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Marine pollution: an overview

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This overview of marine pollution follows the methodology as proposed below. Firstly, well-known databases (*Science Direct*, *GeoRef*, *SpringerLINK*, etc.) on technological research were studied. All collected references were divided into 27 sections following the key words associated with marine pollution, oil spills, alien species migration, etc. The most commercially promising research and development (R & D) activities seem to be market-oriented sections: detection of oil spills at sea, containment and recovery of floating oil at sea, detection of oil spills on land, disposal of oil and debris on land, alien species migration prevention from ballast water and underwater hull cleaning in water, NO_x and SO_x emissions, pollutions from ship-building and repair, and biogeochemical modelling. Great market demands for commercially patented innovations are very attractive for initiating new R & D projects.

Key words: oil spills, modelling, MARPOL, IMO, alien species migration

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INTRODUCTION

Today the world and particularly Europe are concerned with the pollution of marine environments, which result in instant and long-term damages to coastal and marine habitats and ecosystems. Unfortunately, various recent disasters (e. g., in Alaska), alongside all other current sources of pollutions, have proven that the current means of struggle are inefficient. It is thus increasingly urgent to develop new solutions for fighting pollution by combining actors' skills from the maritime field.

Worldwide seas and oceans are under threat where recent accidental oil spills, such as the ERIKA tragedy or the IEVOLI SUN accidents, have jeopardized the marine environment, causing both immediate and long-term damage to coastal and marine habitats and ecosystems. The last tragedy in Alaska (December 2004) demonstrates the permanence of such phenomena.

However, according to the report "The EU Fleet and Chronic Hydrocarbon Contamination of the Oceans", dated November 2004, chronic hydrocarbon contamination from washing-out tanks and dumping bilge water and other oily waste represents a danger at least three times greater than that posed by oil slicks that result from oil tanker accidents. Every year around 3,000 cases of illegal hydrocarbon dumping are detected in European waters. The amount of hydrocarbons received by European waters each year has been estimated to be 109,000 tons, 62% of them (around 90,000 tons) being small spillages of less than 20 tons.

In addition, land-based activities (industry, agriculture) and 'run-offs' from land are major sources of coastal water pollution.

Other issues which are equally or even more dangerous than oil pollution also threaten the marine world, for example, alien species migration, NO_x and SO_x emissions, hydrocarbons in ballast water, biocides, pollution from ship-building, pollution from ship repair, pollution from ship scrapping, and noise pollution that affects sea mammals.

Taking all these manifold sources of pollution into account and the fact that current protection measures are limited, a stronger involvement of EU citizens and decision-makers is needed to protect and conserve the marine environment.

It is therefore more than necessary to develop innovative and efficient means for early prevention, detection, warning and treatment of all types of marine pollution. As environment problems are trans-boundary by definition, it is necessary to develop and spread new solutions that will be efficient on the European scale.

METHODS

This work on an overview of marine pollution follows the methodology presented below. Firstly, worldwide and well-known databases (such as *Science Direct*, *GeoRef*, *SpringerLINK*, etc.) on technological research were searched studied. All collected references were divided into 27 sections following the key words: *marine pollution, oil spills, detection techniques, oil spills modelling, oil containment, oil recovery, in-situ oil burning, sunken oil*

recovery, oil spills behaviour, oil disposal, debris disposal, Marine Pollution (MARPOL), International Maritime Organisation (IMO) conventions, notification/report system, classification societies, port state control, liability and compensation, environmental protection government acts, port regulation, land use, alien species migration, ballast water, hull / propeller cleaning, No_x / SO_x emissions, hydrocarbons control, biocides, ship building / repair / scrapping pollutions, and biogeochemical modelling. In general, a very good response from searching into databases was detected, i. e. approximately 2,000 references were analysed following the search results. The limiting publishing year was selected as 1990 because older articles were found only in a very few databases and, following conventional search during the overview assessment, are not up-to-date and have no novelty from the scientific or commercial point of view.

Statistical estimation using Excel spreadsheets and statistically approved results were used for the overview so as to assess data from the technological and commercial points of view.

OIL SPILLS IN MARINE ENVIRONMENT

Detection of oil spills

Different methods are available to detect oil spills, including both airborne and space-borne techniques (e. g., Synthetic Aperture Radar (SAR) (Keramitsoglou et al., 2006; Martinez and Moreno, 1996), Radarsat ((Marghany, 2004), European Remote Sensing Satellite (ERS) (Gade and Alpers, 1999), etc.) following from regional services, but a global observing/monitoring system has not yet been developed.

The SAR system analyses satellite images and detects a dark image shape which could be an oil spill (Keramitsoglou et al., 2006). The difference between oil spills, present as a film with reduced roughness on the sea surface, and the surrounding water can be detected on SAR images. The RADARSAT data are used to model the current movement and easy detection of an oil spill area (Marghany, 2004). The RADARSAT model, for instance, contains texture algorithms for automatic oil slick detection and can be used for oil slick trajectory forecast. The ERS is used to acquire SAR images and to detect of oil spills, for instance, in the southern Baltic Sea, the North Sea, and the Gulf of Lion in the Mediterranean Sea (Gade and Alpers, 1999). Analysis of SAR images has shown that the seas are most heavily polluted along the main shipping routes and that oil spill depends on wind speeds.

Oil spill detection techniques are well developed, but some additional research could be carried out to improve the existing systems (Brekke, Solberg, 2005).

Modelling of oil spills

This requires knowledge and computerized modelling systems (e. g., for the prediction of drifting oil spills (Jorda et al., 2007) or of tides (Young et al., 2000), but their level of both validation by governments and usage by oil spill responders remains pretty low. There are a great variety of oil spill models (James, 2002) and many of them have a low level of accuracy in making predictions; therefore, previous to new research, it is recommended that one should carry out a study and evaluation (including validation) of existing models and then use the results to propose a new study.

Behaviour and fate of oil spills

The behaviour and fate of oil spills in the marine environment is described by complex processes of oil transformations, which depend on the composition or other properties of the oil itself, as well as on the parameters of oil spills or environmental conditions. Most of the processes (physical transport, evaporation, dissolution, natural degradation, oxidation, sedimentation, etc.) are natural and do not require commercialized equipment or products. The following two processes may require advanced research: biodegradation and emulsification. Biodegradation in terms of provoked microbial degradation (bioremediation) has been the matter of various studies (Prince, 1997; Fernandez-Alvarez et al., 2007), some of them promoted by the European Commission's Environment Directorate-General (DG) (Marine..., 2002). Research projects on emulsification may be addressed to develop more efficient products so as to avoid emulsification (Fingas and Fieldhouse, 2004). The use of chemical dispersants is another topic for possible research (Chapman et al., 2007), but due to the existing controversy on its use and the possible environmental implications it should be accompanied by an environmental impact assessment.

Oil containment and recovery

World producers offer a broad selection of containment and pumping equipment (booms, skimmers, sorbents, etc). IMO and ISO cooperated to develop guidelines for evaluating the performance of such recovery systems. Many difficulties are encountered by oil spill responders in order to obtain a good efficiency level from this type of equipment. The general opinion of experts involved in the response operations is that the traditional booms are useful to contain or concentrate the oil in ports, bays and other sheltered waters or in calm seas, but in the open sea, the level of efficiency is very low. Innovative booms combined with some kinds of collecting devices were used during the "PRESTIGE" oil response operations. Therefore, it is suggested to continue the research on these types of boom / skimmers (Oebhius, 1999; Mullin, Champ, 2003). Similar comments on efficiency are applicable to the use of traditional skimmers in open seas or in calm waters for which reason the present tendency is to develop other types of oil recovery equipment such as the catamaran or trimaran mentioned in the Oil Sea Harvester (OSH) project (OSH, 2007), or skimmer vessels in general.

Natural, physical methods and bioremediation are used to recover oil on land, but it is difficult to reach complete removal without damaging the shoreline, marine and freshwater habitats.

The developments for detecting, investigating and pumping automotive systems for deep sunken oil are still at an initial stage. There are no practical experiences of sunken oil from a spill in massive quantities, nor how to organize a recovery operation. On the contrary, the recovery of oil contained in a sunken ship is a matter of innovative research.

In-situ burning of oil

Burning of oil *in situ* is strictly regulated and requires prior approval from governmental bodies. *In-situ* burning of oil spills usually has a negative environmental impact, but it can be used when oil needs to be removed quickly to prevent the spread of contamination or further environmental damage or when other

cleanup options prove ineffective or might be more harmful to the environment, and as the only alternative when spill locations have restricted access due to terrain, weather or other factors (Mullin, Champ, 2003; Zengel et al., 2003).

Disposal of oil and debris
In some cases, oil and debris can be placed in a landfill. Governments strictly regulate the disposal of such materials. Landfill, land farming and similar methods have important environmental implications and its practice is less and less used, so research should focus mainly on recycling (oil), incineration or on finding oil spill debris clean-up methods, e. g., thermal desorption (Araruna et al., 2004).

Control of hydrocarbons in ballast water
The existing technology requires samples to be tested in a laboratory; and need real time decisions. Since the entry into force of Annex I of MARPOL Convention in 1983, equipment (oil content meters, oil water separators, interface detectors, etc.) has been developed and improved so that at present research should be focused on the design of new and more reliable devices based on the new IT systems.

Biocides
New biocides could be introduced if they are registered. A need for an affordable registration system that enables new innovative ideas (from small companies) to be tested / used also exists. The existing legislation inhibits all new biocide introductions because of registration cost, and biocides that already exit are under threat.

Pollution from shipbuilding and from ship repair
Pollution of water, land and air mainly from coating activities, including VOC emissions, needs a uniform implementation of regulations. Some software systems are available for VOC management, but not for other activities, to enable prompt and accurate real-time reporting. Waste disposal of removed antifouling paints from ships is a matter of important priority for further research.

Pollution from ship scrapping
There are many different issues in the subject of pollution from ship scrapping, mainly related to the containment of waste, classification of hazardous materials and identification of materials. A Green Passport has been introduced for new ships, but 90,000 ships afloat do not have such registration. The system requires the collecting of data over time, so that one can be issued with a Passport retrospectively. As above, the waste disposal of scrapped materials having antifouling paints from ships is another matter of important priority for research.

Biogeochemical modelling
In the research community, a large number of ecosystem models have been developed that continuously undergo upgrades, with different model strategies being applied to different tasks and in different regions (Lacroix et al., 2007; Pereira et al., 2006). Some regional coastal models have aimed at modelling local food-web interactions explicitly and include a large number of different ecosystem variables describing various trophic levels – up to fish and birds. In contrast, marine ecosystem models applied to study the cycling of nitrogen or carbon on a basin or global scale typically have a much simpler structure with only a handful of variables representing the lower trophic levels of primary producers (phytoplankton) and their immediate grazers. This dichotomy has emerged not only in response to computational restrictions, but also because of considerable differences in the degree to which observations are available to validate the different models in different regions. For the basin and global scales, the present models range from those nitrogen-based with few variables (four to seven) to more complex models that explicitly resolve different nutrient cycles and some of the structure in the phytoplankton and zooplankton communities. Approaches to better resolve the functional diversity in plankton include representation of different sized classes and of different key species or functional groups.

The model complexity considerably increases the number of poorly known biological parameters, and the degrees of freedom in the model cannot be constrained by the available data. A common result of much data assimilation studies performed so far with various marine ecosystem models is that while none of the models are able to fit the observations within their uncertainty range, all models contain parameters (degrees of freedom) that cannot be constrained by the available data. Often, it is not clear to what extent errors in the physical environment that forces the ecosystem model are responsible for the model–data misfits.

MARPOL, IMO Conventions

The MARPOL Convention is the main international convention covering the prevention of pollution of the marine environment by ships from operational or accidental causes.

There are a lot of various conventions focused on different areas of marine pollution, such as *Particularly Sensitive Sea Areas* (*PSSA*) (Larsen et al., 2007; Detjen, 2006), *International Convention for the Control and Management of Ships' Ballast Water and Sediments,* which have been criticized but are still appropriate tools for marine pollution control (Gollasch et al., 2007). MARPOL and other pollution-related conventions are more a question of the control of compliance through Port State and Flag State controls than a matter of research.

Classification societies
Classification societies are organisations that develop and apply technical standards to the design, construction and assessment of ships as well as carrying out survey work on ships. Flag states can authorise classification societies to make inspections and statutory certification of ships (EMSA, 2007). There are more than 50 organisations worldwide, which define their activities as providing marine classification, but only 13 classification societies are presently recognised by the European Union.

A stricter monitoring of classification societies is required. This is already done through the Council Directive 94/57/EC of 22 November 1994 *on common rules and standards for ship inspection and survey organizations and for the relevant activities of maritime administrations*. Attention should be focused on the improvement of low-cost methods and new solutions

in social–political behaviour. In fact, this is rather a matter of monitoring the operation of Classification Societies than a research activity. In order to grant initial recognition to those classification societies wishing to be authorised to work on behalf of the EU Member States, compliance with the provisions of the Directive 94/57/EC must be assessed more effectively by the European Commission together with the Member States requesting the recognition.

Liability and compensation
Legislation must be urgently set in motion because this is the only action which severely penalises offenders and prevents the pollution of seas. There are no international instruments on liability and compensation for operational pollution that are regulated in the MARPOL Convention. The infractions are penalized under the National legislations.

Control of compliance and penalization of infractions related to land-based pollution is an internal competency of National Authorities in any case following the concerned EU Directives.

PREVENTION OF OIL SPILLS ON LAND

Prevention of oil spills on land is one of the possible measures to avoid oils being discharged from land-based sources into the marine environment.

Soil-water management at catchment and river basin scales requires identification of the relevant processes and the quantification of associated parameters, and the development of numerical models of the groundwater–soil–sediment–river system to identify adverse trends in soil functioning, water quantity and quality. The AquaTerra models will integrate the key biogeochemical, climatic and hydrological processes over relevant scales in time and space The AquaTerra integrates across multiple disciplines, from geosciences, environmental engineering and chemistry to socio-economic sciences, from catchment to the regional scale with case studies located in major European river basins (Barth et al., 2007). The AquaTerra involves practitioners and end-users to elaborate operational tools for the different stake-holders, i. e. policy-makers, river basin managers, regional and urban land planners. BIOGEOCHEM quantifies filter and transport functions in the vadose zone and will deliver a better understanding of the fate of pollutants in soils and sediments. This includes particle as well as colloid transport, sorption and bioprocesses. It therefore will yield an improved understanding of indirect impacts on the water quality. The processes include facilitated transport of solid matter and pollutants in subsurface and surface waters, the interaction of pollutants between solids and water (adsorption, partitioning, desorption) and biodegradation. Inorganic as well as organic pollutants are selected by their environmental properties such as persistence, bioactivity, flux and dispersal behaviour.

ALIEN SPECIES MIGRATION

Pollution from ballast water
Needs testing to assess the capability of ballast water systems. Only one or two proper systems exist, but they are not yet fully proven.

Pollution from underwater hull cleaning in water
Needs new systems in the market. Needs to map migration to assess the potential areas of damage. No full mapping has been made.

Pollution from propeller cleaning in water
The underwater hull cleaning procedure needs a solution that allows particulates to be collected / recovered, etc. Underwater hulls need new technology to deal with problems resulting from hulls and propellers. Existing techniques have no such capability. No one reference was dedicated to prevention from propeller cleaning in water-related issues. Low numbers of scientific reference sites show a lack of research, and it should be concentrated on development stage.

NO_X AND SO_X EMISSIONS

IMO regulations on air pollution from ships came into force on 19 May 2005. No technology that is already approved, other than reduction of sulphur in fuel, exists at present. New techniques as alternatives to low sulphur concentration in fuels need to be developed and alternative fuel sources should be searched for.

STATISTICAL ANALYSIS OF MARINE POLLUTION REFERENCES

Approximately one hundred special articles and presentations on research related to marine pollution have been found and divided into different sections. The figure presenting the general analysis shows the biggest percentage of references related to the behaviour and fate of oil spills at sea (15.7%), as well as 14.6% of ship scraping references (Figure). Fewer references were found regarding the behaviour and fate of oil spills on land, control of hydrocarbons in ballast water (9%), prevention of pollution from ballast water (7.9%), pollution from shipbuilding and repair (5.6%). Very few references were found related to liability and compensation (2.3%); only 1% of references concerned the following sections: the notification / reporting system, disposal of oil and debris, detection of oil spills on land, and modeling of oil spills at sea. This marine pollution overview provides an information on the sections of marine pollution that need to be researched more intensively and can therefore be useful while preparing proposals for the FP7 program.

CONCLUSIONS AND RECOMMENDATIONS

1. We recommend research units working on the following sections: detection of oil spills at sea, modelling oil spills at sea, containment and recovery of floating oil at sea, detection of oil spills on land, notification / reporting systems, classification societies, prevention on land in general, biocides, and biogeochemical modelling. Also, we recommend trying to join the ongoing project consortia and to continue research with skilled partners. The best practice lessons need to be learned, and the existing gaps can be proposed for future R & D projects.
2. No significant R & D activities directly dealing with marine pollution have been found on the following sections: behav-

iour and fate of oil spills at sea or on land, *in-situ* burning of oil at sea or on land, recovery of sunken oil at sea, disposal of oil and debris, MARPOL, IMO Conventions, liability and compensation on land or at sea, governmental acts on environmental protection, port regulations, land use, alien species migration prevention from ballast water, underwater hull and propeller, NO_x and SO_x emissions, control of hydrocarbons in ballast water, pollution from ship building, repair, and scrapping. We strongly recommend that big research companies and institutes base new priorities on the above sections or combine them into one complex big project or divide them into separate smaller projects excluding the sections of *in-situ* burning of oil at sea or on land and port regulations, land use because of the above presented reasons.

3. The most commercially promising R & D activities seem to be market-oriented sections: detection of oil spills at sea, containment and recovery of floating oil at sea, detection of oil spills on land, disposal of oil and debris on land, alien species migration prevention from ballast water and underwater hull cleaning in water, NO_x and SO_x emissions, pollution from ship building and repair, and biogeochemical modelling. High market demands for commercial patented innovations are very attractive to research units for initiating new R & D projects.
4. Some gaps, manifested in low research activities, have been found in the following sections: recovery of sunken oil at sea, containment and recovery of deposited oil on land, classification societies, port state control, liability and compensation

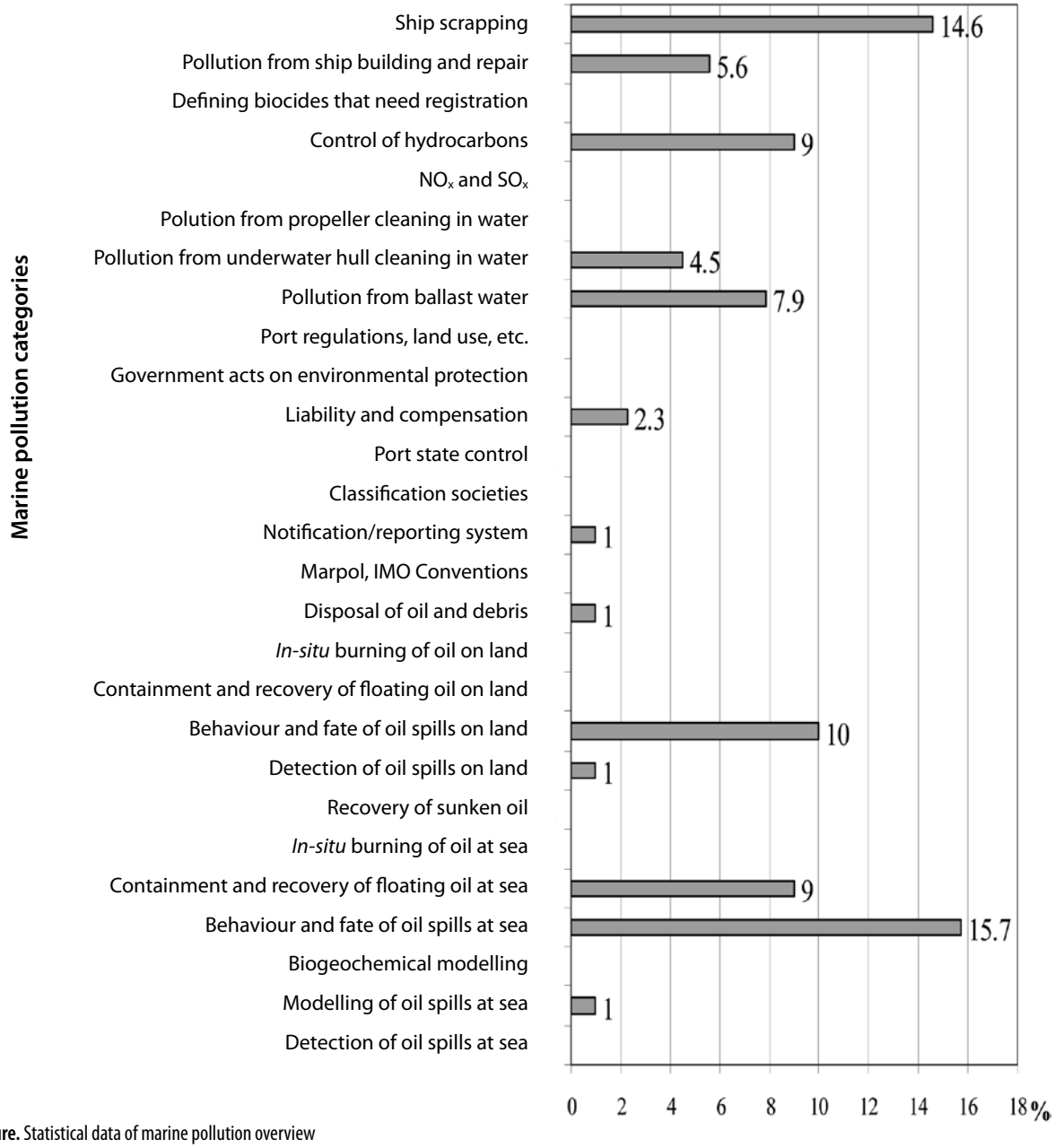

Figure. Statistical data of marine pollution overview
Pav. Jūros taršos apžvalgos statistikos duomenys

at sea and on land, alien species migration prevention from ballast water, underwater hull / propeller cleaning in water, NO_x and SO_x emission regulations, control of hydrocarbons in ballast water, biocides, and pollutions from ship scrapping. Highly-skilled research institutions need to be motivated to work on these gaps and together with industrial companies to provide the marked with reliable productions from R & D on marine pollutions.

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Marina Valentukevičienė, Evelina Brannvall

JŪROS TARŠOS APŽVALGA

S a n t r a u k a

Jūros taršos apžvalga atlikta remiantis pateikta metodika. Visų pirma buvo peržiūrėtos gerai žinomos technologinių tyrimų pasaulinės duomenų bazės – *Science Direct*, *GeoRef*, *SpringerLINK* ir kt. Visos literatūrinės nuorodos buvo suskirstytos į 27 kategorijas pagal raktažodžius, susijusius su jūros tarša, naftos išsiliejimais, svetimų rūšių migracija ir kt. Labiausiai komerciškai perspektyvios mokslinių tyrimų plėtojimo kryptys, pvz., naftos išsiliejimų nustatymas jūroje bei sausumoje, naftos ir atliekų saugojimas sausumoje, svetimų rūšių migracija iš balastinių vandenų ir povandeninių laivų dalių valymo vandenyje prevencija, NO_x ir SO_x emisijos, laivų statybos ir remonto tarša, biogeocheminis modeliavimas, yra orientuotos į rinką. Didelis komercinių inovacinių patentų poreikis skatina mokslininkus siūlyti naujus tyrimų plėtojimo projektus.

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ОБЗОР ПО ПРОБЛЕМЕ МОРСКИХ ЗАГРЯЗНЕНИЙ

Р е з ю м е

Использовались широко известные в мире базы данных по технологическим исследованиям (такие, как *Science Direct*, *GeoRef*, *SpringerLINK* и др.). Все собранные источники были разделены на 27 секций по ключевым словам, которые ассоциируются с морскими загрязнениями, выбросами нефти, миграцией чуждых видов и т. д. Наиболее перспективными коммерческими видами научно-исследовательской деятельности оказались рыночно ориентированные секции: выявление выбросов нефти в море, сбор и переработка плавающей в море нефти, обнаружение пятен нефти на поверхности земли, хранение нефти и мусора на полигонах, превенция миграции чуждых видов из балластных вод и очистки корпуса корабля в воде, эмиссии NO_x, SO_x, загрязнения, связанные с кораблестроением и ремонтом судов, биогеохимическое моделирование. Широкая потребность рынка в коммерческих запатентованных инновациях особенно интересует исследовательские объединения для инициирования новых научно-исследовательских проектов.