environments

MDPI

Article

Revolutionizing Ocean Cleanup: A Portuguese Case Study with Unmanned Vehicles Fighting Spills

Nuno Pessanha Santos [1,2,3,*], Ricardo Moura [3,4,5], Teresa Lourenço Antunes [3] and Victor Lobo [3,6]

1 Portuguese Military Research Center (CINAMIL), Portuguese Military Academy (Academia Militar), R. Gomes Freire 203, 1169-203 Lisbon, Portugal
2 Institute for Systems and Robotics (ISR), Instituto Superior Técnico (IST), Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal
3 Portuguese Navy Research Center (CINAV), Portuguese Naval Academy (Escola Naval), Base Naval de Lisboa, Alfeite, 2800-001 Almada, Portugal; rp.moura@fct.unl.pt (R.M.); teresa.lourenco.antunes@marinha.pt (T.L.A.); vlobo@novaims.unl.pt (V.L.)
4 Centro de Matemática e Aplicações (NovaMath), Universidade Nova de Lisboa, Campus da Caparica, 2829-516 Almada, Portugal
5 School of Economics and Management (ISEG), Universidade de Lisboa, Rua do Quelhas 6, 1200-781 Lisbon, Portugal
6 NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Campus de Campolide, 1070-312 Lisbon, Portugal
* Correspondence: nuno.pessanha.santos@tecnico.ulisboa.pt or santos.naamp@academiamilitar.pt

Abstract: It is of the utmost importance for every country to monitor and control maritime pollution within its exclusive economic zone (EEZ). The European Maritime Safety Agency (EMSA) has developed and implemented the CleanSeaNet (CSN) satellite monitoring system to aid in the surveillance and control of hydrocarbon and hazardous substance spills in the ocean. This system's primary objective is to alert European Union (EU) coastal states to potential spills within their EEZs, enabling them to take the necessary legal and operational actions. To reduce operational costs and increase response capability, the feasibility of implementing a national network (NN) of unmanned vehicles (UVs), both surface and aerial, was explored using a Portuguese case study. The following approach and analysis can be easily generalized to other case studies, bringing essential knowledge to the field. Analyzing oil spill alert events in the Portuguese EEZ between 2017 and 2021 and performing a strengths, weaknesses, opportunities, and threats (SWOT) analysis, essential information has been proposed for the optimal location of an NN of UVs. The study results demonstrate that integrating spill alerts at sea with UVs may significantly improve response time, costs, and personnel involvement, making maritime pollution combat actions more effective.

Keywords: environmental monitoring; oil spill detection; pollution prevention; pollution control; sea pollution; sustainable ocean management; unmanned vehicles; unmanned aerial vehicle; unmanned surface vehicle; strategy

check for updates

Citation: Pessanha Santos, N.; Moura, R.; Lourenço Antunes, T.; Lobo, V. Revolutionizing Ocean Cleanup: A Portuguese Case Study with Unmanned Vehicles Fighting Spills. *Environments* **2024**, *11*, 224. https://doi.org/10.3390/environments11100224

Academic Editors: Sergio Ulgiati and Chin H. Wu

Received: 18 August 2024
Revised: 20 September 2024
Accepted: 8 October 2024
Published: 13 October 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The seas and oceans are crucial for life on Earth as they cover around 70% of the planet's surface and contain 97% of all available water [1,2]. The world as we know it would not be the same without algae and phytoplankton's crucial role in producing half of the oxygen we breathe through photosynthesis [3,4]. It should be noted that the ocean plays a crucial role in the regulation of global climate and temperature [5], as well as supporting a wide range of marine life that provides a significant source of protein for people in many parts of the world, particularly in less developed regions [6]. Unfortunately, ocean pollution threatens this biodiversity and the future of those who depend on these critical resources for their livelihoods.

Over the years, Earth has been seriously affected by increased pollution and environmental degradation due to technological advances and human activities [7,8]. Pollution in the seas and oceans is one of the most worrying consequences that have occurred [9–11]. The increase in this pollution has occurred mainly due to the following [12,13]: (i) oily residues from agriculture or industries that end up reaching coastal waters, (ii) deliberate discharges of dangerous and harmful substances from maritime transport, and (iii) waste, specifically plastics.

Worldwide, most global trades occur through sea routes [14], resulting in a higher risk of oil spill occurrence. Portugal, located near the Atlantic Ocean (AO), extends over a vast coastline and has one of the world's largest exclusive economic zones (EEZs) [15]. Consequently, addressing this issue is of paramount importance. The continuous monitoring and control of EEZ activities is an obligation for each coastal state since they need to take the necessary actions to ensure activity regulation. Monitoring and controlling actions, especially when dealing with limited resources, must have acceptable costs while providing an adequate response.

The role of the European Maritime Safety Agency (EMSA) is essential to supervise and protect European maritime regions against pollution. Furthermore, it takes charge of maritime safety and security matters. The CleanSeaNet (CSN) service has the objective of helping to identify possible pollution that occurs in the waters of the European Union (EU) [16]. When a potential pollution site is detected, the state along the coast receives an alert. It must then take the appropriate measures to verify the information and clean up the area if required.

The Portuguese Navy (PoN) receives the CSN alert and verifies its authenticity in Portuguese waters. If the alert is confirmed to be genuine, the PoN must take all necessary actions to clean the affected area to minimize the impact on the maritime environment. This is crucial because there have been numerous incidents of sea pollution caused by massive oil spills, such as the *Prestige* tanker in 2002 [17], which occurred off the coast of Galicia, and the *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010 [18]. It is crucial to promptly and effectively address the consequences of sea pollution.

Unmanned Vehicles (UVs) are being utilized in various fields and can also be utilized to perform pollution surveillance, monitoring, and cleaning with efficiency [19–21]. Their use can significantly reduce operational costs and enhance the response capability of the coastal state [22]. A combination of unmanned surface and air vehicles can maximize the benefits of each type and lead to more effective utilization, as shown in Figure 1. An unmanned surface vehicle (USV) usually has a lower cruise speed and autonomy than Unmanned Aerial Vehicles (UAVs). Still, it has the advantage of being able to combat pollution in the affected area directly [21]. This article will explore and analyze the utilization of UVs without focusing on specific models, allowing for easier generalization of the study. Estimates for the trajectory of the oil spill and the weather conditions are crucial, as illustrated in Figure 1, as UVs take some time to reach the affected area. However, we can optimize the trajectory by continuously obtaining updates on the weather conditions via satellite. We can also use some sensor information like the buoys managed by the Portuguese Hydrographic Institute, *Instituto Hidrográfico* [23], to estimate the environmental conditions along the coast better. Since obtaining full area coverage is difficult and cost-impractical due to the EEZ's vastness, this option cannot be considered a feasible standalone information source but information that can be combined with other data sources using data fusion techniques [24].

Analyzing and evaluating the current context is essential to developing a proper UV network. As with any area of application, developing an effective implementation strategy is essential, and one useful approach is conducting a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis [25–27]. This analysis involves comparing and correlating various categories to generate insights and recommendations. It is a proposal that reflects the current reality and needs to be updated regularly to account for any changes in the existing context. This widely accepted framework is a useful tool commonly used for strategic planning and decision-making processes [26,28].

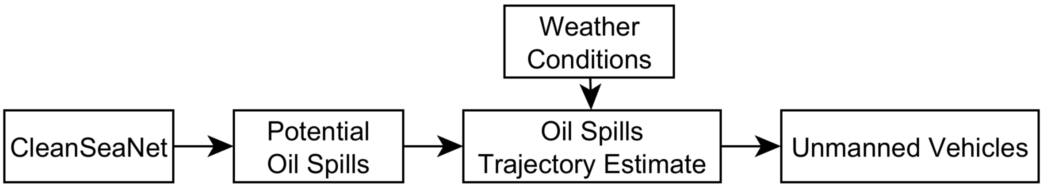

Figure 1. Simplified diagram of the proposed approach for using a network of UVs for maritime pollution combat operations.

The main aim of this article is to perform a more extensive, complete, and comprehensive analysis than the one presented in [22]. The upcoming sections will elaborate on this objective. The significant contributions identified are as follows:

- An analysis of the potential oil spill occurrences between 2017 and 2021 in Portuguese waters;
- An analysis and evaluation of sea pollution monitoring and control using UVs;
- The development of a SWOT analysis to understand the current implementation context, being able to retrieve essential insights for strategy development;
- An initial analysis of a strategy for using UVs in pollution control that can be easily generalized to other case studies.

This article is organized as follows. Section 2 explores related work in the study area, giving essential insights to understand the field of study. Section 3 formulates the problem in more detail. Section 4 performs a simplified statistical analysis of the oil spill occurrences in Portuguese waters between 2017 and 2021. Section 5 proposes a SWOT analysis and performs its description and evaluation. Section 6 introduces a National Network (NN) of UVs for potential oil spill monitoring and combat, considering the characteristics of the proposed vehicles. Finally, Section 7 presents the conclusions and provides the necessary directions for further research.

2. Related Work

This section is intended to provide the needed analysis of the current related work, which is essential to understanding the analysis performed during the article. Section 2.1 explores sea pollution and some of the existing legislation. Section 2.2 explores pollution by hydrocarbons and some of their characteristics. Section 2.3 explores the CSN service that monitors maritime domain pollution. Section 2.4 briefly explores the UVs essential in creating an NN for potential oil spill monitoring and cleaning.

2.1. Sea Pollution

According to the United Nations Convention on the Law Of the Sea (UNCLOS), sea pollution is the direct or indirect human introduction of substances in the maritime domain that lead to harmful effects on humans and animals [29]. The leading cause of pollution in the maritime environment is human activity, which introduces harmful substances or energy. Additionally, some natural changes in coastal areas due to numerous factors, such as resource exploration or new construction, can also directly affect existing ecosystems and endanger marine life, directly impacting the economy [30]. The progressive increase in chemical contamination and acidity in the oceans has harmed species such as corals and mollusks, affecting the food chain and causing ecological imbalances [31]. To deal with the vast increase in current pollution, since it is currently one of the major ambient causes of diseases [32,33], it is essential to implement an integrated approach involving governments, organizations, and the population. A comprehensive analysis shows that most human actions in the maritime domain are undeniably responsible for polluting our oceans [34]. Prioritizing prevention is crucial, as a future with reduced pollution levels will lead to a healthier environment for the existing population, directly impacting the quality of life.

Regarding international legislation, several accords and conventions primarily focus on maritime pollution. One of the most important is the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 convention [35], which establishes specific criteria for ship construction and prohibits discharges that cause marine pollution, except those processed through oil filtering or separating equipment. In addition to the MARPOL convention, other international agreements, such as the International Convention for the Safety of Life at Sea (SOLAS) [36], the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) [37,38], and the International Convention on Oil Pollution Preparedness, Response, and Co-operation (OPRC) [39] also play a crucial role in the regulation and the treatment of seawater pollution. It is important to regulate, but equally important to monitor and implement efficient legal mechanisms that penalize polluters.

The collaboration between global organizations is crucial, and the environmental sector is no different. If an oil spill is significant and can pose a major danger to the environment and nearby countries, according to the OPRC [39], the responsible coastal state is required to notify the International Maritime Organization (IMO). The IMO is a United Nations (UN) agency responsible for the safety and security of shipping and the prevention of marine pollution by ships [40], being able to provide technical assistance and mobilize resources to help through the Global Response Network (GRN) [41,42].

Portugal has implemented the Clean Sea Plan (CSP) strategy since 1993 [43]. This plan defines the emergency measures that must be taken to combat pollution in the maritime domain and allows direct actions. To enable a faster response, the country has implemented a Pollution Report System (POLREP) [44], which provides authorities with detailed information about existing pollution occurrences in the maritime domain. The PoN coordinates all maritime domain pollution operations in Portuguese waters, ensuring they are executed safely and efficiently. In most cases, and mainly due to a lack of resources, pollution monitoring in situ is not always possible, mainly due to the vast existing maritime area to cover.

2.2. Hydrocarbons

The main sources of hydrocarbon pollution in the maritime industry are petroleum operations and shipping [45]. Petroleum is commonly extracted from underground reservoirs, particularly in the Persian Gulf [46]. When petroleum comes into contact with the ocean, it causes contamination and is one of the leading sources of ocean pollution. Approximately 90% of the world's trade is conducted by sea, with petroleum being one of the major primary materials transported [47]. As a result, it is natural for these activities to involve a risk of spills, which may be accidental or intentional [48,49].

Hydrocarbons have physical and chemical properties that affect their behavior. These properties include viscosity, which is the resistance of the fluid to movement; density, which is the amount of mass per unit volume; pour point, which is the lowest temperature at which the hydrocarbon still flows at a specific speed; flash point, which is the minimum temperature at which the hydrocarbon is capable of emitting combustible vapors in sufficient quantity to form a flammable mixture with air; boiling point, which is the temperature at which oil passes from liquid state to the gaseous state at atmospheric pressure; solubility, which is the ability of a substance to dissolve in water [50,51]. Understanding the chemical properties of hydrocarbons is crucial for effectively and quickly cleaning up the pollution they cause without impacting existing ecosystems.

To better understand the impact of hydrocarbons, they can be classified based on their properties. This is mainly determined by their relative density and concentration of aromatic compounds [52–54]. Oils with higher concentrations of aromatic compounds are more harmful and tend to evaporate more easily than oils with higher concentrations of heavier components, which are more persistent in the environment. Volatility is a characteristic of hydrocarbons that can result in varying degrees of environmental damage, depending on the type of hydrocarbon [55,56].

If we know the type of hydrocarbon and its characteristics, we can tailor the cleaning response operation to make it more effective. This, in turn, leads to reduced costs and environmental impact. Unfortunately, it is not always feasible to obtain this information in advance. Satellite images are typically used to detect the spill [57,58] and determine its thickness [59,60], but cannot still provide the specific details required for more efficient spill response planning.

2.3. CleanSeaNet

To accurately detect oil spills, remote sensing is essential as it helps to ensure timely detection and action while also reducing the occurrence of false positives [61,62]. Most commonly used sensors rely on Red, Green, and Blue (RGB) or Synthetic Aperture Radar (SAR) satellite images, which, after preprocessing, are combined with feature extraction algorithms to detect and classify oil spills [63]. With the growing use of Deep Neural Networks (DNNs) across various fields, the remote sensing of oil spills has also followed this trend. It has become increasingly common to apply Convolutional Neural Networks (CNNs) for oil spill detection [64,65].

EMSA has developed the CSN satellite monitoring system. The primary objective of this system is to alert EU coastal states about potential spills within their EEZs, enabling them to take the necessary legal and operational actions. The EMSA offers technical and operational assistance to EU countries on pollution-related matters. The CSN service uses SAR and RGB satellite images to detect possible oil spills [66]. When an oil spill occurs, SAR technology is usually used. Using this technology, it can be difficult to accurately measure and detect the spill in an area where wind-caused capillary waves exist since they affect wave reflection [67]. Furthermore, ships made of metal tend to reflect more, making them easily detectable. If possible and needed, ship identification can be performed using Vessel Monitoring System (VMS) data, which can obtain radar and Automatic Identification System (AIS) data [68]. Some natural phenomena, such as algae or ice in places without wind, can be detected as false positives [69,70]. Another limitation is the inability to detect the oil source directly from satellite images [71], as described in the previous section.

In an oil spill, a report is immediately generated and sent to the coastal state for appropriate measures within approximately 20 min [72]. The CSN service categorizes detections into two classes: (i) class A, which has a high probability of being an oil spill, and (ii) class B, which presents a lower probability of being an oil spill [69,73]. It is crucial to confirm the presence of all detected oil spills in situ and undertake rigorous monitoring and control measures to mitigate sea pollution caused by oil spills.

2.4. Unmanned Vehicles

The EMSA currently provides a UAV service free of charge that can assist coastal states in monitoring existing occurrences, with a minimum deployment of two months [74]. A network of UVs is an excellent way for countries to reduce operational expenses and achieve near real-time response. Moreover, it can be highly beneficial for these nations to offer services to other countries that lack access to such resources. In recent decades, UAVs have become increasingly popular and accessible to many users [75–78]. They are currently being used in many applications [79–81], and are also widely accessible as Commercial-Off-The-Shelf (COTS) products [82,83].

Tekever is a company that the EMSA contracts for various tasks, including detecting oil spills, managing traffic and piracy, aiding in fishery inspection, and monitoring ship oil emissions [74,84,85]. This partnership has been proven to have numerous advantages and high-performance results [86]. The UAV developed and used by *Tekever*, illustrated in Figure 2 (left), has a main wing measuring 7.3 m, a length of 4 m, a cruising speed of 100 km/h, a payload capacity of 50 kg, and an impressive endurance of 20 h [85–87]. Equipped with five gyrostabilized gimbals, electro-optical (EO) and Infrared Radiation (IR) sensors, an AIS, Emergency Position Indicator Radio Beacon (EPIRB), Maritime Radar (MR), and SAR capabilities, this UAV is a powerful tool for many tasks [85–87].

Figure 2. *Tekever* company AR5 UAV [85] (**left**) and *Elbit Systems* company *Silver Marlin* USV [88] (**right**).

The EMSA does not use USVs in its operations. However, USVs offer the advantage of directly addressing pollution in situ. For example, the *Elbit Systems Silver Marlin* USV [88], illustrated in Figure 2 (right), can undertake diverse missions, including Intelligence, Surveillance, and Reconnaissance (ISR), force protection, anti-terrorism, Mine Warfare (MW), search and rescue, pollution treatment, firefighting, and special research tasks. This USV is 10.67 m long, can reach a maximum speed of 45 knots, has an endurance period of 24 to 36 h, and has a projected range of 500 nautical miles. It also features a range of sensors, such as EO and acoustic sensors.

Some concepts that combine UAVs and USVs have already been developed, where UAVs are responsible for monitoring oil spills and USVs for the oil spill combat (cleaning) process [89]. With this combination, it is expected to perform the operations at lower costs and with higher efficiency. Despite these efforts, Europe still does not have a cooperative and interoperable network of unmanned systems that could automate this operation, depending on the necessities and payload possibilities. Different types of payloads, like sensors, can offer more comprehensive information through data fusion, leading to better decision-making processes.

This article's purpose is not to provide a detailed review of the working modes and characteristics of UAVs and USVs but to give an overview of what is being used. The study and analysis can be easily adapted to other UVs with different specifications and generalized to other case studies, as the explored scenario is common to all coastal states. The ability to generalize is crucial, as it provides important scientific rigor to this study.

3. Problem Formulation

Portugal is a unique country with many distinguishing qualities and challenges due to its location. Its location near the AO is particularly advantageous, but its extensive coastline makes it highly connected to the ocean. Portuguese waters are frequented by ship traffic due to the presence of crucial choke points [90]. This increased traffic demands greater responsibility for monitoring and control, as illustrated in Figure 3. It is important to note that a large portion of maritime traffic involves the transportation of oil [91], which, unfortunately, increases the accident risk and, consequently, the potential for pollution. Apart from other reasons, pollution can occur due to irresponsible practices of some crew members who discharge oil at sea [92] and accidents, which pose a permanent risk [93].

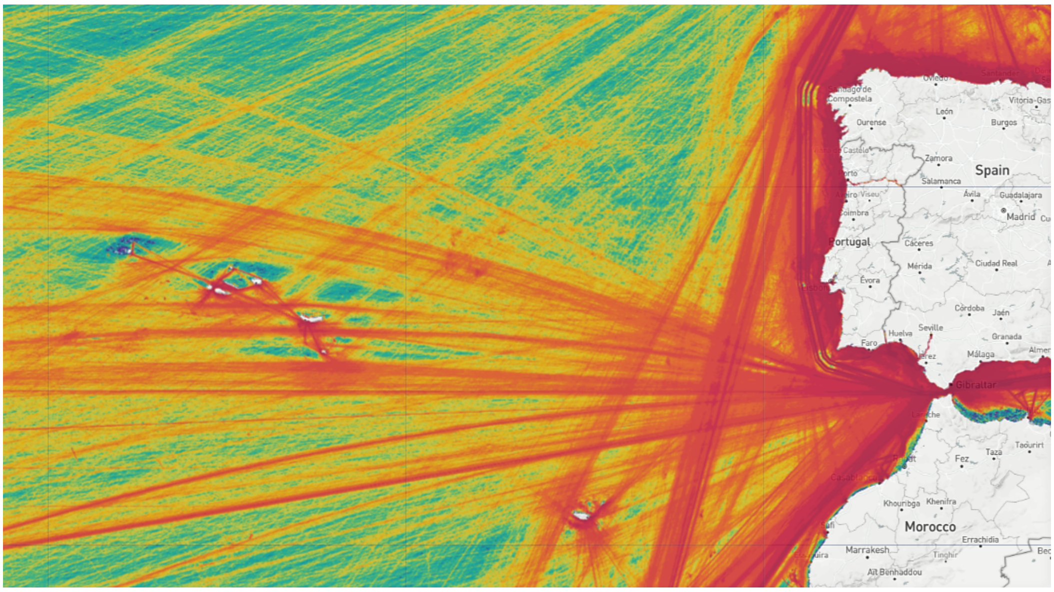

Figure 3. Density of maritime traffic near Portugal in 2022 [94]. Regions with lower traffic are represented in lighter shades of red, while regions with higher traffic are shown in darker red.

Real-time monitoring and control are crucial due to Portugal's vast maritime area under sovereignty and jurisdiction and the need to comply with international legislation on pollution combat [95]. It is imperative to follow the established conventions that offer clear guidelines on minimizing the probability of a pollution incident, as briefly described in Section 2.1.

The Portuguese EEZ is divided into three regions of ocean areas, as illustrated in Figure 4. The region beyond and adjacent to the territorial water of the mainland (287,521 km^2), the Azores (930,687 km^2), and Madeira (442,248 km^2). Given the existing maritime traffic, as illustrated in Figure 3, proper supervision and control of this area are crucial to prevent illegal or accidental spills of hazardous and toxic substances into the sea. Each coastal state monitors and regulates activities within its EEZ and responds promptly to possible incidents.

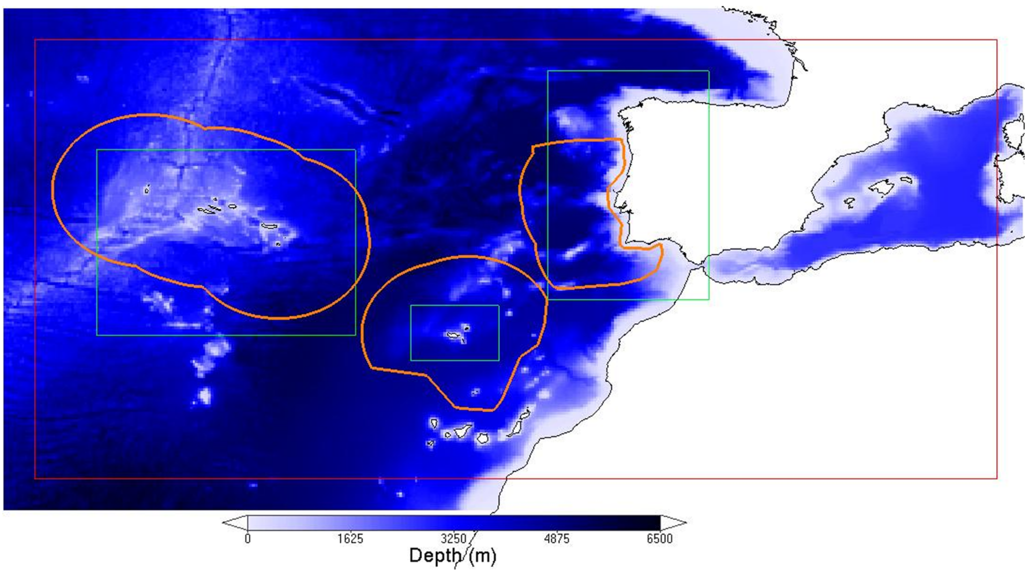

Figure 4. The Portuguese EEZ, encompassing the mainland, Azores, and Madeira, is represented by orange polygons, while the region delimitations are shown in green [96].

The time difference between the possible oil spill alert and the UV arriving at the scene must be considered. Some approaches use a complex formulation considering oil spread, evaporation, and dissolution [97]. To simplify the analysis process, a basic oil spill model that considers ocean currents and wind speeds should suffice for accurate approximations [22,98]. With the use of UVs equipped with satellite connections and onboard processing capabilities, any errors in our oil spill modeling trajectory can be corrected online during the course from the base to the occurrence site [22].

To respond to oil spills cost-effectively, it is important to match the capabilities of UVs effectively with the location of the spill. It is essential to analyze this pairing properly to achieve success. To optimize the deployment of UVs along the Portuguese coast, statistical analysis of existing oil spill alerts is necessary. Moreover, it is important to consider the time needed between the alert and arrival at the scene, as the possible oil spill may move due to wind and sea currents [99–101].

We will consider the UAV and USV models for the analysis performed, briefly described in Section 2.4. These models are appropriate for this type of operation. Moreover, it is worth noting that this analysis can be easily adapted to other UV models, given their operational specifications. As described before, the purpose of this article is not to delve into specific UV models but to conduct a thorough analysis of how these models can be combined and utilized to combat spills.

4. Analyzing Oil Spills in Portuguese Waters

Performing a statistical analysis is essential to fully understand a particular area, particularly when dealing with temporal information. We have analyzed data collected from the CSN service between 2017 and 2021 in Portuguese waters, as illustrated in Figure 5, to identify the main areas affected by these incidents (alerts). This analysis is crucial for identifying areas with more occurrences, which helps optimize UV locations throughout the territory.

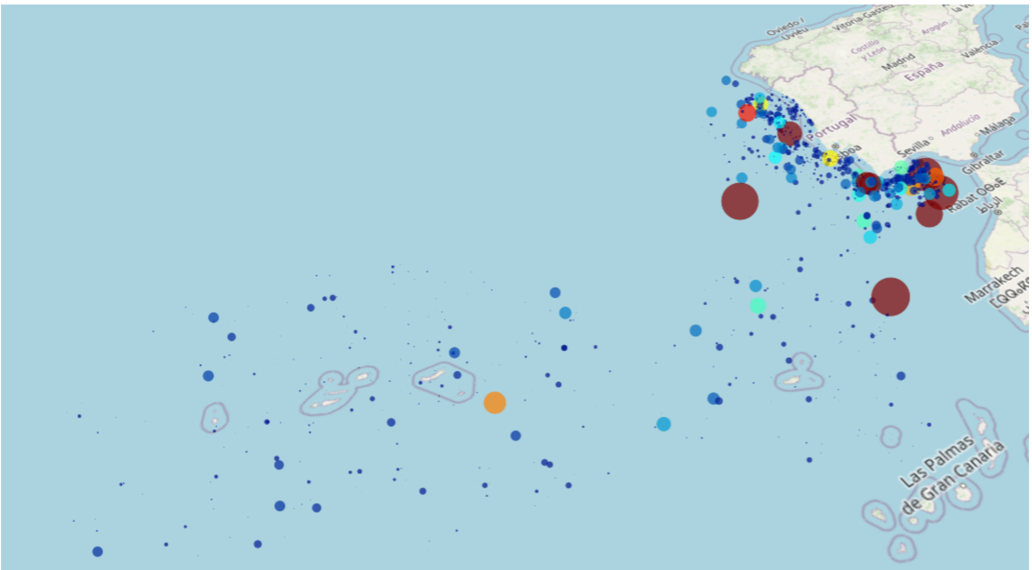

Figure 5. Alerts for oil spills in Portuguese waters from 2017 to 2021, visualized as circles whose sizes correspond to the potential spill area. Different colors indicate various clusters of spill incidents.

After examining Figure 5, it is evident that most alerts are concentrated in the areas identified as high-traffic zones in Figure 3. It would be impractical and expensive to deploy manned ships or aircraft to monitor the vast areas we need to cover. Between 2017 and 2021, 1245 alerts were reported, but only two were verified in situ, meaning that Portugal has received an average of approximately 250 alerts annually. However, the confirmation rate of these alerts is only 0.4 per year, which is notably low. This is mainly due to a lack of resources and a high volume of alerts, which means confirmation takes a lot of material and human resources, which are very expensive.

Based on the data presented in Figure 6, a significant number of alerts happen in the southern region of Portugal. Therefore, this area should be given priority for coverage. However, it is crucial to recognize that oil spills are a permanent risk along the Portuguese coast, as any seafaring vessel poses a potential threat. This underscores the importance of maintaining vigilance and preparedness across all coastal regions, not just areas with a higher frequency of incidents.

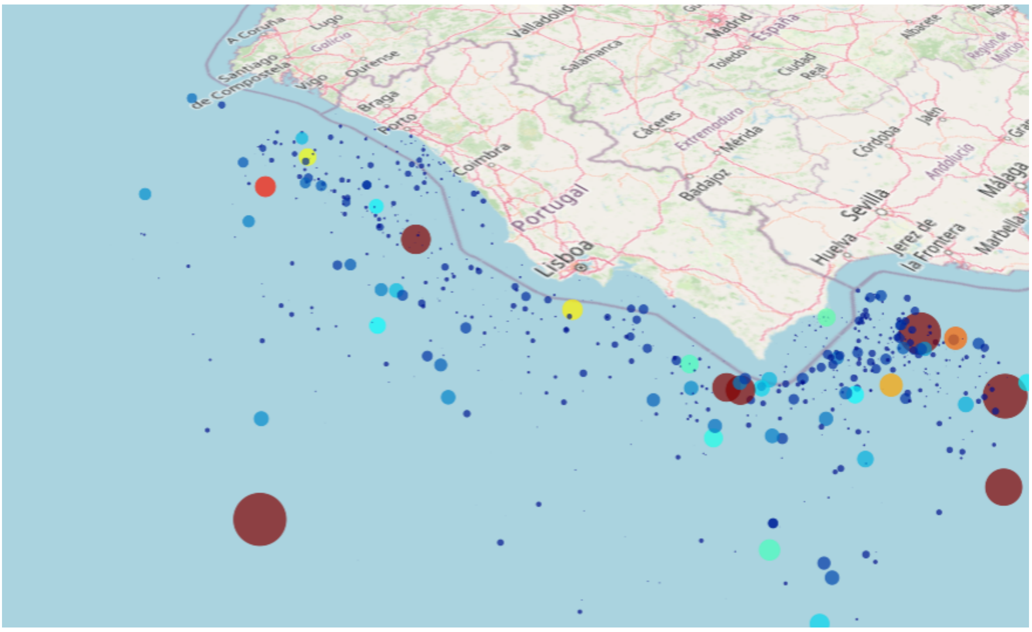

Figure 6. Alerts for oil spills near the Portuguese mainland from 2017 to 2021, visualized as circles representing the potential spill area, with sizes corresponding to the area. Different colors indicate various clusters of spill incidents.

The Macaronesia region, which comprises Madeira and the Azores islands, is a well-liked tourist destination [102]. However, due to the rise in the number of tourist ships sailing around the islands, there is a greater likelihood of potential oil spills, as shown in Figure 7.

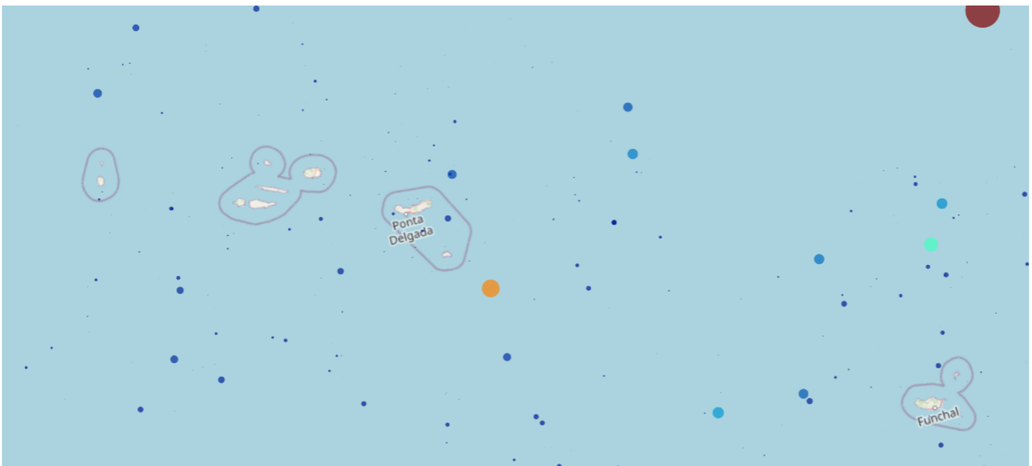

Figure 7. Alerts for oil spills near the Azores and Madeira islands from 2017 to 2021, visualized as circles that represent the potential spill area, with sizes reflecting the scale of the spill. Different colors indicate distinct clusters of spill incidents.

Given the vast maritime area under consideration, some regions require increased attention, particularly those with a higher likelihood of oil spill incidents. It is crucial to balance prompt response measures with cost-effectiveness. The subsequent section will delve into a SWOT analysis to better comprehend the current context and perform strategic planning [26,28]. This analysis will aid in identifying strengths, weaknesses, opportunities, and threats, facilitating a more informed and effective approach to managing oil spill risks in maritime areas.

5. Characterizing the Environment and Defining a Strategy

Conducting a SWOT analysis to develop a proper UV network [103,104] is important. The success of a strategy relies more on its correct execution than its content. Evaluation and control of strategy implementation are critical factors for success. Using proper performance metrics for evaluation and control is essential to clearly understand the obtained performance by analyzing specific dimensions [105,106]. The SWOT analysis is a widely accepted framework and an important strategic planning tool that contributes directly to the decision-making process [26,28,107,108]. The SWOT analysis is a globally used methodology to identify strengths, weaknesses, opportunities, and threats in a specific context or environment [25–27]. These can be described as follows:

- **Strengths:** Internal characteristics or resources that provide an advantage, corresponding to the positive aspects of the identified internal factors;
- **Weaknesses:** Internal characteristics or resources that could lead to disadvantages, corresponding to the negative aspects of the identified internal factors;
- **Opportunities:** External factors that promote success, corresponding to the positive aspects of the identified external factors;
- **Threats:** External factors that could cause failure, corresponding to the negative aspects of the identified external factors.

A SWOT analysis is useful when examining an environment. However, it should not be the only aspect to consider [109]. Systematically aligning and examining the relationships among opportunities, weaknesses, strengths, and threats enables a deeper understanding of how these elements interrelate [109,110]. Balancing the strengths, weaknesses, opportunities, and threats is crucial to developing effective solutions. This analysis allows for more thorough and customized strategy recommendations, as the current environment is accurately defined. By reviewing the literature and examining the data, we acquired valuable insights into the present context [103,111]. These findings will guide the development of a robust strategy to tackle future challenges. The main objective of the analysis is to implement an NN of UVs, considering the country's current situation and the growth potential.

The identified strengths, which represent the positive aspects of the identified internal factors for implementing an NN of UVs, are as follows:

- Technological innovation;
- The development of national industry;
- The ability to develop internal knowledge;
- The ability to develop knowledge to perform research and development of new systems and solutions;
- The development of an infrastructure that can be used for UVs performing different types of operations;
- The ability to perform completely unmanned operations;
- An NN of UVs provides a versatile approach that can be applied in various scenarios;
- The promotion of sustainable development and innovation.

The identified weaknesses, which represent the negative aspects of the identified internal factors for implementing an NN of UVs, are as follows:

- Low technical knowledge;
- Technological risk;

- Necessary initial investment;
- Difficult access to capital for investment;
- The need for partnership with private companies to raise financing;
- The country's legislation regarding autonomous vehicle operation.

The identified opportunities, which represent the positive aspects of the identified external factors for implementing an NN of UVs, are as follows:

- The project and idea can be easily adapted to other countries;
- Funding source access;
- Partnership with private companies in the UVs sector;
- Contribution to political, economic, and social factors;
- Direct contribution to worldwide pollution monitoring and control;
- Boosting the economy;
- The enhancement of UVs global knowledge.

The identified threats, which represent the negative aspects of the identified external factors for implementing an NN of UVs, are as follows:

- Technological dependence on the CSN service's oil spill detection;
- Investment risk;
- UVs legislation is not globally well-defined;
- Under-developed technology;
- A network of UVs creates potential cybersecurity risks.

Based on the results, investing in the national UV network and providing specialized training and necessary infrastructure can reduce human resource dependence. The technology offers many benefits, including enhancing existing knowledge, research and development, and increasing operational efficiency. However, there are also weaknesses, such as associated risks and the need for secure investments. The opportunities for UVs are vast, including boosting the economy and contributing to worldwide pollution monitoring and control. However, there are also threats, such as the lack of existing legislation for UVs and dependence on the CSN service for oil spill detection. It is through the relationship between these factors that strategic planning is performed, providing crucial insights for the decision-making process.

We can divide strategic planning into short-, medium-, and long-term actions. In the short term, focusing on existing manned vehicles in areas with frequent oil spills, as outlined in Section 4, is crucial. These initial efforts also include improving existing infrastructures and conducting research and development to ensure that the developed solution will be suitable. Forming strategic partnerships and seeking financial support internally or externally is also important. In the medium term, the focus should be on implementing an NN of UVs and investing in reducing the dependence on human resources. It is essential to gain operational experience and establish procedures to ensure the correct and speedy use of UVs. In the long term, it is necessary to establish the NN and ensure full operational capability is installed. Ideally, all the construction and maintenance should be carried out internally to boost the local economy.

6. Unmanned Vehicles National Network

Portugal has a long coastline, making the sea a vital aspect of its economy. However, managing its vast EEZ and responding quickly to emergencies can be challenging. Therefore, it is crucial to explore alternative ways of addressing this issue. The alert's location and the spill's potential movement are crucial factors when deciding on the most suitable UV. When dealing with multiple alert situations, it is crucial to prioritize the correct location. This can be achieved through statistical analysis and oil spill trajectory estimation, as illustrated in Figure 8, where oil spill alerts in Portuguese waters between 2017 and 2021 are represented. Representation and analysis are essential in the UV network design and analysis. It is important to analyze the situation carefully to ensure the most effective response.

As described in Section 2.4, USVs and UAVs display distinct differences in autonomous capabilities and cruising speeds. USVs usually offer an added advantage over UAVs' ability to monitor and combat pollution (cleaning). It is crucial to approach spill fighting with monitoring and cleaning to ensure prompt action. A dual-use approach [112] can also be assumed to utilize USVs in combating ship fires and reducing operational costs in this domain. Based on current data analysis, the most effective strategy would be to use USVs for occurrences near the coastline and UAVs for those further away.

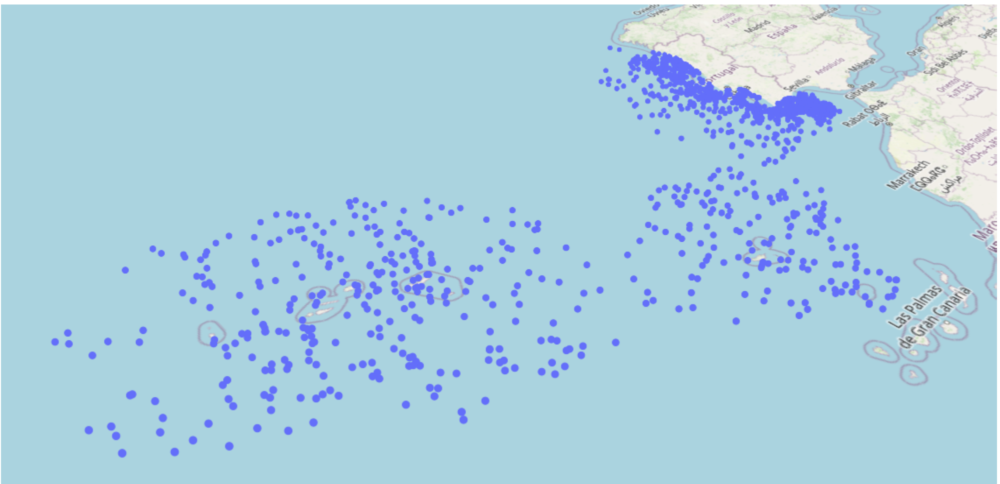

Figure 8. Oil spill alerts, represented as blue dots, that occurred in Portuguese waters from 2017 to 2021.

To ensure maximum coverage in areas with high incidence rates, we initially propose implementing five USV and three UAV bases, as outlined in Table 1. According to the information presented in Section 3, we assume that the UAVs can cover a distance of up to 900 km (≅486 NM), while USVs can cover a distance of 300 km (≅162 NM). As illustrated in Figure 9, our solution provides complete coverage of all affected areas at the most reasonable cost since it guarantees area coverage while minimizing the number of used vehicles. The center locations of the UV range are represented in Table 1, corresponding to the provided circles.

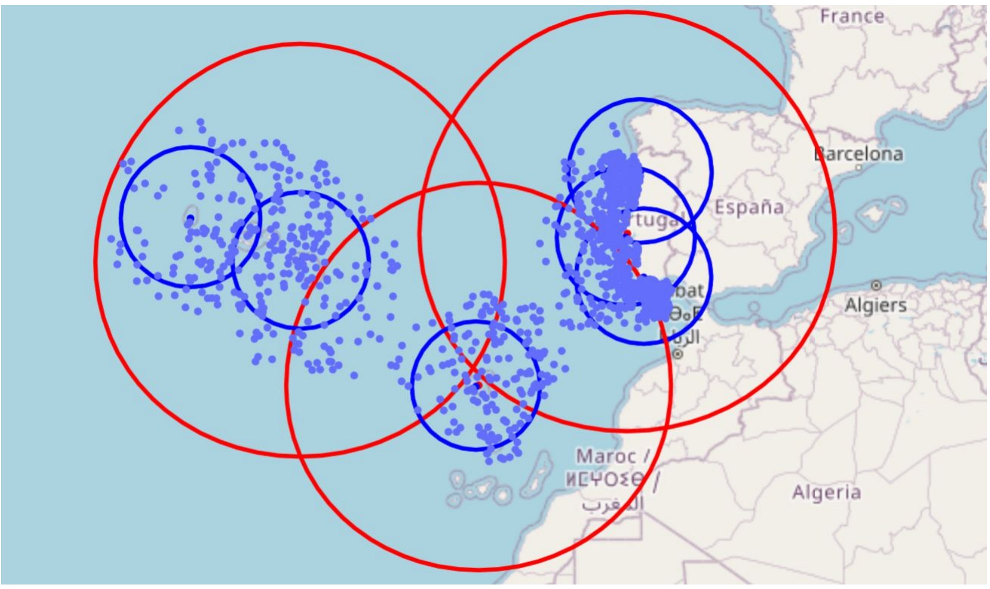

Figure 9. Blue circles represent the coverage areas of potential USV bases, while red circles indicate the coverage areas of potential UAV bases near the Portuguese mainland and the Azores and Madeira islands.

It is essential to determine the number of UVs stationed at each base location, and this number should be adjustable and subject to revision over time. To determine the optimal number of vehicles, we can review the frequency of incidents between 2017 and 2021 and allocate additional resources to areas with higher incident rates. Based on this analysis, we recommend reinforcing the USV station near the Portuguese coastline, specifically in the southern region, as it requires additional resources. However, this number and its location can be adjusted appropriately, even considering the specific time of the year. Another approach is to perform forecasting [100,113] using existing data and adjusting the number of UVs at each location since it is possible to combine data such as winds, sea currents, and wave direction to predict future oil spill occurrences [114,115].

The possibility of implementing a dual-use strategy increases the development of an NN of UV importance, allowing it to have multiple purposes. In particular, search and rescue operations are crucial in a coastal state like Portugal with a vast EEZ. Figure 10 illustrates the search and rescue incidents in the Portuguese EEZ between 2013 and 2021. Upon analyzing search and rescue incidents, it is clear that most occur near the coast and are related to flooding, false alarms, breakdowns, or medical assistance, making it easier for UVs to respond quickly if needed.

Table 1. Possible locations for USV and UAV bases.

Location	Coordinates		Type
Air Base n.º 1—Sintra	38°50′26″ N	009°20′37″ W	UAV
João Paulo II Airport	37°44′32″ N	025°41′56″ W	UAV
Funchal Airport	32°41′41″ N	016°46′36″ W	UAV
Port of Cascais	38°41′37″ N	009°24′53″ W	USV
Port of Portimão	37°07′04″ N	008°31′35″ W	USV
Port of Leixões	41°10′42″ N	008°42′18″ W	USV
Port of Funchal	32°38′43″ N	016°54′29″ W	USV
Port of Ponta Delgada	37°44′33″ N	025°40′13″ W	USV
Port of Lajes	39°25′40″ N	031°10′37″ W	USV

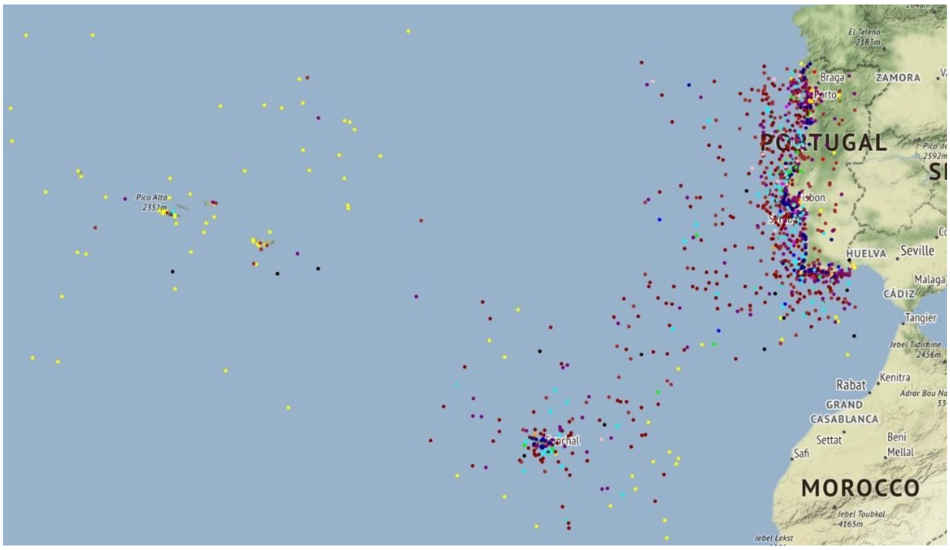

Figure 10. Search and rescue incidents in the Portuguese EEZ between 2013 and 2021. Red: aerial accidents; green: sinking; blue: flooding; yellow: alerts outside the Portuguese search and rescue area; light blue: breakdowns; pink: collisions, black: strandings; brown: medical assistance; light orange: false alerts; light pink: man overboard; gray: missing persons; dark yellow: bridge falls; green: towing and lighter; blue: telemedical assistance services.

UVs have proven highly useful for maritime search and rescue operations. They offer great benefits regarding aerial surveillance and reconnaissance, particularly for monitoring and managing rural fires. Using UAVs enhances the ability to quickly detect and assess fire situations, which is crucial in rural areas. This dual application amplifies the network's value, contributing to maritime safety and effective land-based emergency responses.

7. Conclusions and Future Work

Pollution is a significant global issue that seriously threatens our environment. Therefore, it is essential to acknowledge and incentivize efforts to combat it. Monitoring and preventing oil spills is one effective way to prevent the harmful effects of oil spills on ecosystems. With its extensive coastline, Portugal is highly connected to the ocean and has a challenging geostrategic location, as it is highly vulnerable to oil spills. Such spills occur usually due to accidents or illegal discharges by ship crews at sea.

A statistical analysis of oil spill incidents was performed between 2017 and 2021 to identify high-risk areas. It is crucial to have a quick and cost-effective response plan to ensure the effectiveness and endurance of the vehicles involved in the cleanup process. We conducted a SWOT analysis focused on creating an NN of UVs that allowed for the proper evaluation of the environment, which is critical in evaluating and defining the best strategy, taking into account the characteristics of the UVs. The analysis suggests implementing short-, medium-, and long-term actions. In the short term, focus on existing manned vehicles in areas with frequent oil spill occurrences. In the medium term, an NN of UVs should be implemented, and dependence on human resources should be reduced. Establishing an NN with full operational capability is critical in the long term.

Our initial proposed implementation strategy involves setting up three UAV and six USV stations to cover most Portuguese waters efficiently. These strategically placed stations can also serve a dual purpose, as they can significantly aid in search and rescue operations and monitor and manage rural fires. This illustrates the project's adaptability and relevance in various emergencies, contributing to a broader spectrum of environmental protection and safety measures. As this work is still under development, there is room for improvement. For example, more comprehensive optimization can be performed, considering the costs and response times of both single and multiple events. All the obtained results are easily generalizable and applicable to other case studies, as the explored environment is similar to that of all coastal states.

Author Contributions: Conceptualization, N.P.S., R.M. and V.L.; methodology, N.P.S. and R.M.; software, R.M. and T.L.A.; validation, N.P.S., R.M. and T.L.A.; formal analysis, N.P.S., R.M. and T.L.A.; investigation, N.P.S., R.M. and T.L.A.; resources, N.P.S., R.M. and V.L.; data curation, N.P.S., R.M. and T.L.A.; writing—original draft preparation, N.P.S. and R.M.; writing—review and editing, N.P.S. and R.M.; visualization, N.P.S. and R.M.; supervision, N.P.S., R.M. and V.L.; project administration, N.P.S., R.M. and V.L.; funding acquisition, not applicable. All authors have read and agreed to the published version of the manuscript.

Funding: The research carried out by Nuno Pessanha Santos was supported by national funds through *Fundação para a Ciência e a Tecnologia* (FCT) under the projects—LA/P/0083/2020, UIDP/50009/2020 and UIDB/50009/2020—Laboratory of Robotics and Engineering Systems (LARSyS). National funds funded the research conducted by Ricardo Moura through FCT, I.P., Center for Mathematics and Applications (NOVA Math) under the scope of the projects UIDB/00297/2020 and UIDP/00297/2020. The research carried out by Victor Lobo was supported by national funds through FCT under the project—UIDB/04152/2020—*Centro de Investigação em Gestão de Informação* (MagIC)/NOVA IMS.

Data Availability Statement: The manuscript contains all the data and materials that support the conclusions presented. The Mar-IA web platform provides access to the dataset used, which contains the occurrences of oil spills in Portuguese waters at https://mar-ia.pt/groups/potential-oil-spill-allerts-in-portugal/ (accessed on 20 September 2024). The search and rescue events analyzed in Portuguese waters between 2013 and 2021 can be accessed at https://portal.emsa.europa.eu/emcip-public/#/public-occurrences (accessed on 20 September 2024). For further inquiries, please contact the corresponding author.

Conflicts of Interest: The authors state that they have no conflicts of interest.

Glossary

AIS	Automatic Identification System
AO	Atlantic Ocean
CNN	Convolutional Neural Network
COTS	Commercial-Off-The-Shelf
CSN	CleanSeaNet
CSP	Clean Sea Plan
DNN	Deep Neural Network
EEZ	Exclusive Economic Zone
EMSA	European Maritime Safety Agency
EO	Electro-Optical
EPIRB	Emergency Position Indicator Radio Beacon
EU	European Union
GRN	Global Response Network
IMO	International Maritime Organization
IR	infrared Radiation
ISR	Intelligence, Surveillance, and Reconnaissance
MARPOL	International Convention for the Prevention of Pollution from Ships
MR	Maritime Radar
MW	Mine Warfare
NN	National Network
OPRC	International Convention on Oil Pollution Preparedness, Response, and Co-operation
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
POLREP	Pollution Report System
PoN	Portuguese Navy
RGB	Red, Green, and Blue
SAR	Synthetic Aperture Radar
SOLAS	International Convention for the Safety of Life at Sea
SWOT	Strengths, Weaknesses, Opportunities, and Threats
UAV	Unmanned Aerial Vehicle
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
USV	Unmanned Surface Vehicle
UV	Unmanned Vehicle
VMS	Vessel Monitoring System

References

1. Seckler, D.W. *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues*; Iwmi: Colombo, Sri Lanka, 1998; Volume 19.
2. Ekins, P.; Gupta, J. Perspective: A healthy planet for healthy people. *Glob. Sustain.* **2019**, *2*, e20. [CrossRef]
3. Chapman, R.L. Algae: The world's most important "plants"—An introduction. *Mitig. Adapt. Strateg. Glob. Chang.* **2013**, *18*, 5–12. [CrossRef]
4. O'Dor, R.; Berghe, E.V. Hidden Beneath the Seas. *World Policy J.* **2012**, *29*, 101–108. [CrossRef]
5. Chisholm, S.W.; Falkowski, P.G.; Cullen, J.J. Dis-Crediting Ocean Fertilization. *Science* **2001**, *294*, 309–310. [CrossRef] [PubMed]
6. Ehrlich, P.R.; Ehrlich, A.H.; Daily, G.C. Food security, population and environment. *Popul. Dev. Rev.* **1993**, *19*, 1–32. [CrossRef]
7. Hollar, S. (Ed.) *Poisoning Planet Earth: Pollution and Other Environmental Hazards*; Britannica Educational Publishing: Chicago, IL, USA, 2011.
8. Das, P.; Horton, R. Pollution, health, and the planet: Time for decisive action. *Lancet* **2018**, *391*, 407–408. [CrossRef]
9. Levent, B.; Öztekin, A.; Şahin, F.; Arici, E.; Özsandikçi, U. An overview of the Black Sea pollution in Turkey. *Mediterr. Fish. Aquac. Res.* **2018**, *1*, 66–86. [CrossRef]
10. Korshenko, A.; Gul, A.G. Pollution of the Caspian Sea. In *The Caspian Sea Environment. The Handbook of Environmental Chemistry*; Springer: Berlin/Heidelberg, Germany, 2005; Volume 5P. [CrossRef]
11. Rheinheimer, G. Pollution in the Baltic sea. *Naturwissenschaften* **1998**, *85*, 318–329. [CrossRef] [PubMed]
12. Coe, J.M.; Rogers, D. *Marine Debris: Sources, Impacts, and Solutions*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012.
13. Rhodes, C.J. Plastic pollution and potential solutions. *Sci. Prog.* **2018**, *101*, 207–260. [CrossRef]

14. Mangan, D.J. Trends in the Transport of Goods by Sea. In *Future of the Sea: Trends in the Transport of Goods by Sea*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 1–23.
15. Santos, C.F.; Teixeira, Z.G.; Janeiro, J.; Gonçalves, R.S.; Bjorkl, R.; Orbach, M. The European Marine Strategy: Contribution and challenges from a Portuguese perspective. *Mar. Policy* **2012**, *36*, 963–968. [CrossRef]
16. Carpenter, A. European maritime safety agency CleanSeaNet activities in the North Sea. In *Oil Pollution in the North Sea. The Handbook of Environmental Chemistry*; Springer: Cham, Germany, 2016; Volume 41. [CrossRef]
17. Riera, J.A.; Morales-Nin, B.; Vilas, F. The Prestige oil spill: A scientific response. *Mar. Pollut. Bull.* **2006**, *53*, 205–207. [CrossRef]
18. McNutt, M.K.; Camilli, R.; Crone, T.J.; Guthrie, G.D.; Hsieh, P.A.; Ryerson, T.B.; Savas, O.; Shaffer, F. Review of flow rate estimates of the Deepwater Horizon oil spill. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 20260–20267. [CrossRef] [PubMed]
19. Bayirhan, İ.; Gazioğlu, C. Use of Unmanned Aerial Vehicles (UAV) and Marine Environment Simulator in Oil Pollution Investigations. *Balt. J. Mod. Comput.* **2020**, *8*, 327–336. [CrossRef]
20. Jiao, Z.; Jia, G.; Cai, Y. A new approach to oil spill detection that combines deep learning with unmanned aerial vehicles. *Comput. Ind. Eng.* **2019**, *135*, 1300–1311. [CrossRef]
21. Al Maawali, W.; Al Naabi, A.; Al Yaruubi, M.; Saleem, A.; Al Maashri, A. Design and implementation of an unmanned surface vehicle for oil spill handling. In Proceedings of the 2019 1st International Conference on Unmanned Vehicle Systems-Oman (UVS), Muscat, Oman, 5–7 February 2019; IEEE: Piscatway, NJ, USA, 2019; pp. 1–6. [CrossRef]
22. Antunes, T.L.; Pessanha Santos, N.; Moura, R.P.; Lobo, V. Sea Pollution: Analysis and Monitoring using Unmanned Vehicles. In Proceedings of the 2023 IEEE Underwater Technology (UT), Tokyo, Japan, 6–9 March 2023; IEEE: Piscatway, NJ, USA, 2023; pp. 1–8. [CrossRef]
23. Pessanha Santos, N.; Moura, R.; Santos da Silva, C.; Lamas, L.; Lobo, V.; de Castro Neto, M. Long-term in situ Eulerian Sea surface temperature records along the Portuguese Coast. *Data Brief* **2024**, *54*, 110287. [CrossRef]
24. Castanedo, F. A Review of Data Fusion Techniques. *Sci. World J.* **2013**, *2013*, 704504. [CrossRef]
25. Sarsby, A. *SWOT Analysis—A Guide to SWOT for Business Studies Students*; Leadership Library: Suffolk, UK, 2016.
26. Benzaghta, M.A.; Elwalda, A.; Mousa, M.M.; Erkan, I.; Rahman, M. SWOT analysis applications: An integrative literature review. *J. Glob. Bus. Insights* **2021**, *6*, 55–73. [CrossRef]
27. Leigh, D. SWOT Analysis. In *Handbook of Improving Performance in the Workplace: Volumes 1–3*; Pfeiffer: San Francisco, CA, USA, 2009.
28. Helms, M.M.; Nixon, J. Exploring SWOT analysis—Where are we now? A review of academic research from the last decade. *J. Strategy Manag.* **2010**, *3*, 215–251. [CrossRef]
29. United Nations. United Nations Convention on the Law of the Sea. 1982. Available online: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf (accessed on 20 September 2024)
30. Agardy, T. *Ocean Zoning: Making Marine Management More Effective*; Earthscan from Routledge: New York, NY, USA, 2010.
31. Doney, S.C.; Fabry, V.J.; Feely, R.A.; Kleypas, J.A. Ocean acidification: The other CO_2 problem. *Annu. Rev. Mar. Sci.* **2009**, *1*, 169–192. [CrossRef]
32. Fleming, L.; Broad, K.; Clement, A.; Dewailly, E.; Elmir, S.; Knap, A.; Pomponi, S.; Smith, S.; Gabriele, H.S.; Walsh, P. Oceans and human health: Emerging public health risks in the marine environment. *Mar. Pollut. Bull.* **2006**, *53*, 545–560. [CrossRef]
33. Landrigan, P.J.; Stegeman, J.J.; Fleming, L.E.; Allemand, D.; Anderson, D.M.; Backer, L.C.; Brucker-Davis, F.; Chevalier, N.; Corra, L.; Czerucka, D.; et al. Human health and ocean pollution. *Ann. Glob. Health* **2020**, *86*, 151. [CrossRef] [PubMed]
34. Chaudhry, F.N.; Malik, M. Factors affecting water pollution: A review. *J. Ecosyst. Ecography* **2017**, *7*, 225–231. [CrossRef]
35. Julian, M. MARPOL 73/78: The International Convention for the Prevention of Pollution from Ships. *Marit. Stud.* **2000**, *2000*, 16–23. [CrossRef]
36. Joseph, A.; Dalaklis, D. The international convention for the safety of life at sea: Highlighting interrelations of measures towards effective risk mitigation. *J. Int. Marit. Saf. Environ. Aff. Shipp.* **2021**, *5*, 1–11. [CrossRef]
37. Czybulka, D. The Convention on the Protection of the Marine Environment of the North-East Atlantic. In *Managing Risks to Biodiversity and the Environment on the High Sea, Including Tools Such as Marine Protected Areas-Scientific Requirements and Legal Aspects*; Bundesamt für Naturschutz (BfN): Bonn, Germany, 1994; Volume 175.
38. Simcock, A. Ospar Convention On The Protection Of The Marine Environment Of The North-East Atlantic. In *Ensuring Compliance with Multilateral Environmental Agreements*; Brill Nijhoff: Leiden, The Netherlands, 2006; pp. 97–114. [CrossRef]
39. ÇİÇEK, K. International Convention on Oil Pollution Preparedness, Response and Co-Operation (Oprc) 1990 and Its Applications Related with Oil Spill In Turkey. *Oil Spill along Turk. Straits* **2018**, *1972*, 381.
40. Christodoulou, A.; Echebarria Fernández, J. Maritime Governance and International Maritime Organization Instruments Focused on Sustainability in the Light of United Nations' Sustainable Development Goals. In *Sustainability in the Maritime Domain: Towards Ocean Governance and Beyond*; Carpenter, A., Johansson, T.M., Skinner, J.A., Eds.; Springer International Publishing: Cham, Switzerland, 2021; pp. 415–461. [CrossRef]
41. Jørgensen, K.L. Moving the dial through collaboration—The Global Response Network. *Int. Oil Spill Conf. Proc.* **2021**, *2021*, 682648. [CrossRef]
42. Limb, R.; Nicoll, A. Sharing Good Practice Throughout the Responder Community: Ten Years of the Global Response Network. *Int. Oil Spill Conf. Proc.* **2017**, *2017*, 1109–1127. [CrossRef]

43. Resolução Conselho Ministros n.º 25/1993. Diário da República, Série I-B de 1993-04-15. 1993. Available online: https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/25-1993-690248 (accessed on 20 September 2024)
44. Poluição - Relato de Episódio de Poluição no Mar. Circular N.º 107/2005-P. 2005. Available online: https://www.amn.pt/dcpm/documents/circular (accessed on 20 September 2024)
45. Uddin, S.; Fowler, S.W.; Saeed, T.; Jupp, B.; Faizuddin, M. Petroleum hydrocarbon pollution in sediments from the Gulf and Omani waters: Status and review. *Mar. Pollut. Bull.* **2021**, *173*, 112913. [CrossRef]
46. Harayama, S.; Kishira, H.; Kasai, Y.; Shutsubo, K. Petroleum biodegradation in marine environments. *J. Mol. Microbiol. Biotechnol.* **1999**, *1*, 63–70. Available online: http://europepmc.org/abstract/MED/10941786 (accessed on 20 September 2024)
47. Rodrigue, J.P. *The Geography of Transport Systems*; Routledge: London, UK, 2020. [CrossRef]
48. Ng, A.K.; Song, S. The environmental impacts of pollutants generated by routine shipping operations on ports. *Ocean. Coast. Manag.* **2010**, *53*, 301–311. [CrossRef]
49. Tsimplis, M. Marine pollution from shipping activities. In *Maritime Law*; Informa Law from Routledge: London, UK, 2020; pp. 403–464.
50. Wang, Z.; Hollebone, B.; Fingas, M.; Fieldhouse, B.; Sigouin, L.; Landriault, M.; Smith, P.; Noonan, J.; Thouin, G.; Weaver, J.W. Characteristics of spilled oils, fuels, and petroleum products: 1. Composition and properties of selected oils. *United States Environ. Prot. Agency* **2003**, 280.
51. Fingas, M. *Handbook of Oil Spill Science and Technology*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
52. Lee, R.F.; Anderson, J.W. Significance of cytochrome P450 system responses and levels of bile fluorescent aromatic compounds in marine wildlife following oil spills. *Mar. Pollut. Bull.* **2005**, *50*, 705–723. [CrossRef] [PubMed]
53. Krahn, M.M.; Ylitalo, G.M.; Buzitis, J.; Chan, S.L.; Varanasi, U.; Wade, T.L.; Jackson, T.J.; Brooks, J.M.; Wolfe, D.A.; Manen, C.A. Comparison of high-performance liquid chromatography/fluorescence screening and gas chromatography/mass spectrometry analysis for aromatic compounds in sediments sampled after the Exxon Valdez oil spill. *Environ. Sci. Technol.* **1993**, *27*, 699–708. [CrossRef]
54. Wang, Z.; Fingas, M.; Page, D.S. Oil spill identification. *J. Chromatogr. A* **1999**, *843*, 369–411. [CrossRef]
55. Gros, J.; Nabi, D.; Wurz, B.; Wick, L.Y.; Brussaard, C.P.; Huisman, J.; van der Meer, J.R.; Reddy, C.M.; Arey, J.S. First day of an oil spill on the open sea: Early mass transfers of hydrocarbons to air and water. *Environ. Sci. Technol.* **2014**, *48*, 9400–9411. [CrossRef]
56. Kennicutt II, M.C.; Sweet, S.T. Hydrocarbon contamination on the Antarctic Peninsula: III. The Bahia Paraiso—Two years after the spill. *Mar. Pollut. Bull.* **1992**, *25*, 303–306. [CrossRef]
57. Krestenitis, M.; Orfanidis, G.; Ioannidis, K.; Avgerinakis, K.; Vrochidis, S.; Kompatsiaris, I. Oil spill identification from satellite images using deep neural networks. *Remote Sens.* **2019**, *11*, 1762. [CrossRef]
58. Tysiac, P.; Strelets, T.; Tuszyńska, W. The application of satellite image analysis in oil spill detection. *Appl. Sci.* **2022**, *12*, 4016. [CrossRef]
59. Svejkovsky, J.; Hess, M.; Muskat, J.; Nedwed, T.J.; McCall, J.; Garcia, O. Characterization of surface oil thickness distribution patterns observed during the Deepwater Horizon (MC-252) oil spill with aerial and satellite remote sensing. *Mar. Pollut. Bull.* **2016**, *110*, 162–176. [CrossRef]
60. Sun, S.; Hu, C. The challenges of interpreting oil–water spatial and spectral contrasts for the estimation of oil thickness: Examples from satellite and airborne measurements of the deepwater horizon oil spill. *IEEE Trans. Geosci. Remote Sens.* **2018**, *57*, 2643–2658. [CrossRef]
61. Jha, M.N.; Levy, J.; Gao, Y. Advances in Remote Sensing for Oil Spill Disaster Management: State-of-the-Art Sensors Technology for Oil Spill Surveillance. *Sensors* **2008**, *8*, 236–255. [CrossRef] [PubMed]
62. Fingas, M.; Brown, C. Review of oil spill remote sensing. *Mar. Pollut. Bull.* **2014**, *83*, 9–23. [CrossRef]
63. Al-Ruzouq, R.; Gibril, M.B.A.; Shanableh, A.; Kais, A.; Hamed, O.; Al-Mansoori, S.; Khalil, M.A. Sensors, Features, and Machine Learning for Oil Spill Detection and Monitoring: A Review. *Remote Sens.* **2020**, *12*, 3338. [CrossRef]
64. Seydi, S.T.; Hasanlou, M.; Amani, M.; Huang, W. Oil Spill Detection Based on Multiscale Multidimensional Residual CNN for Optical Remote Sensing Imagery. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2021**, *14*, 10941–10952. [CrossRef]
65. Baek, W.K.; Jung, H.S. Performance Comparison of Oil Spill and Ship Classification from X-Band Dual- and Single-Polarized SAR Image Using Support Vector Machine, Random Forest, and Deep Neural Network. *Remote Sens.* **2021**, *13*, 3203. [CrossRef]
66. Trieschmann, O.; Bal, L.; Chintoan-Uta, M.; Djavidnia, S.; Hayes, A.M.; Journel, M.; Lourenco-Bento, P.; Pelizzari, S.; Price, M.; del Rio Vera, J. Identification of Oil Spills by Satellite. In *Proceedings of the ESA Living Planet Symposium*; Lacoste-Francis, H., Ed.; European Space Agency Special Publication: Paris, France, 2010; Volume 686, p. 257. Available online: https://www.academia.edu/download/47322772/Living_Planet_TrieschmannEtAl_final.pdf (accessed on 20 September 2024)
67. Topouzelis, K.; Singha, S. Oil spill detection: Past and future trends. In Proceedings of the ESA Living Planet Symposium. European Space Agency (Special Publication), Paris, France, 9–13 May 2016; Volume 1, pp. 387–402.
68. Moura, R.; Pessanha Santos, N.; Vala, A.; Mendes, L.; Simões, P.; de Castro Neto, M.; Lobo, V. Fisheries Inspection in Portuguese Waters from 2015 to 2023. *Sci. Data* **2024**, *11*, 362. [CrossRef] [PubMed]
69. Djavidnia, S.; Del Rio Vera, J. European maritime safety agency cleanseanet activities in the baltic sea. *Oil Pollut. Balt. Sea* **2012**, 41–51. [CrossRef]

70. Ferraro, G.; Trieschmann, O.; Perkovic, M.; Tarchi, D. Confidence levels in the detection of oil spills from satellite imagery: From research to the operational use. In Proceedings of the SAR Image Analysis, Modeling, and Techniques XII, Edinburgh, UK, 26–27 September 2012; SPIE: Bellingham, WA, USA, 2012; Volume 8536, pp. 84–94. [CrossRef]
71. Alexandrov, C.; Kolev, N.; Sivkov, Y.; Hristov, A.; Tsvetkov, M. Oil spills detection on sea surface by using Sentinel–1 SAR images. In Proceedings of the 2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA), Bourgas, Bulgaria, 3–6 June 2020; IEEE: Piscatway, NJ, USA, 2020; pp. 1–4. [CrossRef]
72. Hajduch, G. VIGISAT ground receiving station and EMSA CleanSeaNet services. *Remote Detect. Marit. Pollut. Chem. Spill Stud.* **2021**, 77–86. [CrossRef]
73. Helmke, P.; Baschek, B.; Hunsänger, T.; Kranz, S. Influence of satellite alerts on the efficiency of aircraft monitoring of maritime oil pollution in German waters. In Proceedings of the Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2014, Amsterdam, The Netherlands, 24–25 September 2014; SPIE: Bellingham, WA, USA, 2014; Volume 9240, pp. 63–72. [CrossRef]
74. Csernatoni, R. Constructing the EU's high-tech borders: FRONTEX and dual-use drones for border management. *Eur. Secur.* **2018**, *27*, 175–200. [CrossRef]
75. Pessanha Santos, N.; Lobo, V.; Bernardino, A. Fixed-Wing Unmanned Aerial Vehicle 3D-Model-Based Tracking for Autonomous Landing. *Drones* **2023**, *7*, 243. [CrossRef]
76. Pessanha Santos, N.; Lobo, V.; Bernardino, A. Unscented particle filters with refinement steps for uav pose tracking. *J. Intell. Robot. Syst.* **2021**, *102*, 52. [CrossRef]
77. Pessanha Santos, N.; Lobo, V.; Bernardino, A. Directional statistics for 3D model-based UAV tracking. *IEEE Access* **2020**, *8*, 33884–33897. [CrossRef]
78. Pessanha Santos, N. Fixed-Wing UAV Pose Estimation Using a Self-Organizing Map and Deep Learning. *Robotics* **2024**, *13*, 114. [CrossRef]
79. Lu, Y.; Xue, Z.; Xia, G.S.; Zhang, L. A survey on vision-based UAV navigation. *Geo-Spat. Inf. Sci.* **2018**, *21*, 21–32. [CrossRef]
80. Pessanha Santos, N.; Lobo, V.; Bernardino, A. Autoland project: Fixed-wing UAV landing on a fast patrol boat using computer vision. In Proceedings of the OCEANS 2019 MTS/IEEE SEATTLE, Seattle, WA, USA, 27–31 October 2019; IEEE: Piscatway, NJ, USA, 2019; pp. 1–5. [CrossRef]
81. Morais, F.; Ramalho, T.; Sinogas, P.; Marques, M.M.; Pessanha Santos, N.; Lobo, V. Trajectory and guidance mode for autonomously landing an UAV on a naval platform using a vision approach. In Proceedings of the OCEANS 2015, Genova, Italy, 18–21 May 2015; pp. 1–7. [CrossRef]
82. Rangel, R.K.; Kienitz, K.H.; Brandao, M.P. Development of a complete UAV system using COTS equipment. In Proceedings of the 2009 IEEE Aerospace conference, Big Sky, MT, USA, 7–14 March 2009; IEEE: Piscatway, NJ, USA, 2009; pp. 1–11. [CrossRef]
83. Bernard, É.; Friedt, J.M.; Tolle, F.; Marlin, C.; Griselin, M. Using a small COTS UAV to quantify moraine dynamics induced by climate shift in Arctic environments. *Int. J. Remote Sens.* **2017**, *38*, 2480–2494. [CrossRef]
84. Bogue, R. Beyond imaging: Drones for physical applications. *Ind. Robot. Int. J. Robot. Res. Appl.* **2023**, *50*, 557–561. [CrossRef]
85. Tekever. AR5–TEKEVER. 2023. Available online: https://www.tekever.com/models/ar5/ (accessed on 20 September 2024)
86. Bauk, S. Performances of Some Autonomous Assets in Maritime Missions. *Transnav Int. J. Mar. Navig. Saf. Sea Transp.* **2020**, *14*, 875–881. [CrossRef]
87. Bauk, S.; Kapidani, N.; Sousa, L.; Lukšić, Ž.; Spuža, A. Advantages and disadvantages of some unmanned aerial vehicles deployed in maritime surveillance. In *Maritime Transport VIII: Proceedings of the 8th International Conference on Maritime Transport: Technology, Innovation and Research: Maritime Transport'20*; Universitat Politècnica de Catalunya, Departament de Ciència i Enginyeria Nàutiques: Barcelona, Spain, 2020; Volume 102, p. 91. Available online: http://hdl.handle.net/2117/329709 (accessed on 20 September 2024).
88. Heo, J.; Kim, J.; Kwon, Y. Analysis of design directions for unmanned surface vehicles (USVs). *J. Comput. Commun.* **2017**, *5*, 92. [CrossRef]
89. Bella, S.; Belalem, G.; Belbachir, A.; Benfriha, H. HMDCS-UV: A concept study of Hybrid Monitoring, Detection and Cleaning System for Unmanned Vehicles. *J. Intell. Robot. Syst.* **2021**, *102*, 44. [CrossRef]
90. Weitz, R. Strategic Maritime Chokepoints: Perspectives from the Global Shipping and Port Sectors. In *Eurasia's Maritime Rise and Global Security*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 17–29. [CrossRef]
91. Hai-Ying Zhang, Q.J.; Fan, Y. What drives the formation of global oil trade patterns? *Energy Econ.* **2015**, *49*, 639–648. [CrossRef]
92. Gullo, B.S. Illegal discharge of oil on the high seas: The US coast Guard's ongoing battle against vessel polluters and a new approach toward establishing environmental compliance. *Mil. L. Rev.* **2011**, *209*, 122.
93. Kirby, M.F.; Law, R.J. Accidental spills at sea–Risk, impact, mitigation and the need for co-ordinated post-incident monitoring. *Mar. Pollut. Bull.* **2010**, *60*, 797–803. [CrossRef] [PubMed]
94. MarineTraffic. MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic. 2023. Available online: https://www.marinetraffic.com/ (accessed on 20 September 2024)
95. Balkin, R. The International Maritime Organization and Maritime Security. *Tul. Mar. LJ* **2006**, *30*, 1.
96. Campuzano, F.; Juliano, M.; Fernandes, R.; Pinto, L.; Neves, R. Downscalling from the deep ocean to the estuarine intertidal areas: An operacional framework for the portuguese exclusive economic zone. In Proceedings of the 6th SCACR–International Short Course/Conference on Applied Coastal Research, Aachen, Germany, 4–7 June 2013; pp. 1–9.

97. Spaulding, M.L. State of the art review and future directions in oil spill modeling. *Mar. Pollut. Bull.* **2017**, *115*, 7–19. [CrossRef] [PubMed]
98. Yang, Z.; Chen, Z.; Lee, K. Development and testing of a 2D offshore oil spill modeling tool (OSMT) supported by an effective calibration method. *Res. Sq.* **2022**, *188*, 114696. [CrossRef]
99. Leifer, I.; Lehr, W.J.; Simecek-Beatty, D.; Bradley, E.; Clark, R.; Dennison, P.; Hu, Y.; Matheson, S.; Jones, C.E.; Holt, B.; et al. State of the art satellite and airborne marine oil spill remote sensing: Application to the BP Deepwater Horizon oil spill. *Remote Sens. Environ.* **2012**, *124*, 185–209. [CrossRef]
100. Barker, C.H.; Kourafalou, V.H.; Beegle-Krause, C.; Boufadel, M.; Bourassa, M.A.; Buschang, S.G.; Androulidakis, Y.; Chassignet, E.P.; Dagestad, K.F.; Danmeier, D.G.; et al. Progress in Operational Modeling in Support of Oil Spill Response. *J. Mar. Sci. Eng.* **2020**, *8*, 668. [CrossRef]
101. Sebastiao, P.; Soares, C.G. Modeling the fate of oil spills at sea. *Spill Sci. Technol. Bull.* **1995**, *2*, 121–131. [CrossRef]
102. Andrade, C.; Robertson, M.H. Turismo de Cruzeiros: Perspectivas para a Macaronesia. *Rev. Tur. Desenvolv.* **2010**, *2*, 485–498.
103. Olson, E.M.; Slater, S.F.; Hult, G.T.M. The importance of structure and process to strategy implementation. *Bus. Horizons* **2005**, *48*, 47–54. [CrossRef]
104. Okumus, F. Towards a strategy implementation framework. *Int. J. Contemp. Hosp. Manag.* **2001**, *13*, 327–338. [CrossRef]
105. Norton, D.P. The balanced scorecard. *Wiley Encycl. Manag.* **2015**, *3*, 1253–1269.
106. Neely, A. *Business Performance Measurement: Theory and Practice*; Cambridge University Press: Cambridge, UK, 2002.
107. Panagiotou, G. Bringing SWOT into focus. *Bus. Strategy Rev.* **2003**, *14*, 8–10. [CrossRef]
108. Pessanha Santos, N. Hydrogen in the Portuguese Navy: A case study. *Int. J. Hydrogen Energy* **2022**, *47*, 28684–28698. [CrossRef]
109. Augier, M.; Teece, D.J. SWOT Analysis. In *The Palgrave Encyclopedia of Strategic Management*; Palgrave Macmillan: London, UK, 2018. [CrossRef]
110. Weihrich, H. The TOWS matrix—A tool for situational analysis. *Long Range Plan.* **1982**, *15*, 54–66. [CrossRef]
111. Mintzberg, H.; Ahlstrand, B.; Lampel, J.B. *Strategy Safari: A Guided Tour through the Wilds of Strategic Management*; Simon & Schuster Inc.: New York, NY, USA, 1998.
112. Dias, F.; Neves, J.; Conceição, V.D.; Lobo, V. Maritime situational awareness, the singular approach of a dual-use navy. *Sci. Bull. Mircea Cel Batran Nav. Acad.* **2018**, *21*, 1–14. [CrossRef]
113. Pärt, S.; Björkqvist, J.V.; Alari, V.; Maljutenko, I.; Uiboupin, R. An ocean–wave–trajectory forecasting system for the eastern Baltic Sea: Validation against drifting buoys and implementation for oil spill modeling. *Mar. Pollut. Bull.* **2023**, *195*, 115497. [CrossRef]
114. Keramea, P.; Kokkos, N.; Zodiatis, G.; Sylaios, G. Modes of Operation and Forcing in Oil Spill Modeling: State-of-Art, Deficiencies and Challenges. *J. Mar. Sci. Eng.* **2023**, *11*, 1165. [CrossRef]
115. Daniel, P.; Josse, P.; Dandin, P.; Gouriou, V.; Marchand, M.; Tiercelin, C. Forecasting the Erika Oil Spills. *Int. Oil Spill Conf. Proc.* **2001**, *2001*, 649–655. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.