient and safe. Knowledge about the specific conditions, for example, estimate time of the oil arrival, could be the basis to foment a limit of time of action that could be implement on coastal guard procedures, or, the supply of materials that every facility should have as a basic oil fighting kit, fence booms (versatile for rough sea conditions), dispersant and skimmers. Preparing the vanguard of oil spill fighting with training and provisional material, could significantly low the impacts, as seen on the simulations, the oil does not arrive instantly at the coastline, but, has some critical time x action limit. So ER institutions should at least cope with minimum materials for a response.

5.2.3 Work with Natural Processes

On this topic, oil spills generally follow natural forcing, principally the wind, working with natural process in that case, could be providing as much as environmental safety as possible, and do not intervene on already settled nature. Spills can be cleaned in different ways, but, can be turned into very complex issues if not well managed, the effect of this pollutants on some natural areas can be irreversible and although natural processes could help deterioration of the material, human intervention corresponds as the most desirable action. The matter is to intervene in a responsible way, trying to not add more impact to the environment. For that it is important the observation of the coastal zone natural processes and how the oil spills behave within them, so, constantly upgrade about coastal structures, animal settlements, currents and winds dynamics are essential for the development of action planning, emergency wise and prevention wise.

5.2.4 Ensure that Decisions Taken Today Do Not Foreclose Options for the Future

Being a coastal zone such a dynamic and plural environmental area, static directives or plans, does not match with the flexibility needed for foreseeing changes and adaptability. The Emilia-Romagna coastline can follow this premise, and develop an annual strategy, with the characterization of the main coastal activities, risk prone areas under certain weather conditions, its degrees of risk (how the oil could impact different activities), buffer zones and other factors that could contribute for development of yearly reports. Cooping with the Italian Piano Nazionale, that could offer an flexible alternative for management and also follows the coastline hazards evolution, offering the opportunity for constant improvement.

5.2.5 Use Participatory Planning to Develop Consensus

Participatory planning is a way of management that involves the community in a whole. The Piano Nazionale (2010) talks about main government vehicles of action (Coastal Guard and Civil Protection), but not only those institutions are affected or deal with a possible spill. Local business, industries, residents, academic institutions, governmental agencies and other bodies, need to participate in a certain degree on a risk management project. Raising awareness with different stakeholder not only inform them, but also, allows the manager to have different perspectives. For example, research with local beach goers and tourists of "how the oil would impact your holidays", could provide numbers that could reflect significant risk assessment for economic impacts, or presenting the risk to local companies. When having different parties informed, an eventual catastrophe can be taken into more soft and understandable way, or even strengthen the local community ideas regarding to the coastal and marine safety. This can facilitate allocation of financial resources on emergency situations and raises the public approval and private institution co-operations.

5.2.6 Points that could improve Emilia-Romagna coast protection to oil spill hazard:

- Developing a regional plan taking into account the "Stato di Mare" (Sea Conditions), defining time of action and protection moves (containment buoy placement) and tracing main "oil routes" of vessels that could carry potential material on the radius of the administrative limits. - Provide Guarda Costiera (Coastal Guard) equipment and training for rough seas conditions and drills, whereas time would be essential for contained a potential oil threat. Supply this organizational with at least main fighting spill material (dispersants and fence booms), for rough seas operational efficiency. - Update and re-assess the land use along the coast, for a proper lookout under search of waste deposition points and identification of sensible activities that could be affected on the vanguard by an oil arrival. -

Develop an "Coastal Activities Map" with main activities and environments that takes place along the coast, with a ranking provided by local institutions assessing economic importance and pollution vulnerability or health hazard tendencies, that also could include the susceptibility to other hazards, not only oil spills. - Define critical zones based on distance, for example, separating the coast on 15 miles (5,10 and 15) and previously designating the coastal guard post responsible for determined section.

5.3 Final considerations

Despite of the new types of energy and material, oil and its derivations, still continues and will continue to be a very strong pillar of the economy. The main objective for nowadays managers are to provide a more reliable service for the coastal communities threats, and being oil hazard one of the main risk worldwide, the constant assessment of the issue on different settings and situations, will always contribute for the development of a safer and sustainable future. For the Emilia-Romagna coast, even with its low risk prone to oil accidents, considering and planning for a possible catastrophe, can avoid future situations that could impact in various important sectors of the area and bring economic, health and environment cascading events, to such an important property of Italian coast. As competent agencies safeguard and lookout for other natural and human driven issues, including an oil spill management plan exclusively for the Emilia-Romagna coast, would contribute to make this monitoring even more complete, providing more safety and reliability to the zone in various aspects, such as, life quality, investments and natural development.

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A Appendix

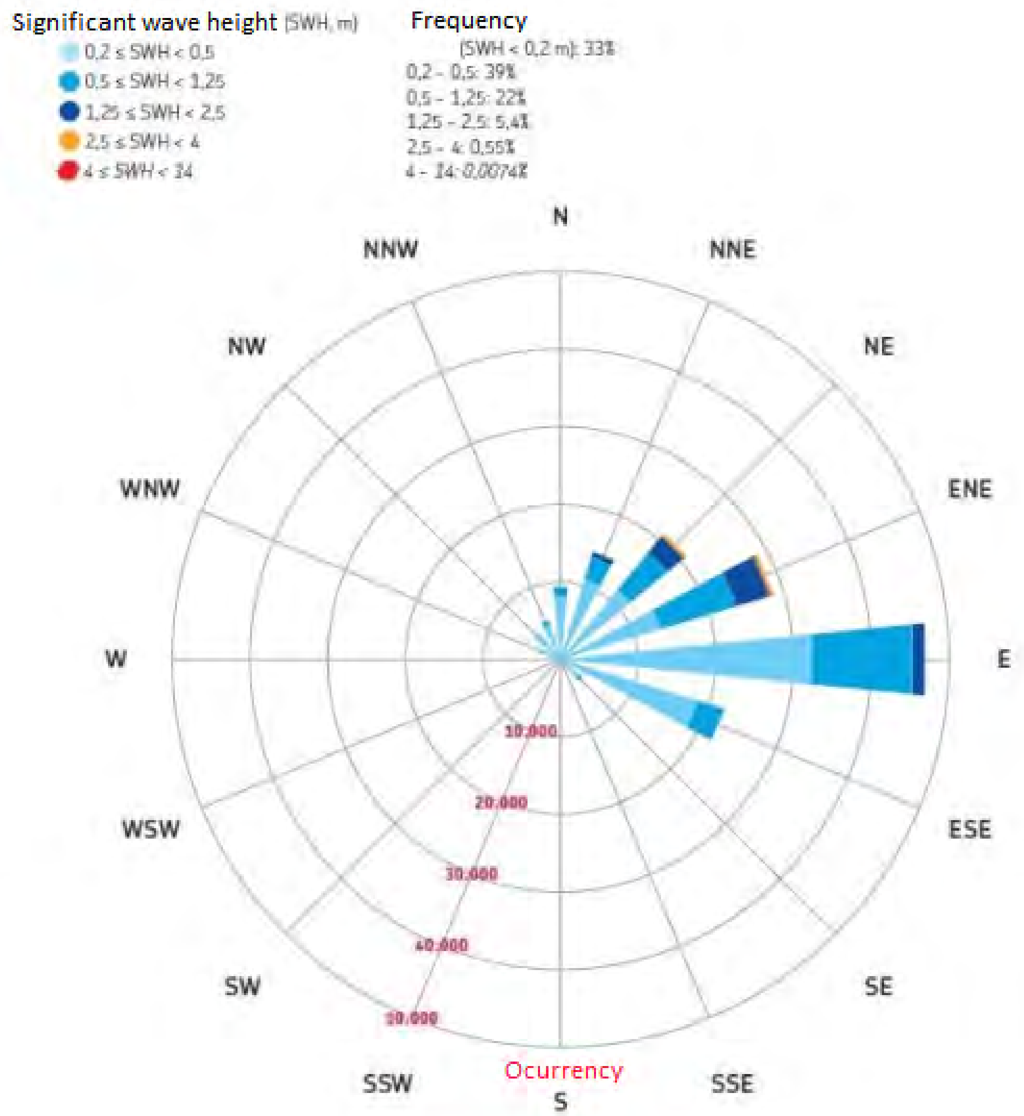

Figure 52: Waves registered in between 2007-2019 at the Cesenatico buoy (IdroMeteoClima 2019).

Value Rank	Soil Impact Site(s) Description	Examples	Cost Modifier Value
Extreme	Predominated by areas with high socioeconomic value that may potentially experience a large degree of *long-term* impact if oiled.	Subsistence/ commercial fishing, aquaculture areas	2.0
Very High	Predominated by areas with high socioeconomic value that may potentially experience some *long-term* impact if oiled.	National park/reserves for ecotourism/nature viewing; historic areas	1.7
High	Predominated by areas with medium socioeconomic value that may potentially experience some *long-term* impact if oiled.	Recreational areas, sport fishing, farm/ranchland	1.0
Moderate	Predominated by areas with medium socioeconomic value that may potentially experience *short-term* impact if oiling occurs.	Residential areas; urban/suburban parks; roadsides	**0.7***
Minimal	Predominated by areas with a small amount of socioeconomic value that may potentially experience *short-term* impact if oiled.	Light industrial areas; commercial zones; urban areas	0.3
None	Predominated by areas already moderately to highly polluted or contaminated or of little socioeconomic or cultural import that would experience little short- or long-term impact if oiled.	Heavy industrial areas; designated dump sites	0.1

Figure 53: EPA BOSCEM Socioeconomic and Cultural Value Rankings (Etkin, 2005)

Category	Cost Modifier value
Urban/Industrial	0.4
Roadside/Suburb	0.7
River/Stream	1.5
Wetland	4.0
Agricultural	2.2
Dry grassland	0.5
Lake/Pond	3.8
Estuary	1.2
Forest	2.9
Taiga	3.0
Tundra	2.5
Other sensitive areas	3.2

Figure 54: EPA BOSCEM Habitat and Wildlife Sensitivity Categories (Etkin, 2005)

Category	Cost Modifier value
Wildlife Use	1.7
Drinking	1.6
Recreation	1.0
Industrial	0.4
Tributaries to drinking/recreation	1.2
Non-specific	0.9

Figure 55: EPA BOSCEM Freshwater Vulnerability Categories (Etkin, 2005)