Ballast water and sustainability: identification of areas for unballasting by geoprocessing — case study in Todos os Santos Bay, Brazil

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Abstract. This study focuses on the GIS identification of areas recommended for unballasting in exceptional circumstances, within the 200 nautical miles of the coast, when vessels and/or travelers are exposed to high-risk situations, as a preliminary attempt to implement in advance some guidelines of the International Convention for the Control and Management of Ships' Ballast Water and Sediments – 2004 (BWM). The Todos os Santos bay, located in the state of Bahia, Brazil, was chosen as a case study. The work starts with the definition of areas of exclusion, based on the identification of potential risk to urban areas, mangroves swamps, and nature conservation units, using as a parameter the speed of the water movement inside the bay. Overlaying the maps of areas susceptible to contamination by ballast water with thematic maps of water velocity and bathymetry, it was created a final map containing the areas recommended for unballasting of ships in exceptional circumstances. There, it was identified two contiguous regions (Area 1 with 16.19 km^2 and Area 2 with 15.20 km^2), being Area 2 more recommended for unballasting than Area 1.

Keywords: Geoprocessing, Ballast Water, Environmental Management, unballasting.

Resumo. **Águas de lastro e sustentabilidade: identificação de áreas para deslastre por geoprocessamento – estudo de caso na Baía de Todos os Santos-BA, Brasil.** O estudo trata da identificação, por geoprocessamento, de áreas com potencial de risco de contaminação ambiental por águas de lastro e áreas recomendadas para desastre em situações excepcionais, dentro das 200 milhas náuticas da costa, numa tentativa de avançar na operacionalização das diretrizes gerais da Convenção Internacional sobre controle e gestão de Água de Lastro e Sedimentos (BWM 2004). A Baía de Todos os Santos, Bahia – Brasil foi escolhida como estudo de caso. Inicialmente, procedeu-se à definição de áreas de exclusão baseadas na identificação de potencial de risco a áreas urbanas, áreas de manguezais e Unidades de Conservação, tomando-se como parâmetro a velocidade de deslocamento das águas no interior da baía. Cruzando-se o mapa de potencial de risco à contaminação por água de lastro, com os mapas de velocidade das águas e a batimetria, chegou-se ao mapa final de áreas recomendadas para deslastre de navios, em situações excepcionais. Foram identificadas duas áreas contíguas (Area 1 com 16.19 km^2 e Area 2 com 15.20 km^2), sendo a Area 2 mais recomendada para realização de deslastre que a Area 1.

Palavras-Chave: Geoprocessamento, Água de Lastro, Gestão Ambiental, deslastre

Introduction

The issue of sea pollution caused by maritime traffic has been debated more intensely since the intensification of commercial exchange by the end of the last century (Goldberg 1995, Elliot 2003). Among the many types of sea pollution, the one that has been drawing most attention is pollution resulting from the ballast water of ships. During the procedures of ballasting and unballasting, there is a transfer from one locality to another of contaminants and species of living beings, which include everything from viruses and bacteria to invertebrates, at a rate of between three to five billion tons of ballast water every year (Pollard & Hutchings 1990, Thresher 1999, Hayes & Sliwa 2003). This lead to the fear of the spread of epidemic diseases — such as cholera — and the outbreak of new epidemic diseases associated with the transport of microorganisms in ballast water. The epidemiological and environmental risk associated with the uncontrolled discharge of ballast water has become a source of growing concern among the governments of many countries. Just like the chemical pollutants, exotic invasive species are considered biological pollutants by Elliot (2003), which makes government of many countries to be increasingly geared to a measurable and anticipated form of detection of the risks involved. Thus, in this paper, the term "contaminants" in general also includes exotic invasive species and other harmful aquatic organisms and pathogens.

In this context, the International Convention for the Control and Management of Ships' Ballast Water and Sediments – 2004 (BWM) adopted in a Diplomatic Conference in February of 2004, is a very significant fact in environmental management in recent history. The BWM Convention objectives are "prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources arising from the transfer of Harmful Aquatic Organisms and Pathogens through the control and management of ships' Ballast Water and Sediments, as well as to avoid unwanted side-effects from that control and to encourage developments in related knowledge and technology". About the control and management of ships' ballast water and sediments in maritime transport, the BWM Convention requires that the change of the content of ballast water tanks should be carried out in oceanic waters. In other special cases, when the vessel is caught up in an emergency situation and the navigability of the ship or safety of the crew is at stake, a competent authority should indicate an appropriate place for unballasting without any impact or risk to either human health or the ecosystem. (Regulation B-4, paragraph 4: "A ship conducting Ballast Water exchange shall not be required to comply with paragraphs 1 or 2, as appropriate, if the master reasonably decides that such exchange would threaten the safety or stability of the ship, its crew, or its passengers because of adverse weather, ship design or stress, equipment failure, or any other extraordinary condition").

Once Brazil has a coastline extension of nearly 8,500 km and an economic partner to countries all over the world with intense and constant maritime port movement, it is a country highly exposed to the possible environmental dangers resulting from the unballasting of commercial ships, with emphasis in the marine concern.

In this context, the purpose of the present work is a preliminary attempt to use a methodology based on geoprocessing to identify areas for the unballasting of ships under special circumstances and for their own safety, as were previewed in Regulation B-4, paragraph 4 of BWM Convention, taking the Todos os Santos bay, in the state of Bahia, Brazil, as case study. Thus, this study can be seen as an effort to prepare Brazilian government staff to handle GIS perspective in the control and management of ships' ballast water and sediments, considering the future entry into force of BWM Convention.

Study Area. The Todos os Santos bay (TSB) occupies an area of approximately 1,000 km^2 and has 184 km of continental coastal extension. The bay appears as a recess in the coastline by which the sea penetrates the continent, in the form of a channel between the city of Salvador and the island of Itaparica, in the state of Bahia. It has a width of nearly 9 km and a maximum depth of approximately 50 m, free of silting (CRA, 2001).

Characterized by a variety of estuary plains, small inland bays, flooded estuaries and mangrove swamps surrounding it, the bay has a complex tributary drainage network, with a total area of approximately 60,500 km^2. In spite of the fact that it faces a number of serious environmental challenges at specific points, the TSB has 54 islands and countless beaches around it, including 320 km of rocky sandy beaches that offer an indisputable tourist potential, all in an area that is well-served by a mesh of paved roads and easy access to the surrounding cities (CRA, 2001).

Material and Methods

Geoprocessing is a set of processes designed to support decision-making, logically and physically based on a technology known as Geographic

Information Systems (GIS), a computational structure that allows for the storing, retrieving, handling, and outputting of georeferenced data (Tomlinson & Boyle 1971, Aronoff 1991), supporting both quantitative and qualitative analysis (Pavlovskaya, 2006).

In order to identify areas recommended for unballasting, a general criteria structure is presented in Figure 1, similar to presented in Wood & Dragicevic (2007), based on Malczewski (1999). As a multicriteria evaluation (MCE), it was assumed there is no weight differences among the criterion layers and they were just normalized by defining the same amplitude of ordering theoretical axis (Malczewski, 1999).
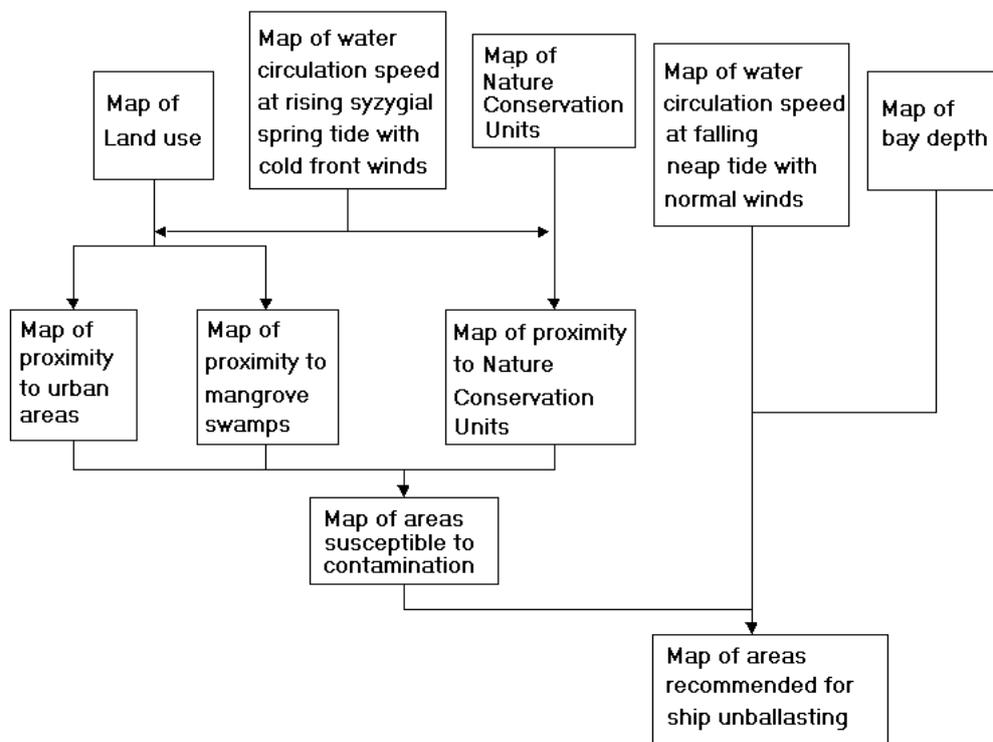

Figure 1. Flow chart of the procedures for identification of areas recommended for unballasting of ships inside the TSB.

The map of areas susceptible to contamination was get by overlapping three maps: proximity to urban areas, proximity to mangrove swamps, and proximity to nature conservation units (NCU). In every these three maps it was established a risk zone, corresponding to the capacity of a contaminant to reach a sensitive target land use. Each risk evaluation was done separately before being assessed in a integrated analysis procedure to produce a Map of areas susceptible to contamination.

The risk zone was determined based on physical data (water circulation speed), devised to express the spreading capacity of the contaminating load coming from the discharge of ballast water by a ship. The map of water circulation speed at rising spring tide with cold front winds, produced by the CRA, was chosen as the basis for this study, due to the fact that under such conditions the water circulation speed is maximized, sustaining a conservative analysis. The velocity of water circulation at the entrance to the bay at flood tide, multiplied by the time it takes for the tide waters to alternate between rising tide and ebb tide makes it possible to calculate the maximum reach of a contaminant during a complete period of spring tide with cold front winds, considering the fact that the tides alternate between their rising tide flux and ebb tide flux every 06:21h (six hours and twenty-one minutes). The width of the proximity buffer to urban areas, mangrove swamps, and NCU corresponds to this maximum reach of a contaminant during a complete period of spring tide with cold front winds.

Because of the generic character of this modelling process, it was not considered the possible influence of self movement of certain species or their larvae forms. In the same way, once it was proposed to locate the risk zone by the reach of water circulation speed, it was assumed that the contaminants body form or weight is negligible and

every contaminant can be carried out at the same speed of the water in which it is immersed. The robustness of this modelling procedure is based on a heuristic evaluation of the risk, based on the uncertainty of the effective contamination, which is incorporated by mapping the buffering zones of the grades of probable risk.

The urban areas were selected in view of the possible impact on public health as the result of the presence of contaminants such as pathogenic microorganisms contained in the ballast water, which could lead to the outbreak of diseases transmitted in water, such as cholera, typhoid fever, and hepatitis A. In TBS, the urban areas area characterized as the projection of this area to TBS coastline, where it is situated all the beaches where people use for swimming, and it was done no distinction among these projections, considering that all of them had direct or indirect human contact. The mangrove swamps were chosen due to the fragility of these ecosystems and to the fact that they often are the reproduction sites for several marine organisms. Chemical contaminants present in ballast water could cause a serious damage to this very fragile ecosystem, besides the fact that the exotic invasive species contained in ballast water could upset the balance of the intricate web of ecological relationship among the species therein. Furthermore, the mangrove swamps, in contrast to the urban areas or the on-land NCU, suffer the direct impact of the contaminants found in ballast water because mangroves exist in an environment where water is a component, not only a contact medium. This was one more reason for choosing protection areas in the form of nature conservation units, to be mapped and evaluated in terms of areas of their proximity to ship unballasting.

By realizing the need to harmonize environmental interests with socioeconomic ones, studies must be conducted to identify areas recommended for unballasting within the range of the 200 nautical miles of the coast, under exceptional circumstances, excluding the areas which have been mapped for potential risk of contamination, to avoid arbitrary unballasting in any area near the coast. This anticipatory attitude meets the demands of planning based on a diagnostic approach to the real situation, according to a sustainable development point of view. Moreover, this proposition also meets the Regulation B-4, paragraph 2, of the International Convention for the Control and Management of ships' ballast water and sediment – 2004, which states that "In sea areas where the distance from the nearest land or the depth does not meet the parameters described in paragraph 1.1 or 1.2, the port State may designate areas, in consultation with adjacent or other States, as appropriate, where a ship may conduct Ballast Water exchange, taking into account the Guidelines described in paragraph 1.1".

To this end, the target of these areas should consider the greatest water circulation speed at ebb tide on the way out of the TSB, allowing for the greatest dilution of the contaminants present in the discharged ballast water and its quickest carrying away to open sea, far away from the coastline.

On the map showing the depth of the bay (bathymetric map), the deepest areas were positively selected, because they provide the maximum height of water columns and thus the greatest potential for dilution of the contaminants. The definitive criteria adopted are described in Table I.

Table I. Criteria used for classification on the map of areas recommended for ship unballasting.

Variables represented on the maps	Criteria for classification
Depth	Above 30 meters
Speed	Above 0.5 m/s
Potential risk	Medium, Low-Medium, and Low

Based on the map of water circulation speed, some areas were positively selected, those where the water velocity corresponded to the highest speed within the amplitude range of the locality. This circumstance favors the dilution of the contaminants present in the discharged ballast water and a quicker carrying away of these contaminants to the open sea, far from the coast. On the map showing the depth of the sea at the bay (bathymetric data), the deepest areas were positively identified.

The selection of areas with the greatest depth allows for the contaminants present in

unballasted water to be diluted more easily, due to the greater height of the water column, thus minimizing the contamination risk potential. The overlaying of these two maps, cross-checked against the former map showing the areas susceptible to contamination, once again using Boolean analysis, led to the final map which shows the areas recommended for ship unballasting.

Results

The velocity of water circulation at the entrance to the bay at flood tide was determined as

0.5 m/s and the maximum spread of a contaminant during a complete cycle of spring tide with cold front winds was defined as 11,430 meters. This value was divided into three equal parts of 3,810 meters, to establish the areas of high, medium, and low risk potential in each proximity map: proximity to urban areas, to mangrove swamps, and to NCU. Farther than 11,430 meters, the potential risk would be null.

The quantitative results — in terms of territorial extension of each proximity zone on each map — are consolidated on Table II. So, after having started based on secondary governmental data, it was possible to proceed with the manipulation of the database in order to generate intermediary maps in the analysis structure presented in Figure 1. Those three maps overlaid, each given equal importance and analyzed according to the Boolean method, yielded a map of areas susceptible to contamination (Fig. 2).

Table II. Territorial extension of each proximity zone on the resulting maps of proximity (to urban areas, mangrove swamps, and nature conservation units) in the interior of Todos os Santos bay (Bahia state, Brazil).

Maps of proximity	Area from 0 km to 3.81 km (km^2)	Area between 3.81 km and 7.61 km (km^2)	Area between 7.61 km and 11.43 km (km^2)
To urban areas	761.2	714.2	419.8
To mangrove swamps	457.5	364.4	143.1
To nature conservation units	891.1	486.6	406.2

Figure 2. Map of areas susceptible to contamination (potential risk of contamination).

That is, at each point on the map five categories of potential risk were determined: very high, high, medium, low-medium, and low susceptibility to contamination. The most susceptible areas to contamination (very high risk) would be those which simultaneously ranked in the high risk categories on all three maps of proximity to urban areas, mangrove swamps, and nature

conservation units. Accordingly, those areas that ranked in the low risk category on the three proximity maps would be classified as the areas as the lowest susceptible areas to contamination (low risk). These are the extremes of an orderly classificatory vector, where the intermediary classes are found. The complete criteria can be found on Table III and the width of the potential risk zones can be seen in Table IV.

To identify the areas recommended for ship unballasting, the greatest water circulation speed at ebb tide on the way out of the TSB should be found.

The velocity range chosen was the one higher than 0.5 m/s, on the map of water circulation speed at neap tide with normal winds (when circulation velocity is minimized). Also, the deepest areas were searched to provide the maximum height of water columns and thus the greatest potential for dilution of the contaminants: the regions chosen were those with a depth greater than 30 meters, which represents the greatest depth within the amplitude range of that locality. The final map of the areas recommended for ship unballasting was shown in Figure 3.

Table III. Criteria adopted for the map of areas susceptible to contamination.

Potential risk	Criteria for classification
Very high	When the zones of greatest potential risk according to proximity (from 0 km to 3.81 km) overlaid each other on all three maps.
High	When two of the greatest potential risk zones according to proximity overlaid one another (from 0 km to 3.81 km).
Medium	Overlaying indicated one component in the range of 0 km to 3.81 km and two components in the range of 3.81 km to 7.61 km, or overlay showing the three components in the range of 3.81 km to 7.61 km.
Low-Medium	Overlay showing at least one component in the range of 3.81 km to 7.61 km.
Low	Overlay showing all components to be in the categories above 7.61 km.

Table IV. The territorial extension of the susceptible areas to contamination in the study area.

Classes of potential risk	Within TSB (km^2)	Outside TSB (km^2)
Very high potential risk	295.80	0.00
High potential risk	418.60	162.40
Medium potential risk	268.50	362.10
Low-Medium potential risk	42.48	145.20
Low potential risk	0.00	954.90
Totals:	1,025.38	1,624.60

In reality, the selected area is composed of two contiguous regions (1 and 2), which were chosen individually, then ranked between them according to the risk they presented due to their proximity to the interior of the TSB. Area 1 totals 16.19 km^2 and Area 2 totals 15.20 km^2. The two areas together total 31.39 km^2. Area 2 is more recommended for unballasting than Area 1. The precise geographical localization is presented in Table V.

Discussion

The map of proximity to urban areas locates the cities surrounding the TSB, including Salvador and the other cities in the metropolitan region under its direct influence. The map of proximity to mangrove swamps points out the sensitive areas of what still remains under the protection of the Área de Proteção Ambiental da Baía de Todos os Santos

(Environmental Protection Area of Todos os Santos bay). These preliminary pieces of information make it possible to identify potential risk areas, and in the case of the bay of Iguapé, these data could serve as the primary risk assessment tool for the Marine Extractivist Reserve of the Iguapé Bay (ExRes), in the districts of Maragojipe and Cachoeira. The map of proximity to nature conservation units was made based on the location of the state NCU (environmental protection areas of Abaeté, TSB, Joanes/Ipitanga, and Bacia do Cobre) — under the management of the CRA — and on the location of the ExRes, a federal NCU for sustainable use.

The delimitation of the proximity zones surrounding the NCU, identifying those which represent potential risk of contamination to the coastal areas by ballast water, could provide valuable information for the preparation of the

respective NCU management plan. This plan, despite being land-related, could help define "buffer zones," including the contiguous marine portions therein, as areas regulated from the point of view of anthropic activities in order to minimize the impact on biodiversity within the NCU.
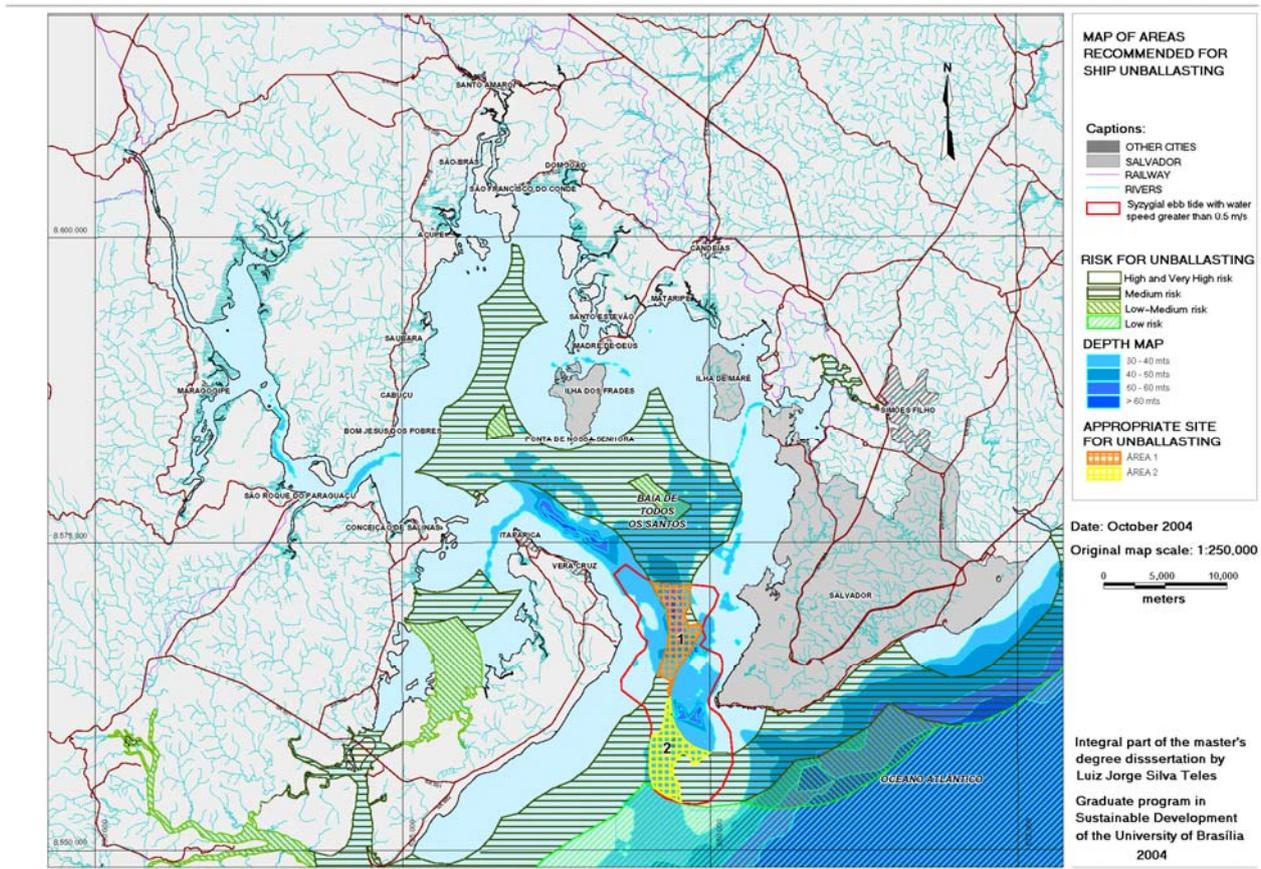

Figure 3. Map showing the areas recommended for ship unballasting.

Table V. The geographical localization of areas recommended for ship unballasting (UTM, SAD-69, zone 24).

Geographical localization of Area 1 (UTM)			Geographical localization of Area 2 (UTM)		
N	**X**	**Y**	N	**X**	**Y**
1	546.765	8.562.945	1	545.416	8.555.092
2	547.255	8.564.481	2	546.094	8.554.606
3	548.679	8.566.627	3	547.661	8.553.866
4	549.253	8.567.763	4	547.598	8.554.288
5	549.318	8.568.121	5	547.492	8.554.688
6	549.017	8.568.590	6	547.515	8.555.256
7	548.966	8.568.398	7	547.282	8.555.615
8	548.408	8.568.313	8	546.965	8.556.100
9	548.253	8.568.217	9	546.945	8.556.605
10	548.157	8.568.582	10	547.009	8.556.921
11	547.926	8.569.215	11	547.243	8.557.300
12	548.381	8.569.905	12	547.519	8.557.510
13	548.326	8.570.671	13	547.561	8.557.826
14	548.476	8.571.640	14	547.985	8.557.846
15	546.765	8.562.945	15	548.303	8.557.614
			16	545.416	8.555.092

Specifically in the case of the ExRes of Iguapé, the NCU management plan and the kinds of use of marine resources by the communities there settled depend on an evaluation of the potential risks to which they are susceptible. The vigilance exercised and even the social negotiation concerning the location of ship unballasting areas depend on the mapping of the zones of potential risks to which the marine resources of the ExRes and in particular the mangrove swamps therein are exposed.

The map of areas susceptible to contamination (Fig. 2) clearly shows the fragility of the TSB in regard to contamination by ballast water. Inside it, there is no area free from the risk of contamination in limit-situations — that is to say, in the extreme case of quickest contaminant spread, as would occur at spring tide with cold front winds.

The most critical areas, which are shown on this resultant map, are the ones which require the highest level of vigilance by competent authorities, in order to restrain the practice of ship unballasting.

It must be emphasized that the study area comprises a large region outside the TSB, including the coastal portions to the south — close to the island of Itaparica — and to the north of the bay. According to these data, the greatest part of the interior of TSB is categorized as high or very high risk, whereas no region inside it could be classified as low risk, thus revealing the fragility of the bay in regard to the discharge of ballast water by ships. The large low risk areas in the region of the study are located outside of the TSB.

The information generated by the study also provides valuable data for a coastal and marine ecological zoning; the areas in dark blue on the map of areas susceptible to contamination (Fig. 2) — a 3.81 km extension starting from the coastline — serve to outline the forbidden area, within which under no circumstances should the vessel perform unballasting. The areas in light blue constitute a moderate risk zone for unballasting.

After having chosen the appropriate site for the unballasting procedure based on Figure 3, and following the parameters decided upon for this purpose, it is believed that the process should cause the minimum possible risk of environmental contamination to the interior waters of the TSB. In the recommended area, the vessels will only be able to carry out the unballasting at ebb tide, so that the possible contaminants are taken away by the sea currents towards the deeper waters away from the coastline, where there is a higher degree of resilience and no risk of contamination to inland TSB. Moreover, since the chosen water circulation speed is moderate, the vessels can function normally at the moment of unballasting, without fearing the sea currents that circulate with a greater force of the tide which might jeopardize the safety of the ship.

The location of these areas should be previously communicated to the ships by the competent authorities, so that the ships that still have not followed the correct procedure — performing the unballasting process gradually during the journey — do so in the area specifically designated for unballasting with the minimum environmental impact possible. In fact, at the moment that the ships communicate the coordinates of their trajectory and/or of the scheduled unballasting, it is possible to compare those coordinates with the ones on the final map showing the areas recommended for ship unballasting. Then to judge, *ad hoc*, whether or not the ships have been operating according to the proper norms. Finally, the necessary adjustments regarding the location of the ship, by the retransmission of the correct coordinates with the location of the recommended areas for ship unballasting.

It is hoped that there can be a conciliation of environmental concerns with prevention procedures at the time of unballasting in locations considered safe outside the TSB. In this way, the vessels which have not carried out the procedure during the journey can continue their trip performing their duty of transporting goods. Also, they can go on integrating national and international economies, within the perspective of sustainable development, independently of the application of the adequate punishments to those who have violated the IMO norms.

Although this study was concluded in 2005, it seems still valid nowadays, even after the Resolution MEPC.151(55) – Guidelines on designation of areas for ballast water exchange (G14), adopted on 13 October 2006, which are created to support the already identified necessity for additional guidance on the designation of areas for ballast exchange, as stated by the Regulation B-4, paragraph 2, of the International Convention for the Control and Management of ships' ballast water and sediment – 2004.

According to this complementary guidelines, the identification of potential sea areas for ballast water exchange by a Port State requires consideration of legal aspects, important resources and protected areas, and navigational constraints. The G-14 is very clear in saying that "the location and size that provide the last risk to the aquatic environment, human health, property or resources should be selected for designation" (9.1). The identified ballast water exchange area(s) should be

assessed in order to ensure that the designation will minimize any threat of harm to the environment, human health, property or resources taking into account but not limited to the following criteria: oceanographic (currents, depths), physico-chemical (salinity, nutrients, dissolved oxygen, chlorophyll 'a'), biological (presence of Harmful Aquatic Organisms and Pathogens, including cysts; organisms density), environmental (pollution from human activities), important resources (fisheries areas, aquaculture farms), ballast water operations (quantities, source, frequency). This assessment step follows the preliminary indication of area(s) promoted by this study and should be done by Port State to confirm the adoption of identified area(s) as official ballast water exchange area(s). Also, after the conclusion of the present manuscript, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) just recently adopted in its 56th session (9-13 July 2007) guidelines for additional measures regarding ballast waters management, including emergency situations (G13). In this guidelines, it is required the precise co-ordinates where and applicable date when additional measures are applicable by a Party to prevent, reduce, or eliminate the identified potential harm from the introduction of harmful aquatic organisms and pathogens in the area to be covered by the additional measures. This study in a certain way fits this guidelines, as gives the motivations to improve environmental protection, the conditions (emergency situations, at ebb tide, and inside the recommended areas 1 and 2) and the precise localization where the orientation should be performed.

Conclusions and Recommendations

In an attempt to locate geographically the susceptible areas to contamination from ballast water in the Todos os Santos bay, a wide range of data that were dispersed have been collected, organized, and presented, regarding urban areas and mangrove swamps, the location of federal and state nature conservation units, water circulation conditions, and bathymetry in the TSB.

Geoprocessing has made it possible, through the cross-checking of several spatialized variables, to delimit an area of minimum environmental impact to be recommended to the competent authorities as the most suitable for ship unballasting, within the range of 200 nautical miles from the Brazilian coastline, in exceptional risk situations when the international norm of ship unballasting outside of the 200 nautical miles range cannot be followed.

This work has also demonstrated that an integrated management of both the coastal and marine zones, with regard to the challenge of ship unballasting, requires a coordinated, interdisciplinary effort, with the participation of sanitation, maritime, port, and environmental authorities, including environmentalists and NCU managers. Such a joint effort should result in a great accomplishment for the protection of the environment, while taking into account the operational expenses of the vessels, in order to avoid a negative economic impact on loading and unloading operations.

Since the focus of this study has been on the Todos os Santos bay, the results apply locally and constitute the main source of data for both Agência Nacional de Vigilância Sanitária (Anvisa — National Sanitary Vigilance Agency) and the local port authority. Nevertheless, since the methodology can be extended to other port regions, it is hoped that it will serve as a starting point for a qualified and effective dialogue with Anvisa in order to prove that, besides the procedures adopted by the countries which have progressed in this area of environmental awareness, new contributions arising from the fundamentals of geoprocessing can be applied not only in the state of Bahia, but in other Brazilian ports as well. Further, the modelling procedure based on GIS, described in this study, can be continuously refined by the addition of new map layers or parameters, giving more accurate locations, reinforcing the directions described in the Guidelines on designation of areas for ballast water exchange (G14), adopted by IMO on 13 October 2006.

It is now recommended that experimental field studies be conducted, in order to confirm the velocity of tide movements and the consequent transport of contaminants, as well as dispersion and dilution effects. These studies can contribute to the refining of the adopted model, to more accurately delineate the classification of the areas recommended in this study for ship unballasting. In addition, it is recommended to promote strategies for informing the social actors involved, so that the data about the location of the areas recommended for ship unballasting can be fully understood and assimilated. A wide but specific environmental education program shall be developed for all the social actors involved, complementary to the adoption of this kind of recommendation. This environmental education program can include themes about sustainability, individual and collective responsibility an ethics, besides the technical aspects of the ship unballasting and the prevention and minimization of the risks to the

environment, human health, property and resources arising from the transfer of Harmful Aquatic Organisms and Pathogens. It can also be recommended a special emphasis onto the vessels commanders, because of the Brazilian experience with informations received about the ballast water exchange performed by vessels. This information is based on an exploratory study intended to identify pathogenic agents in ballast water (General Management of Ports, Airports and Borders Project – GGPAF 2002, Brazil) carried out by the Agência Nacional de Vigilância Sanitária (Anvisa — National Sanitary Vigilance Agency) in 2002, involving nine Brazilian ports and a sample of 99 vessels of several nationalities with maritime transit in national and international ports. This study found that 62% of the vessels whose commanders declared to have performed ballast water exchange in oceanic waters probably did not actually do so, or did it only partially, which means an environmental risk (Anvisa 2003). This conclusion was reached based on the adoption of salinity measurements, which indicated that the salinity found in the ballast water of those ships did not correspond to the levels which were to be expected in oceanic waters. According to Anvisa, the salinity levels, which were less than 35%, pointed to the probability that there was a substitution of the ballast water near the coast, or near river estuaries, which results in a reduction of salinity because of the addition of fresh water. This means they can be aware of the recommendations to perform the replacement of ballast water in oceanic waters or even to perform the ballast water exchange in areas recommended for ship unballasting in emergency situations.

Finally, the identification of possible unballasting areas near the coastline does not preclude the recommendation that, ideally, this procedure should be performed more than 200 nautical miles away from the coast, following the international guideline; nor should it hinder the search for alternative procedures, such as the installation of receptors of residuals like oil, ballast water, and other contaminants at the terminals, or the development of technologies for the decontamination of ballast tanks, ensuring both efficiency and safety, especially for the environment.

Cautionary Notes. It is important to say that the present Brazilian governmental management capability is limited by the lack of disposal data and communication due to the state organization based on federalism and the divisions on civil and military (in this case, navy force) data access, and this had reflections on the profoundity of this study: there were several difficulties to get hands on data, specially maps of water circulation and ships's movement routes. The land use map and the nature conservation unit map (both scaled at 1:250,000) were provided by the Center for Environmental Resources of the State of Bahia (Centro de Recursos Ambientais — CRA).

According to this structure, it was determined the areas of exclusion, that is, those considered to be risk areas, where ship unballasting would be neither recommended nor permitted. The criteria used to define the areas of exclusion were based on the potential risks to the environment or to public health resulting from the unballasting. It also could be previously cut out those area where ships cannot circulate by shallow waters where the navigation did not occur. In the present case study, because of the bay format, this previous exclusion was not done and this would not affect the final result, which is to match areas with minimum risks where ballast water exchange could be occur, differently of those area where ships presently discharges ballast water under normal conditions without any environmental concern. Any way, reviewing the methodological procedure, it can be said that in theory, this previous exclusion should be done at first.

Finally, a fuzzy logic approach could be applied as an improved assessment to this study and can be a strong suggest for further studies with this same goal, as can be seen in Peche and Rodríguez (2009).

Acknowledgements

References

Anvisa. 2003. Projetos GGPAF-2002 (ANVISA. Projects – GGPAF 2002). Brasília, Anvisa, 10 p. (also available at <http://www.anvisa.gov.br/divulga/public/index.htm>).

Aronoff, S. 1991. Geographic Information System: A Management Perspective. Otawa, WDL Publ.

CRA. Modelamento e Avaliação Ambiental. **Relatório de estudos básicos**. Salvador, BA. março/2001. 263 p.

Elliot, M. 2003. Biological Pollutants and Biological Pollution – An Increasing Cause for Concern. *Marine Pollution Bulletin*, Hull, UK. vol. 46,

p. 275-280.

Goldberg, E. D. 1995. Emerging Problems in the Coastal Zone for the Twenty-first Century. *Marine Pollution Bulletin*. California, USA, v. 31, n. 4-12, p. 152-158.

Hayes, K. R. & Sliwa, C. 2003. Identifying Potential Marine Pests – A Deductive Approach Applied to Australia. *Marine Pollution Bulletin*, Australia, v. 46, p. 91-98.

Malczewski, J. 1999. GIS and Multicriteria Decision Analysis. John Wiley & Sons, Inc. pp392.

Pavlovskaya, M. 2006. Theorizing with GIS: a tool for critical geographies? Environment and Planning A, 38:2003-2020.

Peche, R.; Rodríguez, E. 2009. Environmental impact assessment procedure: a new approach based on fuzzy logic. Environmental Impact Assessment Review, 29: 275-283.

Pollard, D. A. & Hutchings, P. A. 1990. A Review of Exotic Marine Organisms Introduced to the Australian Region. II Invertebrates and Algae. *Asian Fisheries Science*, Australia, vol. 3, p. 223-250.

Thresher, R. E. 1999. Diversity, Impact and Option for Managing Introduced Marine Species in Australian Water. *Australia's Journal of Environmental Management*, Australia, v. 6, p. 137-148.

Tomlison, R. & Boyle, R. 1971. The State of Development of Systems of Handling Natural Resources Inventory Data. Reprinted from *Cartographica*, v. 18, n. 4, p. 65-95.

Wood, L. J. & Dragicevic, S. 2007. GIS-based multicriteria evaluation and fuzzy sets to priority sites for marine protection. Biodiv. Conserv. 16:2539-2558.