Journal of
Marine Science and Engineering

MDPI

Review

Environmental Decision Support Systems for Monitoring Small Scale Oil Spills: Existing Solutions, Best Practices and Current Challenges

Davide Moroni, Gabriele Pieri * and Marco Tampucci

Institute of Information Science and Technologies-National Research Council, Via Moruzzi, 1–56124 Pisa (IT), Italy; Davide.Moroni@isti.cnr.it (D.M.); Marco.Tampucci@isti.cnr.it (M.T.)
* Correspondence: Gabriele.Pieri@isti.cnr.it; Tel.: +39-050-621-3120

Received: 29 October 2018; Accepted: 17 January 2019; Published: 21 January 2019

check for updates

Abstract: In recent years, large oil spills have received widespread media attention, while small and micro oil spills are usually only acknowledged by the authorities and local citizens who are directly or indirectly affected by these pollution events. However, small oil spills represent the vast majority of oil pollution events. In this paper, multiple oil spill typologies are introduced, and existing frameworks and methods used as best practices for facing them are reviewed and discussed. Specific tools based on information and communication technologies are then presented, considering in particular those which can be used as integrated frameworks for the specific challenges of the environmental monitoring of smaller oil spills. Finally, a prototype case study actually designed and implemented for the management of existing monitoring resources is reported. This case study helps improve the discussion over the actual challenges of early detection and support to the responsible parties and stakeholders in charge of intervention and remediation operations.

Keywords: marine information systems; environmental monitoring; proactive systems; decision support systems; signal integration; oil spills

1. Introduction

It is well-known that large spills of oil and related petroleum products in the marine environment can have serious biological and economic impacts. According to [1], the 2010 Deepwater Horizon disaster is still exacting an ongoing and largely unknown toll. Public and media scrutiny is usually intense after a spill, demanding that the location and extent of the oil spill be properly identified and quantified. Remote sensing is playing an increasingly important role in oil spill response efforts [2]. Through the use of modern remote sensing instrumentation, oil can be continuously monitored on the open ocean. With knowledge of slick locations and movement, response teams can more effectively plan countermeasures in an effort to curtail the effects of the induced pollution.

Pollution sources in the sea are disparate in size, origin, and nature of the pollutants, and are not limited to major accidents. It is possible to distinguish several classes of pollution sources and to evaluate the impact of each class. Particular classes are: (i) pollution sources caused by oil exploration and production; (ii) pollution sources caused through transporting oil by sea; (iii) natural oil pollution sources; (iv) pollution sources generated by general maritime traffic and shipping operations; and (v) pollution sources caused by coastal activities. While events deriving from (i) and (ii) might produce accidents of great impact to coastal populations, they are relatively rare compared to pollution events, due to the general shipping traffic and coastal activities.

Although operational discharges may be considered small when compared to spills caused by shipping accidents, they tend to be repetitive and even chronic, being concentrated in ports and along shipping routes. Therefore, these spills will have an impact on local marine habitats, including physical disturbances, toxic inputs to sensitive species, and organic sediments enrichment [3]. Ships of all kinds discharge oily residues into the sea during routine operations. Further, ships periodically clean their ballast and bilge water tanks, comprising a considerable source of pollution. It has been estimated that most oil spills are the result of daily operations, most often occurring in oil or port terminals [4]. Indeed, the International Tanker Owners Pollution Federation Limited (ITOPF) reports that small and medium-sized spills account for 95% of the total number of all the incidents recorded [5]. Furthermore, the impact of coastal activities as a source of oil spills does not yet seem to be too well-understood [6–8].

Operational oil spills pose a serious threat to the environment, especially because attention and mitigation measures tend to be focused on large accidental spills. Most of the existing frameworks based on remote sensing and systems for environmental decision support are mainly focused on large catastrophic events, while small-scale oil spills have received somewhat less attention. For instance, the European Maritime Safety Agency (EMSA) provides the CleanSeaNet service [9], covering all European sea areas, which are analyzed in order to detect and track possible oil spills on the sea surface. Besides operational services, the interest of the research community is witnessed by the numerous projects and prototypical systems for marine pollution monitoring [10,11]. Recent works include cloud-based solutions [12], in which a cloud-based image processing the facility for oil spill detection is integrated with a web-based geographical information system, and the framework is introduced in [13] in which a high-resolution hydrodynamic model is used for accurately forecasting oil spill evolution and weathering.

Addressing small and micro oil spills exhibits some challenging differences with respect to large ones. For example, they are on a small spatial scale, and most of them are difficult to detect solely on the basis of remote sensing. For instance, aerial surveys of the North Sea have shown that between 500 and 1200 oil spills have been observed each year, with 73–88% of oil spills having a volume less than 1 cubic meter [14], which make them difficult to be accurately detected and analyzed by satellite-borne sensors alone.

One possible approach to the problem of small-scale oil pollution monitoring is to fuse satellite images with other data sources. For instance, integrating data collected in situ by a suitable network of sensors may improve the pervasiveness of monitoring in a marine area of particular environmental value, while simultaneously helping to resolve ambiguities and filtering false positives deriving from the analysis of data coming from a specific and single modality, i.e., the use of data acquired and processed from only one source. Multisource, i.e., more sensors that can be from different devices that can offer the same typology of data (e.g., SAR with different resolutions or from different satellites), and multimodal, i.e., with reference to the physical features recorded by devices using different typologies for acquisition (e.g., buoys, in situ, airborne, AIS, satellite, SAR/optical), surveillance of the sea thus has good capabilities in addressing small-scale oil spills, but it demands for additional problems to be solved. Collection, cross-correlation, and comparison of multiple data sources cannot be routinely performed manually by authorities and stakeholders in charge of the intervention and remediation operations. For instance, it is difficult to establish possible correspondences between vessels and oil slick positions sampled at different times by: (a) satellite-borne sensors, (b) Automatic Identification System (AIS), and (c) in situ devices, without including and integrating the data into a single information system endowed with models where all encompassing forecasting and retrodiction of slick and ship positions are available. Furthermore, while major pollution events are managed by special contractors for carrying out intervention and remedy actions, small ones are addressed—at least in the first stages—primarily through the use of local monitoring and remedy resources. The orchestration and optimization in the use of such resources also poses some problems in the routine management of small pollution events.

From the above considerations, it may be evinced that while multimodal data integration has strong potential in dealing with small and micro oil spills, suitable algorithms and models are needed to properly exploit such data and optimize the use of both a monitoring network and a local intervention chain.

The main contribution of this paper is to review the relevant literature concerning decision support in environmental monitoring, especially for the marine and maritime domain, and then to establish a rationale for the design and integration of an Environmental Decision Support System (EDSS) devoted to oil spill management. Advanced data gathering functionalities and coordinated management of available models emerge as key components for the design of a successful and useful Information and Communication Technologies (ICT) system. On the basis of the proposed analysis, guidelines are suggested for steering the design of an EDSS, as well as for defining its functional requirements. Such guidelines are then put into practice and properly demonstrated in a case study. EDSS is designed and integrated into the Marine Information System (MIS) presented in [15]. Such integration shows the advantages of decision support services for more efficient management of small and micro oil spills.

2. Related Works

An environmental system is complex, dynamic, spatially distributed, and highly non-linear. Its processes operate on a multitude of interdependent scales in time and space [16,17]. In addition, many of the governing processes are not directly observable, and therefore are not easily understood. Along with such inherent difficulties, every decision related to environmental planning and management is characterized by multiple and usually conflicting objectives, as well as multiple criteria; thus, it is important to be aware of the problem of uncertainty and also of issues arising as a consequence of the increasingly wide public participation in decision-making processes. In this framework, EDSSs are emerging as fundamental tools to aid analysis and planning of all the decisional processes that are pertinent to environmental management. The advantage of using EDSS, in particular for small-scale oil spill, is at least twofold: it aids decision-makers in their activity by facilitating the use of data, models, and structures; and it favors reproducibility and transparency of decision-making. In the following, a general treatment of EDSS is provided, while simultaneously focusing on the requirements and functionalities needed to properly address small-scale events, to which the rest of the present work is devoted.

The three primary axes of intervention of EDSS might be identified as (see also [18]): (i) integrating information into a coherent framework for analysis and decision-making, discerning key information that impacts decision-making from more basic information; (ii) identifying realistic management choices; and (iii) providing a framework for transparency (i.e., all parameters, assumptions, and data used to reach the decision should be clearly documented) and ensuring that the decision-making process itself is documented.

In most applied contexts, environmental monitoring processes imply a continuous intelligent monitoring system, an increasing volume of data, and, in many instances, decreasing time for making decisions. This is particularly true in the case of marine and maritime monitoring for taking care of pollution events, where the so-called *near-real-time* is the amount of time between the occurrence of the event and its notification to the appointed authorities, who take charge of the notification and start possible remediation operations. This time span represents the interval that can be used by automated tools to perform more or less autonomous tasks which lead to a better and more precise description of the polluting event, or to disregard the event if it is a false alarm.

The provision of support services is generally based on Artificial Intelligence (AI) paradigms. In [19], an overview of the impact of AI techniques on the definition and development of the first EDSS during the last fifteen years is reported. Cortés et al. highlights the desirable features that an EDSS must show, and their paper concludes with a selection of successful applications to a wide range of environmental problems. By contrast, in [20], the authors understand that these tools often fail to be truly adopted by the intended end-users, and try to identify and assess key challenges in EDSS development and offer recommendations to resolve them. In particular, to tackle the described challenges, the authors provide a set of best-practice recommendations to improve ease of use, establish trust and credibility, and promote EDSS acceptance.

More general integrated environmental modeling, which fairly comprises Environmental Information Systems (ENVISs), is presented in [21] where the problem is faced from a socio-economic environmental point of view and the decision-making approach follows an integration of resources and analyses to address the problems as they occur in the real-world, including input from appropriate stakeholders [22]. In [23], the authors perform a review of five common modeling approaches for an integrated environmental assessment and management. Integration is defined by the purpose the specific model wants to achieve, from prediction to decision-making, in the context of different environmental assessments. In particular, regarding the approach to modeling complex situations, knowledge-based models offer advice to the users, based both on their own knowledge and on the user's response to a number of *if–then* questions [24]. In parallel, [25] introduced another probabilistic approach producing a framework and claiming to have a holistic view of the global risk assessment. In particular, they operate for what concerns the risk factors on a single species endangered by a polluting event, and providing a model for a quantitative risk estimate. Mokhtari et al. [26] developed a spatial predictive model for estimating the probability of oil spills' occurrence. Their model estimates the probability of oil spills at a pixel level as a function of four specific variables: ship routes, coastlines, oil facilities, and oil wells. It uses a Generalized Linear Model (GLM) with a polynomial function. The number of variables taken into account is very limited, but the spatial mapping approach produces informative raster maps for aggregating and presenting risk estimation, similar to the dynamic risk maps presented by us in [15]. Finally, [27] developed another system for the evaluation of spatially distributed ecological risk related to oil spills. Their system features a tanker accident model based on Bayesian networks which has been placed upstream to an existing oil spill simulation model for evaluating the impact on a set of threatened species.

Oil spill prediction services have also been proposed in the literature and tested in conjunction with operational oil spill detection and monitoring frameworks. In the Mediterranean sea, an oil spill prediction service has been set up, known as Mediterranean Decision Support System for Marine Safety (MEDESS-4MS), whose underlying concept is the integration of existing regional models and national ocean forecasting systems with the Copernicus Marine Environmental Monitoring Service (CMEMS) and their interconnection, through a dedicated network data repository, facilitating access to all these data and to the data from the oil spill monitoring platforms, including satellite data [28]. MEDESS-4MS offers a range of service scenarios, access to multiple models tuned for specific Mediterranean areas, and interactive capabilities to suit the needs of Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) and EMSA. Such variegated prediction services are based on the comparison of oil spill simulation exercises carried out during EU projects, such as ECOOP [29], MERSEA-IP [30], MyOcean [31], and NEREIDs [8,32], which include well-established oil spill models of the Mediterranean region, as well as new oil plume models to simulate the oil from spills located at any given depth below the sea surface [33]. Although the approach of MEDESS-4MS is comprehensive, it is focused on prediction services and, thus, its direct impact on the routine workflow of regional stakeholders is limited.

A particular mention is for the NEREIDs project ended in 2014 [34]. Its goal has been to foster effective cross-border co-operation, while setting best practices for other members of the European Civil Protection Mechanism in order to use innovative ideas and tools as a base to build on training, preparedness, and research.

Again in the Mediterranean, but more specifically in the East, other exercises were conducted and precise models were derived based on novel and high-resolution bathymetric, meteorological, oceanographic, and geomorphological data. Seabed morphology has been correlated to the direction of the oil slick expansion, since it is able to alter the movement of sea currents [35]. The work derived precise a priori information for the management of oil spills, and while it provided aid for civil protection authorities and mitigation teams, it is not yet a real-time decision support method. Specifically, the above work suggests that oil spills in the Eastern Mediterranean Sea should be mitigated within a few hours of their onset, and before wind and currents disperse them, thus prompting the need for an EDSS for prompt mitigation actions. Protocols should be prioritized between neighboring countries to mitigate any oil spills. Similarly, the work in [36,37] shows shoreline susceptibility varies significantly depending on differences in morphology, degree of exposure to wave action, as well as the existence of uplifted wave-cut platforms, coastal lagoons, and pools. The added presence of tourists and environmentally sensitive zones suggests that mitigation work should take into account the high shoreline susceptibility of parts of the Eastern Mediterranean Sea. A significant suggestion arising from experiences like the abovementioned projects is to increase the monitoring of oil-spills.

Another example of an integrated monitoring system is presented in a project regarding the Venice Lagoon, named *Atlas of the lagoon* [38], where heterogeneous dynamic data and tools are published and focused on various thematic maps using a large amount and typology of environmental data.

Other examples of susceptibility analysis include small basins and gulfs, such as the Gulf of Finland. In [39], the presented results characterize the role of surface currents in the transport of contaminants located in the uppermost layer in the Gulf of Finland on a time-scale of the first few weeks. Their work contributes to the understanding of the potential use of the dynamics of currents for environmental management of offshore activities. Again in this case, the proposed services may support the stakeholders in designing and optimizing fairway, but no relevant real-time support can be offered in the case of crises.

Finally, another important and current topic regards the raising of environmental consciousness and awareness, and several projects, even some which have already been mentioned in this section include this aspect as its importance is well-recognized, as shown by an Erasmus+ project called Sea4ALL [40], which specifically addresses this problem through school games and an educational portal.

3. Rationale for an EDSS Devoted to Oil Spill Management

In this section, we survey the main decisional points in which an EDSS can be beneficial, highlighting the importance of both data integration and service orchestration, meant as the coordinated deployment and arrangement of multiple services according to a precise logic. Below, details are provided starting from a general oil spill management system, then looking more closely at what EDSS tasks might be, and ending up with specific details about its design and overall operation.

3.1. Main Tasks to Address in Oil Spill Management

The management of problems related to oil spill detection in a certain site includes a number of tasks that can benefit from the intervention of automatic systems and computational models for a more efficient treatment. Among them, it is important to mention:

(i) Collection of information about the site: In order to be as accurate as possible, the number, frequency, and location of the site-specific data to be collected should be decided on;
(ii) Assessment of the risk: Based on the initial site-characterization data, models for interpolation, extrapolation, and prediction should be applied for evaluating the hazard and guiding the decisions on recovery strategies;
(iii) Projections of contamination levels: Decisions should regard which strategy should be followed for an effective recovery and, to this end, whether more data are needed to better define the region that requires recovery, or to improve the remedy selection or remedy design;
(iv) Monitoring and evaluation of the interventions made: Further decisions should be made on what and where to monitor, the duration of monitoring, and, of course, the effective monitoring of the selected areas.

There is a number of basic decisions that should be made before the actual decision process is developed, such as design choices (what to sample, when to sample, what technologies should be used), as well as policies for determining which risk levels might be considered acceptable.

It is unlikely that any single person will have the knowledge to perform every analysis required to support all of the abovementioned decisions. Typically, a team of people with different areas of expertise are involved in interpreting basic information and providing it in a form useful for other people in the decision process chain. EDSS can be employed to offer support to the team as a whole, by providing more thorough monitoring or strengthening the skills and technical expertise of its members using computational models and automatic reasoning methods.

3.2. Main EDSS Points of Intervention and Reasoning Paradigms

On the basis of the tasks identified above in the management of oil spills, an EDSS is useful for addressing different activities [19], also shown in Figure 1:

(i) Hazard identification, by filtering and screening criteria and reasoning about the activity being considered: This phase may be characterized as a continuous monitoring activity of the system looking for possible adverse outcomes, and includes the search for further data to enhance its own performance.

(ii) Risk assessment, by quantitative and qualitative measurements of the hazard: The heterogeneity of data coming from various sources and with many different levels of precision may be faced by using a number of approaches, including model-based, rule-based and case-based reasoning (see, e.g., [41] for a review of such approaches).

(iii) Risk evaluation: Once potential risks have been assessed, it is possible to introduce judgments regarding the degree of concern about a certain hypothesis. This is possible if the system has accumulated experience solving similar situations using, for instance, a case-based reasoning approach or inferential modeling, where previous experience of risk evaluation is used to assist future judgments.

(iv) Intervention decision-making: The system needs appropriate methods for controlling or reducing risks. The system also requires knowledge about the context where the activity takes place and must be able to interpret its results and knowledge about the risk/benefit balancing methods.

Figure 1. Main and subsequent steps of an EDSS during its activity.

In order to be effective and useful, an EDSS should be able to collect all the relevant data and interpret these data according to prediction models for understanding the situation and assessing the risk. This entails managing the monitoring resources for acquiring more useful data or planning a remedy intervention. Such requirements lead to the definition of a particular design of EDSS, as explained in Section 3.3 below.

3.3. EDSS Design

Design of an EDSS requires an understanding of the environmental problem domain and identifying the experts and authorities to cooperate with. The identification of the problem to be solved by exploiting the EDSS aid has been particularly important, as well as the functionalities by which the system can intervene and improve the current oil spill detection and management procedures. Coherently with the outcome of interviews carried out with experts and authorities, the following three main functionalities have been included: (i) *Data Gathering*, (ii) *Diagnosis and/or Prediction*, and (iii) *Decision Support*.

For (i), the EDSS has to cope with very different types of data, which can be produced and received even in real time from a variety of sensors. Indeed, data can be gathered from various monitoring resources, including Synthetic Aperture Radar (SAR) images, hyperspectral images collected during flight campaigns, data collected by sensorized buoys [42] and Autonomous Underwater Vehicles (AUVs), forecast data obtained by applying simulation models, data about ship traffic through AIS systems, and other miscellaneous reports, possibly including Volunteered Geographical Information (VGI) [43]. Heterogeneity of these data suggests the necessity of distributing interpretation tasks among different subsystems of an EDSS. Identified requirements on data gathering are discussed below.

Resource Management Services (RMSs) should be provided for diagnosis and prediction (ii). In particular, the environmental data acquired by various monitoring resources should be fused by applying simulation and optimization models for site characterization and observation, in order to detect possible marine pollution events.

Finally, for (iii), assistance in decision-making should be supplied by drawing an optimized plan for the exploitation of available monitoring resources and of the modules for data analysis, so as to confirm the detection of an event and raise an alert if required. Suitable presentation and documentation of events are to be supplied, along with feasible suggestions aimed at supporting sustainable event management and recovery interventions.

Once EDSS general requirements have been explained, the EDSS shall have strict interaction with the various components of the information system. Such an interaction will be needed in order to guarantee fulfillment of the following features:

- Ability to acquire, represent and structure the knowledge in the specific domain under investigation;
- Ability to separate data from models, in order to be re-usable;
- Ability to deal with geo-referenced data;
- Ability to provide expert knowledge related to the specific domain;
- Ability to give the end-users (both on the manager/experts side, and the external users) assistance for interfacing with the system and selecting resolution methods.

A prerequisite for such skills is represented by the possibility to transfer data seamlessly among different elements and actors involved in the decision chain (data sources, EDSS modules, and stakeholders), so as to bring different data together easily and in a consistent form, and to facilitate dynamic links between different models and analytical processes. To this end, a network of distributed subjects ensuring integration of every single dataset in the collection, storage, retrieval, and dissemination of environmental information is highly desirable. In brief, an EDSS is required to achieve interoperability at several levels, such as the *measurement and monitoring level*, where the issues principally concern the consistency of observational methods and monitoring network design; the *models and data analysis level* where key issues relate to the consistency and suitability of input data, and to the validity and robustness of the models and algorithms used; the *metadata level*, where agreement needs to be reached on the data attributes described and the form of these descriptions, and the *service level* needed to facilitate data exchange and information retrieval and dissemination.

Despite the recent, great advances in standards and specifications, there is still a real need to test and demonstrate their deployment in large, integrated systems, and to realize the vision of Infrastructure for Spatial Information in the European Community (INSPIRE) [44] for a paneuropean spatial data platform.

4. EDSS Integration into a MIS Platform

In order to have a complete understanding of EDSSs, it is necessary to also briefly review the general platform in which it is integrated and consolidated, i.e., a special kind of ENVIS dedicated to the marine environment, which we will call the Marine Information System (MIS) in the following. It must be kept in mind that all the data, information, and models that are acquired, processed, and applied are all part of the MIS and, to this end, a brief recall of a general MIS architecture and of its main components is provided in this section.

The MIS aims at an effective and feasible detection and management of marine pollution events, by integrating a number of monitoring resources that are exploited to get useful and relevant information about the controlled sites. Each resource collects a specific type of data which are processed by a dedicated module that can be nominally considered a subsystem of the MIS.

The main task of the MIS is, then, to serve as a catalyst for integrating data, information, and knowledge from various sources in the environmental sector by means of adequate ICT tools. The MIS has been conceived as a connected group of subsystems for performing data storage, data mining, and analysis over data warehouses, decision support, as well as a web portal for the access and usage of products and services released to system managers and end-users.

Architecturally, six main units have been identified when designing the MIS—that is, the *Service Unit*, the *Notification Unit*, the *Operational Storage Unit*, the *Graphical User Interface (GUI) Unit*, the *Knowledge Discovery Unit*, and, of course, the *EDSS Unit*, which is the core component surveyed in this paper. A scheme of this composition is shown in Figure 2.

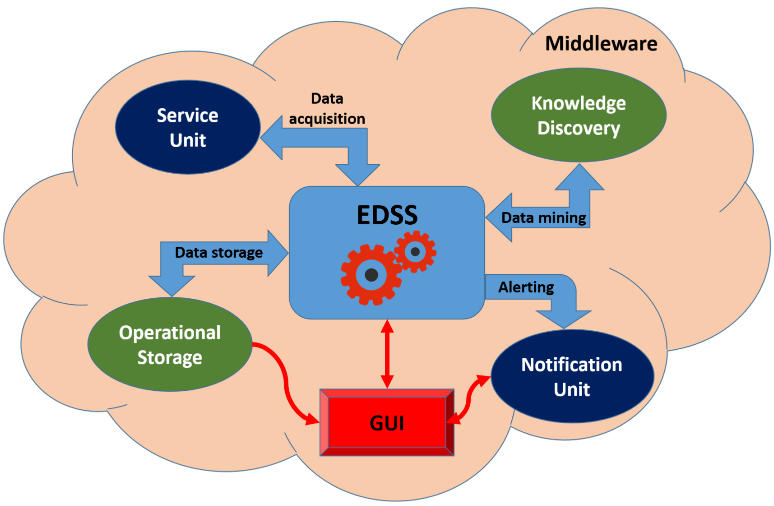

Figure 2. Architecture of a prototypical Marine Information System with its component units.

The Service Unit and the Notification Unit, having a direct interface with the external data sources (i.e., the different technologies and sensors used for data acquisition and processing), provide and allow data access and data exchange from and to the MIS for each external data source. In particular, the Service Unit is in charge of acting as a data manager for integrating information from all available data sources, applications (such as mathematical simulation models and image analysis methods), and repositories (like AIS data). The Notification Unit dispatches messages, such as alerts and suggestions, to personnel enrolled in the system. The Operational Storage Unit constitutes an internal storage unit of the MIS useful for guaranteeing timely access to operational data. In particular, a geo-enabled Data Base (DB) and a multimedia repository constitute the core of this unit. The GUI Unit represents the graphical front-end of the MIS, encompassing the interface for end-users and system manager. The Knowledge Discovery Unit and the EDSS are the most advanced services of the MIS. The first is oriented to off-line trend analysis and to the discovery of hidden patterns in the data in order to learn suitable data models, while the latter aims at providing real-time suggestions to system users, as discussed in detail in Section 5. The management of the data flow and of the main communications among these units is in charge of a central orchestrator, i.e., *Middleware*, detailed in the following Section 4.1.

4.1. The Middleware

The Middleware provides interfaces and methods to allow components to cooperate, and exchange information, products, or results among them in a reliable and efficient way, and with an optimized approach. The middleware allows general access both to the data and software units available in the MIS. From a Service Oriented Architecture (SOA) perspective [45], a middleware layer allows seamless consumption of data into models, making transparent to both users and software agents the transactions with the actual service providers, fully supporting paradigms such as Data-as-a-Service (DaaS) [46] and Software-as-a-Service (SaaS) [47]. Thus, the middleware is not a mere communication bus to transfer data, but consists of an *interface engine* that guarantees the functioning of the entire MIS system. This is the reason why the middleware is actually composed of two modules: the *workflow manager* and the *communication infrastructure*. The former orchestrates business processes in the MIS. An internal business logic engine has to be included for managing complex sequences of process executions and for coping with branching in case of connection failures. The workflow manager has to incorporate a scheduler of the event-driven stream of information/requests. The latter, i.e., the communication infrastructure, covers the connectivity logic part of the MIS and manages message-based communications between the single units and services, routing and transforming the needed data and requests. Communications between MIS units and services is based on generating proper messages (e.g., as XML structured documents or JSON) containing the data to be exchanged. Each unit has to be endowed with a dedicated listener able to retrieve incoming messages, as well as to parse and understand them. The reception of a message will start the process required to manage the contained data. The workflow manager might also be in charge of acting as a logging facility, by keeping track of the platform workflow. When an operation is performed, the relative identifying code is saved into the log, along with the involved units and the operation outcome. In this way, reproducibility, auditing, and transparency of every process, including decision-making, are met.

5. A Prototype Case Study of an EDSS

In MIS architecture, the EDSS Unit has a central role because it is responsible for the combination of all the multi-source data entering the system through the various units introduced in order to detect and monitor oil spills, issue alarms, and support their operational management.

In this section, we discuss how a prototypical case study of an EDSS can be related to other MIS components; then, we detail its functionalities and discuss its main modules.

Whenever the likelihood of a polluting event is determined, either by the risk analysis or reported by the processing results of one of the other MIS subsystems, the EDSS is responsible for developing an optimized exploitation plan of monitoring resources and models, in order to confirm the detection of the event and issue an alarm.

The presentation and documentation of suitable alarms should be provided, together with possible EDSS suggestions aimed at supporting event management and recovery interventions.

5.1. EDSS Main Components and Their Interconnection with the MIS Platform

According to the design of an EDSS introduced in Section 3.3, a prototype EDSS should be logically organized according to a three-level structure that consists in: (i) data-gathering, (ii) analysis and/or prediction, and (iii) decision support. With reference to the MIS platform:

(i) Data need to be gathered through the Service Unit and stored into the Operational Storage Unit. Planning of their collection and retrieval needs to be performed through requests that are orchestrated by the Middleware.
(ii) Analysis and prediction are realized through the risk assessment models within the EDSS that can be applied to the collected data previously retrieved from the Operational Storage Unit through the Middleware.
(iii) Decisions are supported, first of all, by the definition within the EDSS of an optimized exploitation plan of available resources in order to confirm the detection of the event and issue an alarm through the Notification Unit. In addition, suggestions should be provided to support the implementation of event management and recovery interventions.

This logical structure corresponds architecturally to the two main components of the EDSS, namely the Risk Analysis Model (RAM) and the Resource Management Service (RMS). The RAM implements the analysis and prediction function, while the RMS is responsible for organizing the monitoring resources. Their combination results in the decision-support function of the system. In particular, since much of the work of the EDSS regards the planning of various activities, such as the acquisition of monitoring data, its general functioning can be structured according to a workflow model. This approach is also particularly convenient because the entire organization of the MIS operation is organized in a workflow, and therefore, part of the EDSS work can be delegated to the Workflow Manager in the Middleware (see Section 4.1), thus increasing the possibility to control and orchestrate all activities more effectively.

5.2. Functionalities of a Prototypical EDSS

The EDSS Unit consists of a multi-criterion decision support system aimed at helping decision-makers by providing them with criteria for assessing the most suitable way for the prevention, control, and recovery of oil spill pollution events. The system can be defined as the main intelligence of the MIS, and can be imagined as a consultancy and supervision service that implements predictive activities and planning of environmental monitoring. This is achieved by providing the following functional characteristics:

(i) Detection and characterization of possible oil slick events and consequent alerting;
(ii) Organization and management of the different monitoring resources;
(iii) Orchestration and combination of the results of the different data acquisition and processing subsystems;
(iv) Harmonization and issue of alerts;
(v) Suggestions on possible intervention protocols;
(vi) Provision of specific and well-documented alarms to the competent authorities.

In more detail, the system should act according to two different modalities—it could be (a) **reactive**, or (b) **proactive**. In the reactive mode, the EDSS is triggered when new data or new reports coming from the monitoring resources are uploaded into the system and analyzes them in order to detect possible pollution events. In case some anomalies are detected, the system can try to better clarify the situation by collecting all the other related information, such as previous, current, or future data that can be acquired from other monitoring resources. By analyzing all the available monitoring data, the system decides when to issue an alarm or a warning and supply all related information. This could be done automatically, or simply by assisting an operator in the analysis workflow of the different resources. In the case of a proactive mode, the EDSS should apply a dynamic risk analysis derived from a model available for the identification of areas that could be under-monitored, i.e., where there is a high risk of a pollution event, but the resources deployed in situ are not enough to supervise the area. When this happens, the system prioritizes the resources, for example by increasing the rate of data acquisition from a specific device, or by organizing another specific in situ mission in those areas. The analysis of data obtained in this way is then periodically scheduled, and the system could move to the reactive functioning mode.

Once an alarm is issued, the EDSS can provide a protocol that can be followed by the authorities in charge for the intervention activities. This might be selected among a number of possible procedures that are properly represented and stored. Suitable reasoning mechanisms for this selection might be employed, such as simple case-based processing. To supply the above-described functionalities, the EDSS needs to be aware of the monitoring resources available in the whole platform and be able to optimize their employment by suitably handling the different events that can occur. This might be achieved by developing proper optimization and models for risk analysis, and by implicitly encoding the relevant knowledge into orchestration and organization procedures. In particular, as already introduced in the previous chapter, the EDSS Unit comprises:

- a RAM, which concerns the identification of areas with a high risk of oil spills, and needs to be developed following a model-based approach;
- an RMS, which is dedicated to prioritization of resources to detect possible oil spill events, and needs to be developed according to an optimization approach (see e.g., [48]) .

In the following Figure 3, a schematic view is given of the composition of the central Environmental Decision Support System with its described components and the interaction with the rest of the Marine Information System.

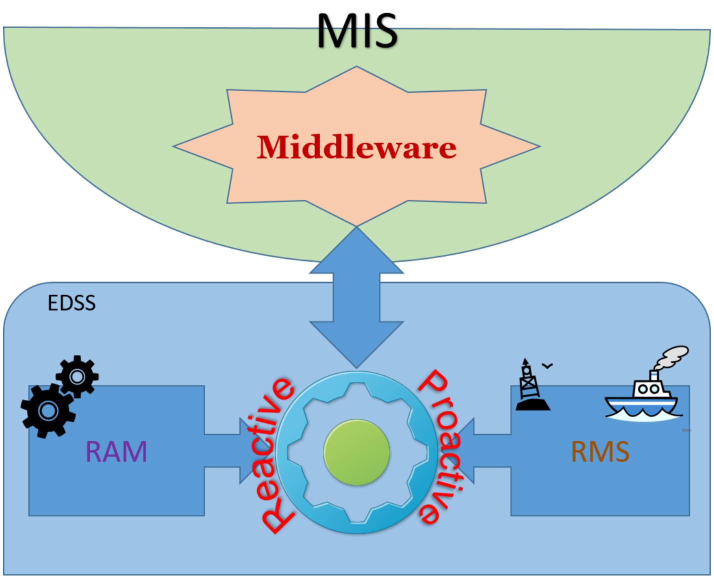

Figure 3. Structure of the Environmental Decision Support System and its components and behavior.

The application of the models, the provision of services, and the integration of the results coming from different resources and subsystems of the MIS might be orchestrated according to a business logics approach based on event handling. This means that the flow of data and actions of the system might be codified according to a workflow-based representation.

5.3. Risk Analysis Model (RAM)

The main task of risk assessment lies in the complex environmental problem of evaluating the likelihood of the occurrence of a hazard balanced with the severity of its consequences [49]. A RAM calculates the probability of spill occurrence, as well as the likely paths or trajectories of spills in relation to the locations of recreational and biological resources which may be vulnerable. The analytical methodology can easily incorporate estimates of weathering rates, slick dispersion, and possible mitigating effects of cleanup. The developed method for providing a risk assessment in *near-real-time*, defined as the actual time lapse passing between the occurrence of the hazard (i.e., oil spill) and the first official notification to the deputed authorities, has been developed with the goal to produce risk-related information in a geographic area of interest which can be both automatically analyzed by proactive services, and visually analyzed by the users involved within the intervention chain in order to reduce the risks and possibly improve the efficiency of the remediation operations.

For example, an implicit codification of the risk is represented by the amount of monitoring resources actually existing in an area, where an augmented number of them decreases the risk level (heavy monitoring and quicker intervention), whereas a smaller number of them, as well as distant location (sparse monitoring and delay in intervention), increase the risk level.

A dynamic risk map can be defined for assessing the hazard of oil slicks by evaluating several risk factors through the combination of the data collected by the MIS. This map can be used for planning and monitoring a prioritization of the resources in order to improve the degree of control of a high-risk area. Aiming at increasing the precision of the risk map, and at the same time lowering the amount of data to be transferred, the map cells with higher risk have smaller dimensions (i.e., thus a higher granularity) with respect to the ones with lower risk.

Risk calculation takes account of data gathered by the MIS, combining and correlating them in order to better estimate the risk of oil slick occurrences. Gathered data contribute to risk calculation by increasing or lowering it: for instance, the presence of vessels in a small area increases the risk at a different degree depending on the typology of the vessel (e.g., a tanker will bring a much increased risk level); meanwhile, a negative analysis from a remote device (e.g., a sensor-equipped buoy) will result in the lowering of the risk in the covered zone. All these variables, and many others which can bring their input data into the MIS, represent factors with specific weights, which, combined, altogether yield a final risk value for each specific location (i.e., cell) of the dynamic risk map.

5.4. Models for the Resource Management Service (RMS)

The RMS is devoted to the optimization of the monitoring resources that compose the available devices in the model in order to cover the monitoring areas and get the most valuable information possible about polluting events. The idea is that when an oil spill event is detected by one of the monitoring resources, the EDSS, with its RMS, organizes the use of the other resources to get more information about the site of interest and to provide suggestions about the recovery strategy to be followed. Methods for the development of RMS are based on optimization models that try to drive the effective and efficient use of resources, according to the tasks to be performed. In particular, the aim is to define strategies for assigning resources to different activities focusing on both process and resource use to optimize task operations. Different options should usually be explored for resource allocation, availability, relevance, and data. The development of descriptive and analytical models is required to accurately represent and simulate the processes that involve resource deployment. These models should be dynamic and provide a new resource deployment plan each time it is required. From a methodological point of view, defining the resource optimization models requires outlining objectives, decision variables, and constraints. How these are involved in the optimization process is illustrated in Figure 4, and described according to the following steps that are being performed to develop the resource optimization model:

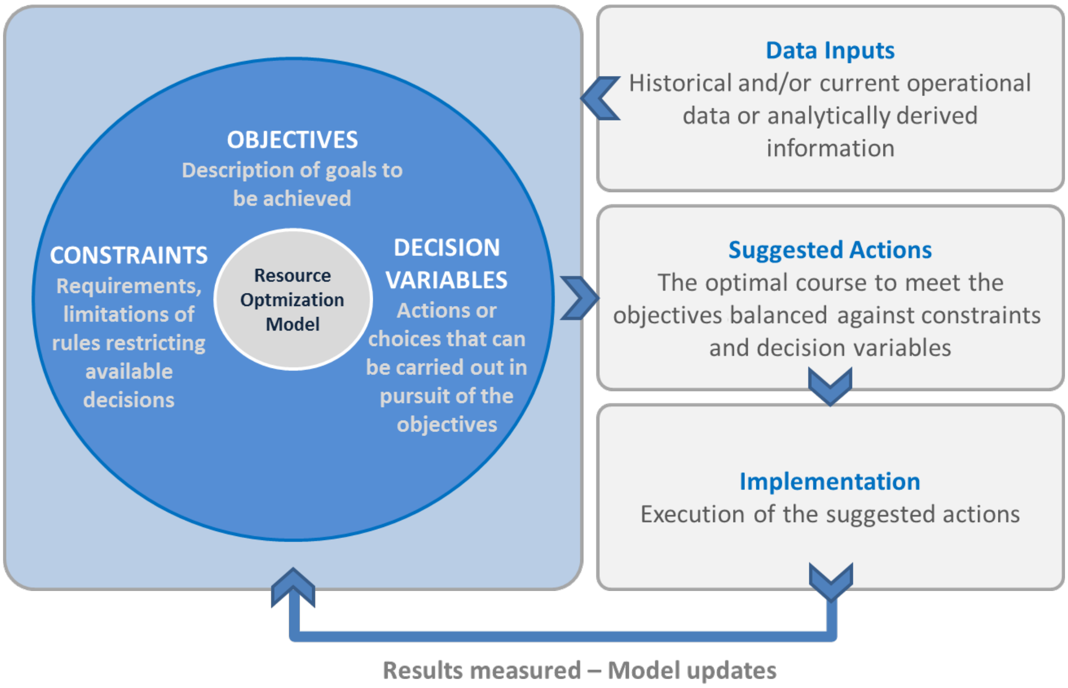

Figure 4. The components of optimization. The optimization models analyzes all possible decisions or actions based on given objectives and constraints.

Step 1. Define the objective to reflect the model mission and strategy.

The objectives to be pursued need to be determined—what the resources are meant to do, and how they are characterized, described, and cataloged for assessing their relevance and availability to the tasks to be performed. Moreover, the activities to reach these objectives should be outlined, as well as how success or failure will be measured.

Step 2. Establish the context.

The requirements, rules, and constraints need to be established to precisely define the action scene of the optimization model and the decisions that will be made.

Step 3. Define the conceptual model.

All the elements of the model should be inserted into a conceptual framework. First of all, input data should be defined, and then decision variables and actions listed in accordance to objectives and constraints.

Step 4. Formulate the resource optimization model.

The conceptual model is then translated into an analytic model with more rigor and detail, represented in mathematical terms. The key elements of the optimization model—the objective, constraints, and decision variables—are initially coded. There is no single "correct" way to use mathematical expressions to represent the elements of a decision problem. Every formulation represents a compromise because no mathematical representation can reflect every detail of a real-world scenario. Good modeling balances realism and workability.

Step 5. Implement and update the model.

The model should finally be implemented, and analytical software can be useful for this task. The real application of the implemented model can then supply some hints about necessary changes to the model for improving performance.

To be more clear, we report as an example within the case study EDSS, the use of an actual device implemented and integrated—in particular, the device is a static floating buoy equipped with several sensors for water quality control, such as hydrocarbons detection, tide measurement, wind and waves measures, and several other environmental variables. Specific details of the sensorized buoy can be found in [42], but for this specific case-study we report it as one of the monitoring resources which could be used for prioritization and active monitoring of a marine area. For example, reception of an oil spill report has been simulated close to a sensorized buoy. Once this information was gathered by the MIS and understood by the EDSS, the latter could proactively perform further investigations autonomously by checking eventual resources in the surrounding area and querying them. In this case, one of the resources was the sensorized buoy, which was questioned and asked to perform new sampling on the water, without any need of user intervention. Once the results from the buoy were received and collected by the MIS, the dynamic risk map was recomputed and a new updated risk value issued for the area being monitored. Once this action was taken, the new risk map could be analyzed, and decisions could be made regarding whether a further proactive action should be made (i.e., maybe querying some different available resources) or whether the end users in charge of the monitoring should be notified about the general situation, in order to take into consideration all available variables [50].

6. Conclusions

In this paper, we addressed the problem of small-scale oil spills at sea, focusing on the scientific and technological advances in Marine Information Systems.

As a first step, existing solutions and approaches have been analyzed, surveying the ever-increasing number of initiatives and funded projects addressing complementary and different aspects—from the assessment of the environmental risks, to the preparedness with respect to polluting events, and from the spread of knowledge and the raising of environmental consciousness and awareness, to the skill development for the training of civil protection, marine pollution professionals, volunteers, and other related stakeholders.

Afterwards, a rationale for an integrated framework was proposed, which we assert to be an important tool as support for the deputed authorities and stakeholders, particularly in view of prompt remediation operations.

We are optimistic that the impact of these advances will grow and improve quality of life and the sea environment. The dedication of research scientists and technological advances in such areas as remote sensing, modeling, and electronic communications have taught us far more about the seas, the surrounding environment, and their resources.

We shared our experiences with regard to actions that it may have undertaken to reduce sea and coastal pollution. Our survey shows that we have learned to make better predictions about how the marine environment resources are responding at both the individual species and ecosystem levels. Improvements and advances in monitoring programs have also been considered—this allows for a more accurate assessment of changes and for a more effective dissemination of such information to policy-makers who would implement science-based management actions [51]. Tools have been developed, along with the knowledge, to design an instrument for the support of policy-making that increases the ability of tomorrow's generation to understand its position in the local, global, coastal, and marine environment, and to sustain that position. The produced tools and instruments proved to be effective and of actual use within the intervention chain of an oil-spill event, when these tools can act as a valuable Environmental Decision Support System for the deputed authorities and stakeholders involved.

Author Contributions: All the authors contributed equally to the paper's preparation.

Funding: This research has been partially supported by the EU FP7-Transport Project ARGOMARINE (Automatic oil-spill recognition and geopositioning integrated in a marine monitoring network, Grant No. 234096).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fingas, M. *Oil Spill Science and Technology*; Gulf Professional Publishing: Houston, TX, USA, 2016.
2. Fingas, M.; Brown, C. Review of oil spill remote sensing. *Mar. Pollut. Bull.* **2014**, *83*, 9–23. [CrossRef] [PubMed]
3. Boteler, B.; Coastal, M.W. European Maritime Transport and Port Activities: Identifying Policy Gaps towards Reducing Environmental Impacts of Socio-Eeconomic Activities. Available online: http://www.ecologic.eu/sites/files/presentation/2014/european-maritime-transport-and-port-activities_0.pdf (accessed on 21 January 2019).
4. Abdulla, A. *Maritime Traffic Effects on Biodiversity in the Mediterranean Sea: Legal Mechanisms to Address Maritime Impacts on Mediterranean Biodiversity*; IUCN: Gland, Switzerland, 2008.
5. The International Tanker Owners Pollution Federation Limited. Oil Tanker Spill Statistics 2017. Available online: https://www.itopf.org/fileadmin/data/Photos/Statistics/Oil_Spill_Stats_2017_web.pdf (accessed on 9 January 2019).
6. Showstack, R. Research urged on impacts of chronic oil releases to marine environment. *Eos Trans. Am. Geophys. Union* **2002**, *83*, 254. [CrossRef]
7. Hyder, K.; Wright, S.; Kirby, M.; Brant, J. The role of citizen science in monitoring small-scale pollution events. *Mar. Pollut. Bull.* **2017**, *120*, 51–57. [CrossRef] [PubMed]
8. Margarit, G. Integrated maritime picture for surveillance and monitoring applications. In Proceedings of the 2013 IEEE International Geoscience and Remote Sensing Symposium-IGARSS, Melbourne, Australia, 21–26 July 2013; pp. 1517–1520.
9. CleanSeaNet. Available online: http://www.emsa.europa.eu/csn-menu.html (accessed on 18 January 2019).
10. Jordi, A.; Ferrer, M.; Vizoso, G.; Orfila, A.; Basterretxea, G.; Casas, B.; Álvarez, A.; Roig, D.; Garau, B.; Martínez, M.; et al. Scientific management of Mediterranean coastal zone: A hybrid ocean forecasting system for oil spill and search and rescue operations. *Mar. Pollut. Bull.* **2006**, *53*, 361–368. [CrossRef] [PubMed]
11. Ferraro, G.; Bernardini, A.; David, M.; Meyer-Roux, S.; Muellenhoff, O.; Perkovic, M.; Tarchi, D.; Topouzelis, K. Towards an operational use of space imagery for oil pollution monitoring in the Mediterranean basin: A demonstration in the Adriatic Sea. *Mar. Pollut. Bull.* **2007**, *54*, 403–422. [CrossRef]
12. Fustes, D.; Cantorna, D.; Dafonte, C.; Arcay, B.; Iglesias, A.; Manteiga, M. A cloud-integrated web platform for marine monitoring using GIS and remote sensing. Application to oil spill detection through SAR images. *Future Gener. Comput. Syst.* **2014**, *34*, 155–160. [CrossRef]
13. Janeiro, J.; Zacharioudaki, A.; Sarhadi, E.; Neves, A.; Martins, F. Enhancing the management response to oil spills in the Tuscany Archipelago through operational modelling. *Mar. Pollut. Bull.* **2014**, *85*, 574–589. [CrossRef]
14. Carpenter, A. The Bonn agreement aerial surveillance programme: Trends in North Sea oil pollution 1986–2004. *Mar. Pollut. Bull.* **2007**, *54*, 149–163. [CrossRef]
15. Moroni, D.; Pieri, G.; Tampucci, M.; Salvetti, O. A proactive system for maritime environment monitoring. *Mar. Pollut. Bull.* **2016**, *102*, 316–322. [CrossRef]
16. Fedra, K. Integrated risk assessment and management: Overview and state of the art. *J. Hazard. Mater.* **1998**, *61*, 5–22. [CrossRef]
17. Fedra, K. Environmental Decision Support Systems: A Conceptual Framework and Application Examples. Ph.D. Thesis, Universitè de Genéve, Geneva, Switzerland, 2000.
18. Mansfield, R.; Moohan, J. The evaluation of land remediation methods. *Land Contam. Reclam.* **2002**, *10*, 25–31. [CrossRef]
19. Cortés, U.; Sànchez-Marrè, M.; Ceccaroni, L.; R-Roda, I.; Poch, M. Artificial intelligence and environmental decision support systems. *Appl. Intell.* **2000**, *13*, 77–91. [CrossRef]
20. McIntosh, B.S.; Ascough, J.; Twery, M.; Chew, J.; Elmahdi, A.; Haase, D.; Harou, J.J.; Hepting, D.; Cuddy, S.; Jakeman, A.J.; et al. Environmental decision support systems (EDSS) development—Challenges and best practices. *Environ. Model. Softw.* **2011**, *26*, 1389–1402. [CrossRef]
21. Laniak, G.F.; Olchin, G.; Goodall, J.; Voinov, A.; Hill, M.; Glynn, P.; Whelan, G.; Geller, G.; Quinn, N.; Blind, M.; et al. Integrated environmental modeling: A vision and roadmap for the future. *Environ. Model. Softw.* **2013**, *39*, 3–23. [CrossRef]

22. EPA (US Environmental Protection Agency). *Toward Integrated Environmental Decision-Making*; Science Advisory Board: Washington, DC, USA, 2000.
23. Kelly, R.A.; Jakeman, A.J.; Barreteau, O.; Borsuk, M.E.; El Sawah, S.; Hamilton, S.H.; Henriksen, H.J.; Kuikka, S.; Maier, H.R.; Rizzoli, A.E.; et al. Selecting among five common modelling approaches for integrated environmental assessment and management. *Environ. Model. Softw.* **2013**, *47*, 159–181. [CrossRef]
24. Forsyth, R. The expert systems phenomenon. In *Expert Systems Principles and Case Studies*; Chapman & Hall: Upper Saddle River, NJ, USA, 1989; pp. 3–21.
25. Nevalainen, M.; Helle, I.; Vanhatalo, J. Preparing for the unprecedented—Towards quantitative oil risk assessment in the Arctic marine areas. *Mar. Pollut. Bull.* **2017**, *114*, 90–101. [CrossRef] [PubMed]
26. Mokhtari, S.; Hosseini, S.M.; Danehkar, A.; Azad, M.T.; Kadlec, J.; Jolma, A.; Naimi, B. Inferring spatial distribution of oil spill risks from proxies: Case study in the north of the Persian Gulf. *Ocean Coast. Manag.* **2015**, *116*, 504–511. [CrossRef]
27. Jolma, A.; Lehikoinen, A.; Helle, I.; Venesjärvi, R. A software system for assessing the spatially distributed ecological risk posed by oil shipping. *Environ. Model. Softw.* **2014**, *61*, 1–11. [CrossRef]
28. Zodiatis, G.; De Dominicis, M.; Perivoliotis, L.; Radhakrishnan, H.; Georgoudis, E.; Sotillo, M.; Lardner, R.; Krokos, G.; Bruciaferri, D.; Clementi, E.; et al. The mediterranean decision support system for marine safety dedicated to oil slicks predictions. *Deep Sea Res. Part II Top. Stud. Ocean.* **2016**, *133*, 4–20. [CrossRef]
29. Perivoliotis, L.; Krokos, G.; Nittis, K.; Korres, G. The Aegean sea marine security decision support system. *Ocean Sci.* **2011**, *7*, 671–683. [CrossRef]
30. Zodiatis, G.; Lardner, R.; Solovyov, D.; Panayidou, X.; De Dominicis, M. Predictions for oil slicks detected from satellite images using MyOcean forecasting data. *Ocean Sci.* **2012**. [CrossRef]
31. Bahurel, P.; Adragna, F.; Bell, M.J.; Jacq, F.; Johannessen, J.A.; Le Traon, P.Y.; Pinardi, N.; She, J. Ocean monitoring and forecasting core services: The European MyOcean Example. *Proc. Ocean.* **2009**, *9*, 2.
32. Pallotta, G.; Horn, S.; Braca, P.; Bryan, K. Context-enhanced vessel prediction based on Ornstein-Uhlenbeck processes using historical AIS traffic patterns: Real-world experimental results. In Proceedings of the 17th International Conference on Information Fusion (FUSION), Salamanca, Spain, 7–10 July 2014; pp. 1–7.
33. Lardner, R.; Zodiatis, G. Modelling oil plumes from subsurface spills. *Mar. Pollut. Bull.* **2017**, *124*, 94–101. [CrossRef] [PubMed]
34. NEREIDs Project. Available online: http://www.nereids.eu (accessed on 21 January 2019).
35. Alves, T.M.; Kokinou, E.; Zodiatis, G.; Radhakrishnan, H.; Panagiotakis, C.; Lardner, R. Multidisciplinary oil spill modeling to protect coastal communities and the environment of the Eastern Mediterranean Sea. *Sci. Rep.* **2016**, *6*, 36882. [CrossRef] [PubMed]
36. Alves, T.M.; Kokinou, E.; Zodiatis, G. A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins. *Mar. Pollut. Bull.* **2014**, *86*, 443–457. [CrossRef] [PubMed]
37. Alves, T.M.; Kokinou, E.; Zodiatis, G.; Lardner, R.; Panagiotakis, C.; Radhakrishnan, H. Modelling of oil spills in confined maritime basins: The case for early response in the Eastern Mediterranean Sea. *Environ. Pollut.* **2015**, *206*, 390–399. [CrossRef] [PubMed]
38. Tosi, L.; Lio, C.D.; Teatini, P.; Menghini, A.; Viezzoli, A. Continental and marine surficial water–groundwater interactions: The case of the southern coastland of Venice (Italy). *Proc. Int. Assoc. Hydrol. Sci.* **2018**, *379*, 387–392. [CrossRef]
39. Delpeche-Ellmann, N.C.; Soomere, T. Investigating the Marine Protected Areas most at risk of current-driven pollution in the Gulf of Finland, the Baltic Sea, using a Lagrangian transport model. *Mar. Pollut. Bull.* **2013**, *67*, 121–129. [CrossRef]
40. Miliou, A.; Quintana, B.; Kokinou, E.; Alves, T.; Nikolaidis, A.; Georgiou, G. Enhancing Students Critical Thinking About Marine Pollution Using Scientifically-Based Scenarios. In Proceedings of the CRETE 2018—Sixth International Conference on Industrial & Hazardous Waste Management, Tinos, Greece, 13–17 July 2018.
41. Liao, S.H. Expert system methodologies and applications—A decade review from 1995 to 2004. *Exp. Syst. Appl.* **2005**, *28*, 93–103. [CrossRef]
42. Moroni, D.; Pieri, G.; Salvetti, O.; Tampucci, M.; Domenici, C.; Tonacci, A. Sensorized buoy for oil spill early detection. *Methods Ocean.* **2016**, *17*, 221–231. [CrossRef]

43. Martinelli, M.; Moroni, D. Volunteered Geographic Information for Enhanced Marine Environment Monitoring. *Appl. Sci.* **2018**, *8*, 1743. [CrossRef]
44. Infrastructure for Spatial Information in the European Community (EU INSPIRE). Directive: Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). *Off. J. Eur. Union L* **2007**, *108*, 50.
45. Laskey, K.B.; Laskey, K. Service oriented architecture. *Wiley Int. Rev. Comput. Stat.* **2009**, *1*, 101–105. [CrossRef]
46. Wang, L.; Von Laszewski, G.; Younge, A.; He, X.; Kunze, M.; Tao, J.; Fu, C. Cloud computing: A perspective study. *New Gener. Comput.* **2010**, *28*, 137–146. [CrossRef]
47. Brunelière, H.; Cabot, J.; Jouault, F. Combining Model-Driven Engineering and Cloud Computing. In Proceedings of the Sixth European Conference on Modelling Foundations and Applications (ECMFA 2010), Paris, France, 15–18 June 2010.
48. Snyman, J.A.; Wilke, D.N. *Practical Mathematical Optimization*; Springer: Berlin/Heidelberg, Germany, 2018.
49. Gasparotti, C.; Rusu, E. Methods for the risk assessment in maritime transportation in the Black Sea basin. *J. Environ. Prot. Ecol.* **2012**, *13*, 1751–1759.
50. Pieri, G.; Cocco, M.; Salvetti, O. A marine information system for environmental monitoring: ARGO-MIS. *J. Mar. Sci. Eng.* **2018**, *6*, 15. [CrossRef]
51. Global Congress on Integrated Coastal Management EMECS 10—MEDCOAST 2013 Joint Conference. Marmaris Declaration. Available online: https://www.medcoast.net/uploads/documents/Marmaris_Declaration.pdf (accessed on 2 November 2013).