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ENVIRONMENTAL IMPACTS SYSTEMATIC ANALYSIS OF PORTS DISPOSED DREDGED SEDIMENTS TECHNIQUES

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ABSTRACT: The selection of sites for disposal of dredged sediments from port areas requires careful consideration. These sites used for disposal undergo several physical-chemical changes, which lead to further disturbances in the marine ecosystem, including biological processes, water quality and social activities. There is a growing concern on the impact of dredging on social and biological systems, however data about its impacts are scattered and not systematically organized. This review evaluated the socioenvironmental impacts caused by ocean disposal (ODP) and contained aquatic disposition (CAD) techniques using the Santos estuary channel (Baixada Santista, Brazil) as example. Data was collected through a systematic bibliographic and documentary review, searching for specific terms related to the Port of Santos and using the main academic databases available. Impacts identified in the review were analyzed qualitatively by their Magnitude and Importance attributes. Impacts were then assessed by degree of significance (i.e. very significant, significant and insignificant), based on the magnitude and importance classification. Data compiled through the systematic literature review were validated using a degree of significance matrix adapted from Leopold matrix. Findings suggested that the level of contamination of the sediments is the major criteria for the selection of the disposal methods. CAD technique showed more significant impacts due to the high load of contaminants associated with sediments that directly interfere in the quality of the physical-chemical parameters of the disposal site.ODP seemed to affect mostly fishing activity, while CAD has impaired the quality of life of residents around the estuary, interference in fishing activity and in protected areas. Overall, we conclude that the CAD technique presents more significant socioeconomic and environmental impacts for coastal environments. Our findings also highlight the importance of studies about environmental impact assessments for the elaboration of dredging plans in guiding decision making and future actions.

Keywords: Dredging disposal techniques; Port of Santos; Socioenvironmental impacts; Environmental impact assessment matrix.

RESUMO: *A seleção de locais para disposição de sedimentos dragados de áreas portuárias requer consideração cuidadosa. Estes locais de disposição sofrem diversas alterações físico-químicas, que levam a perturbações no ecossistema marinho, incluindo processos biológicos, qualidade da água e atividades sociais. É crescente a preocupação com o impacto da dragagem nos sistemas sociais e biológicos, porém os dados sobre seus impactos são dispersos e não estão sistematicamente organizados. Esta revisão tem como objetivo avaliar os impactos socioambientais causados por técnicas de disposição oceânica (PDO) e disposição aquática contida (CAD) utilizando o canal do estuário de Santos (Baixada Santista, Brasil). Os dados foram coletados por meio de revisão bibliográfica e documental sistemática, com busca de termos específicos relacionados ao Porto de Santos e nas principais bases de dados acadêmicas disponíveis. Os impactos identificados na revisão foram analisados qualitativamente por seus atributos de Magnitude e Importância. Os impactos foram avaliados pelo grau de significância (ou seja, muito significativo, significativo e insignificante), com base na magnitude e classificação de importância. Os dados compilados por meio da revisão sistemática da literatura foram validados usando uma matriz de grau de significância adaptada da matriz de Leopold. Os resultados sugerem que o nível de contaminação dos sedimentos é o principal critério para a seleção dos métodos de disposição. A técnica CAD apresentou impactos mais significativos devido à alta carga de contaminantes associados aos sedimentos, prejudicando a qualidade de vida dos residentes ao redor do estuário, a atividade pesqueira e áreas protegidas, enquanto a ODP pareceu afetar principalmente a atividade pesqueira. De maneira geral, concluímos que a técnica CAD apresenta impactos socioeconômicos mais significativos para os ambientes costeiros. Nossos achados também destacam a importância de estudos sobre avaliações de impacto ambiental para a elaboração de planos de dragagem no direcionamento da tomada de decisões e ações futuras.*

Palavras-chave: *Técnicas de disposição de dragagem; Porto de Santos; Impactos socioambientais; Matriz de avaliação de impactos ambientais.*

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1. INTRODUCTION

Dredging activity in coastal waters, mainly in harbors and channels, produces huge quantities of sediments to be disposed. Thereby, the management of such sediments is of great concern worldwide. Dredging corresponds to the process of removal, transport and final disposal of sediment present in the navigation channels, being essential for the maintenance of waterway transport routes (Torres *et al*., 2009; Wasim and Nine, 2017; Méar *et al*., 2018). The global growth of this industry strengthened by 3.8% in 2017, driven mainly by emerging markets and economies (IADC, 2018).

Although dredging promotes economic advantages, like reduction of freight and logistics costs in the country, which generates more competitive prices in global transport, the disposal of dredged sediments is one of the most relevant problems in coastal zone management (Bolam and Rees, 2003; Cesar *et al*., 2014; Simonini *et al*., 2005). This is because in most of the world's dredged sediments have different degrees of contamination (Alvarez-Guerra *et al*., 2007).

In Brazil, contamination in sediments is regulated by the National Council of Environment (CONAMA) Resolution nº. 454/12 which stablishes two major levels of contamination. Level 1 sediments present a low probability of causing adverse effects to biota, thereby can be released into the waters under national jurisdiction.

For sediments with a contamination level above the threshold that are more likely to have adverse effects on biota, classified as Level 2, studies of controlled disposal alternatives are necessary. In this sense, this category requires specific plans that aim to minimize impacts in the disposal area (Frohlich *et al*., 2015). In the Port of Santos, the current dumping procedures for sediments classified as Level 1 are carried out in the open sea, and in a confined area for those with greater contamination (i.e., Level 2) (Frohlich *et al*., 2015).

The management of sediments has received significant attention in recent years (Andrade *et al*., 2018; Oen *et al*., 2017; Zheng *et al*., 2019), mainly focused on impacts that affect the local biotic environment (e.g. differences in the abundance and composition of local communities, interference in pelagic communities, due to increased concentration of suspended sediments, or by burial, in the case of benthic and demersal) (Silva Junior *et al*., 2012; Bolam *et al*., 2006; Bolam and Rees, 2003; Hostin *et al*., 2007; Oen *et al*., 2017).

Specifically, in the Port of Santos, current dumping procedures take place in the open sea (hereafter called the Oceanic Disposition Polygon (ODP)), and in a confined area (hereafter named underwater pit) (CPEA, 2004; Frohlich *et al*., 2015).

Thus, considering that both techniques for disposal of the dredged material pose a threat to the functioning of the marine ecological system, in this review we propose a novelty of systematic impact assessment, which assist in decision making and handling dredged material. For this, we present a systematic analysis of the environmental impacts caused by different techniques for the disposal of dredged sediments from the port activity, taking the Port of Santos as an example.

2. METHOD

2.1 Study Area

The Santos estuarine system is located at the Baixada Santista Metropolitan Region, southeast coastal of São Paulo, Brazil, and is characterized by relatively complex hydrodynamics and receives sediments from the watershed water surrounding the cities Santos, São Vicente, Cubatão, Guarujá and Praia Grande that integrate this region (Torres *et al*., 2009). Its estuary hosts the Port of Santos, internationally recognized as the largest port in Latin America and responsible for 25% of the Brazilian trade balance (Pion & Bernardino, 2018). According to the port authority, the dredging and management activities at the Port of Santos can generate approximately 4.5×10^6 m^3 of sediment per operation (Sousa *et al*., 2007). This dredged material is currently disposed in allocated open sea areas, more specifically in an Oceanic Disposition Polygon (ODP). Sediments are also disposed in a second area, an underwater pit (CAD), located at Largo do Casqueiro, estuary between Santos and Cubatão (Figure 1).

Permanent dredging carried out in the Santos estuary is necessary to maintain the depth of the channel, which allows to meet demands for access and navigability of its public (i.e. located in the so-called Canal of the Port of Santos) and private terminals (i.e. located in the so-called Canal Piaçaguera), contributing to the maintenance of port activity and the country's economic dynamics (Pion & Bernardino, 2018; Buruaem *et al*., 2013). The disposal in the ODP has been in place since 1996 and until 2007 it had eliminated an average of $2{,}641 \times 10^3$ m^3 of sediments, while the installation license for the underwater pit occurred in 2016 with a capacity of 1,560,000 m^3 (FRF, 2008; Santos *et al*., 2017). During the first five months of 2020, there

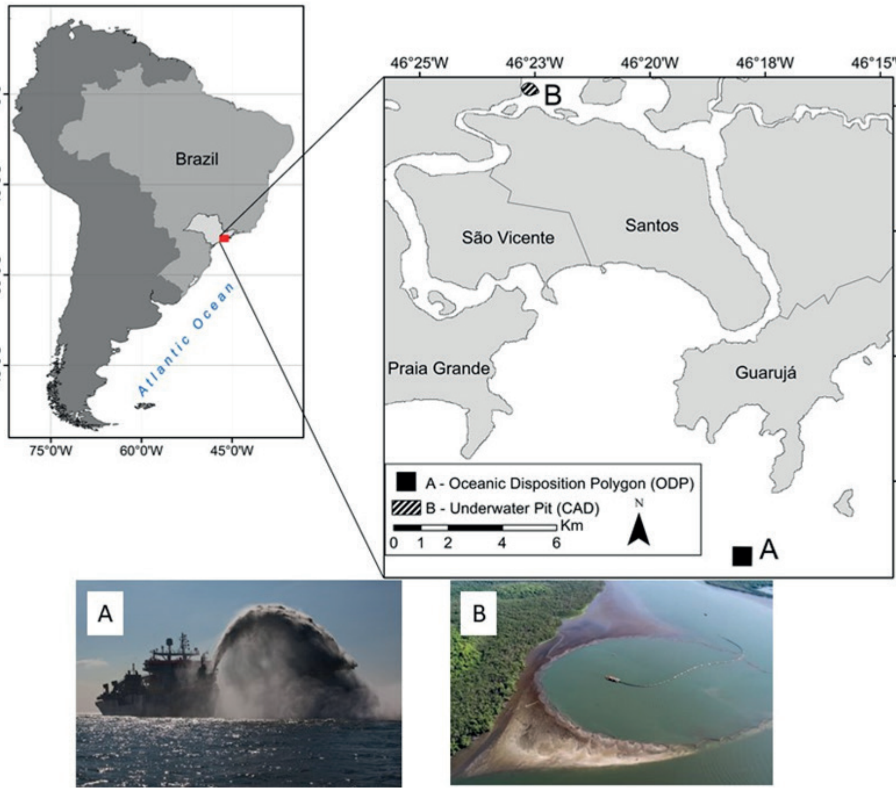

Figura 1. Location of Santos estuary and Port of Santos and its dredging disposal areas: A-Oceanic Disposition Polygon (ODP) and B-underwater pit (CAD).

were 1,996 moorings, a level 1.9% higher than that registered in 2019 (i.e. 1,958 moorings). Excluding passenger and Navy ships, 1,921 moorings were recorded in this period, of which 1,643 were from long-haul vessels (i.e. an increase of 3.8% compared to 2019) and 278 coastal vessels (i.e. a decrease of 4.1%) (Porto de Santos, 2020).

2.2 Systematic review

A systematic review was performed based on the identification and analysis of publications from 2000 to 2020, in the databases SciELO, Periódicos Capes, Google Scholar, Web of Science e Scopus, under the theme "*Environmental impacts of the disposal of the dredged material*".

In addition to peer-reviewed scientific literature, sources of "grey" literature information as local environmental impact assessments and technical reports obtained by Google search were included. In the search, the following key terms were used: *dredged material; environmental impacts of dredged material; management of dredged sediments; dredging planning e environmental monitoring of dredging; dredging operations; dredging disposal site; dredging of contaminated sediments; confined aquatic disposal; dredged material disposal e dredged material from the Port of Santos*. In total, we found 52 scientific articles and 8 documents, such as environmental impact studies/executive report (EIA/RIMA), technical reports opinions and legislation.

We extracted information from the impacts related to the disposal of dredge sediments cited in the literature and then analyzed them according to the level of magnitude and importance as described in Table 1. In this case, the attributes of magnitude and importance of each impact were classified on a scale varying from 1 (weak/low), 2 (medium) to 3 (strong/high) regarding to its environmental change condition.

2.3 Significance assessment of impacts

Data compiled through the systematic literature review were validated using a degree of significance matrix adapted from Leopold Matrix (1971). Several adaptations of the Leopold Matrix have already been adopted for the evaluation the interactions between environmental components and actions that change the environment, such as: comparison of the feasibility of waste management options; mining; air quality assessment.

In addition other studies considering the environmental components that would be affected (Mavroulidou *et al*., 2007; Sousa *et al*., 2011; Mirsanjari *et al*., 2013; Sajjadi *et al*., 2017; Izadi *et al*., 2019; Valizadeh and Hakimian, 2019) were also considered.

The degree of significance of the environmental impacts was assessed from the interrelationships between the magnitude and importance of the impact in relation to the ecosystem or affected social environment. The magnitude considers the force with which the impact is manifested, whereas the importance is related to the intensity of the effect of the impact on the environment (Moreira, 1985).

Thus, an impact of strong magnitude coinciding with one of high importance presents itself as a Very Significant impact, that is, with a Large Degree of Significance, and were represented in red. The crossing between strong magnitude and low importance, or weak magnitude and high importance, indicates a Significant Impact, that is, with an Medium Degree of Significance, and were indicated in yellow. Finally, impacts of Weak magnitude focusing on factors of Low or Medium importance are Less Significant Impacts, or with a Small Degree of Significance, and were characterized in green.

High significant impacts were considered most relevant for the study, as they present high levels of magnitude and importance, and have more severe effects on the environment, being fundamental to identify the most harmful disposal technique.

3. RESULTS

3.1 Oceanic Disposition

Disposal of dredged material in open water is the most common and widely used method in Brazil, as it has the lowest cost among other disposal options (Donázar-Aramendía *et al*., 2018; Manap and Voulvoulis, 2015). This practice is applied to the disposal of clean sediments or with a lower degree of contamination dredged from the Port of Santos channel (Frohlich *et al*., 2015).

There are few restrictions for this method regarding the choice of the disposal site, and a comprehensive survey of the economic viability of the activity is essential; operational safety and the presence of environmentally sensitive or protected areas in and around the region (Frohlich *et al*., 2015).

Table 1. Attributes used for the characterization of the main impacts related to disposal of dredged material in the Port of Santos/SP. Valuation scores vary according to the environmental change imposed by the impact.

Attributes	Definition	Symbology
Magnitude	Considers the severity, size or extent of an impact, following a nominal scale of strong, medium and weak.	Weak - ○ Medium - ◐ Strong - ●
Importance	Relates the intensity of the effect corresponding to the environmental factor, and was classified into high, medium or low.	Low (↓) Medium (↔) High (↑)

3.1.1 Impacts on the physical environment

- *Hydrodynamic and bathymetry*

Continuous disposal of sediments combined with usual alterations caused by dredging operation, such as changes in depth and width of water bodies, causes bathymetric changes in the ODP (Quiala *et al*., 2015). It is an impact of medium magnitude and high importance causing changes in current flows, and in the patterns of penetration of the saline wedge into the estuary (Gupta *et al*., 2005).

Changes in hydrodynamic regime result from bathymetric changes, which influence water courses and tidal plains (FRF, 2008). This impact is classified as of weak magnitude and high importance as it promotes changes in the patterns of currents and tides in the port´s channel, in addition to influencing processes of erosion, silting and modification of the sediment supply.

- *Sediment quality and dispersion*

Disposal of dredged material results in changes in the physic-chemical quality of the bottom sediment in the disposal area (Marmin *et al*., 2014, 2016). This impact has medium levels of magnitude and importance with the main environment impacts as follow: the breakdown and resuspension of the sediment, changes in the bathymetric elevation and the texture and granulometry of the seabed of that location (Chen *et al*., 2018).

The dispersion of the sediments corresponds to an impact of medium magnitude and high importance and is caused due to its disintegration. If these sediments have associated contaminants, disintegration can make them bioavailable, causing serious ecological impacts, affecting or causing great mortality of marine species (Bach *et al*., 2017; Su *et al*., 2002; Sousa *et al*., 2007).

The resuspension of sediments is shown to be an impact of medium magnitude and high importance, given the occurrence of this impact in all phases of the dredging process, from the withdrawal to the transfer of the dredged sediment to the dumping sites (FRF, 2008).

The rate of resuspension of sediments is related to the property of the sediments (density, granulometry and mineralogy) and the conditions of the site (water depth and hydrodynamics of the disposal area) (Bridges *et al*., 2010; Bach *et al*., 2017).

· *Water quality*

Alterations in water quality occurs from the resuspension and aeration of sediment in addition to the reduction of pH and alteration of metals such as mercury (Hg), lead (Pb), cadmium (Cd), and other pollutants such as Polycyclic Aromatic Hydrocarbons (PAHs), aliphatic hydrocarbons and chlorinated hydrocarbons, associated with these sediments (Méar *et al*., 2018; Sousa *et al*., 2007).

The intense alteration in the essential quality parameters of the ecosystem characterizes this impact as of strong magnitude and high importance (Goes Filho, 2004; Torres *et al*., 2009).

The increase in the turbidity of the water column is of medium magnitude and importance, since the predominantly sandy material tends to be deposited quickly, in a few minutes, around the disposal point.

However, longer periods of suspension of fine sediments in the water column lead to the formation of a turbidity plume in the disposal area, extending the impact of disposal to larger areas (Wasim and Nine, 2017; Todd *et al*., 2015).

High levels of turbidity cause a reduction in dissolved oxygen, due to the aerobic decomposition of suspended organic compounds, which causes greater consumption, in addition to affecting the penetration of light into the water column in water, threatening photosynthetic organisms (Manap and Voulvoulis, 2016).

3.1.2 Impacts on the biotic environment

Contaminants such as aliphatic, polyaromatic hydrocarbons (PAHs) and metals, if associated with sediments, are bioavailable when in suspension in the water column (Méar *et al*., 2018). Thus, such components are incorporated and accumulated by organisms, directly from the dissolved phase and by the ingested food particles, causing the bioaccumulation of these contaminants in the tissues and gonads (Bach *et al*., 2017; Sousa *et al*., 2007).

The chemical impacts from bioaccumulation have a strong magnitude and high importance, as they can be more harmful to biota by contamination of the food chain, depending on how much contaminants can be absorbed by aquatic organisms (DelValls *et al*., 2004).

Locations often disturbed by sediment disposal often fail to find ecological balance (Bemvenuti *et al*., 2005). Species different from those found initially recolonize the area, with opportunists being the first to have a rapid occupation of disturbed areas (Hostin *et al*., 2007; Vivan *et al*., 2009).

Thus, the impact has a strong magnitude and high importance, given that the change in the fauna composition, with the decrease in the number of individuals and the biomass as a function of time, is a factor that indicates the environmental stress caused by the constant deposition of the dredged material (Bolam and Rees, 2003; Hostin *et al*., 2007; Silva Junior *et al*., 2012).

· *Demersal communities*

The effects on demersal communities are variable, however, it is known that there is a difference in their abundance and composition after disposal activities. Thus, this impact has a low magnitude and high importance because the effects of the disposition reflect on the spawning, reproduction, feeding and growth of different groups of organisms, as in fish that live most of the time in association with the substrate (Silva Junior *et al*., 2012).

· *Pelagic communities*

The disposal operations have a direct impact on the composition of fish communities, leading to loss of species, deformities and bioaccumulation of contaminants, in addition to promoting the loss of micro-habitats capable of providing food and shelter (Wenger *et al*., 2018).

These factors characterize the impact with weak magnitude and high importance, as they lead to a decrease in the diversity of fish, especially rare species, and the community becomes dominated by the most abundant individuals, or because certain species start to reproduce more intense than usual (Freitas *et al*., 2009; Silva Junior *et al*., 2012).

The impact on pelagic organisms is of weak magnitude and medium importance. Photosynthetic organisms are mainly affected by the obstruction of light entry due to the resuspension of sediments with a reduction in primary production (Bridges *et al*., 2010).

Resuspension also causes other adverse effects for pelagic biota, due to direct toxicity through contact with suspended contaminated sediments, in addition to inhibiting the migration patterns of organisms such as fish and cetaceans, as they find a liquid environment totally modified by the sediment.

Plankton organisms suffer due to increased turbidity and consequent reduction in the incidence of light, which may cause a decrease in photosynthetic activities, indirectly affecting species of economic interest for fishing (Bolam *et al*., 2011). It is an impact of weak magnitude and medium importance, as primary production rates and the dispersion of planktonic biomass are directly affected.

- *Benthic communities*

The disposition in open water bodies tends to be more impacting for the benthic fauna, that is, the invertebrates with less or no mobility, that live buried or fixed on the surface of the sediment (Bolam *et al*., 2006; Bolam and Rees, 2003; Regoli *et al*., 2002). It presents a strong magnitude and high importance, since the disposal of dredged material causes a change in the physical structure of the sediment, together with the suffocation of the organisms, resulting in changes in the taxonomic composition, and in the patterns of dominance and distribution of the benthic assemblies, by reducing the number of species (Hostin *et al*., 2007; Regoli *et al*., 2002; Bemvenuti *et al*., 2005).

3.1.3 Impacts on the socioeconomic environment

Fishing is an important economic activity developed in the Santos estuary, for both commercial and subsistence purposes, to which part of the local community is dependent. Thus, the interference in fishing activity is considered to be of weak magnitude and of high importance, since many species can migrate to areas that were not affected by the change in water quality. Thus, artisanal fishermen are harmed, since the fishing areas are considerably smaller compared to the areas of operation of vessels with greater autonomy (Parizotti *et al*., 2015; FRF, 2008).

3.2 Contained Aquatic Disposal

Contained Aquatic Disposal (CAD) corresponds to the underwater confinement of contaminated sediments (CPEA, 2004). The costs of building and operating a CAD are generally 2 to 3 times higher than the oceanic layout due to the limitations of management and the monitoring that should be constant. However, it is still within the lower range of alternative costs for the management of contaminated sediments (Oen *et al*., 2017; Fredette, 2006).

In Brazil, the alternative of underwater disposal of dredging tailings is still poorly implemented, with the cases of Port of Santos in São Paulo and Port of Sepetiba in Rio de Janeiro being more discussed today (CPEA, 2004).

3.2.1 Impacts on the physical environment

- *Hydrodynamic and bathymetry*

The underwater pit in the Santos estuary channel causes changes in the morphology and characteristics of the estuary, especially in terms of the course of estuarine waters (Wasim & Nine, 2017). It presents a strong magnitude and high importance, representing a diversion of the watercourse and, consequently, of all nutrients, propagules and plant seeds that the estuary carries (CPEA, 2004).

Hydrodynamic changes have effects proportional to the location and size of the pit. However, they have medium magnitude and high importance, as they can lead to the establishment of erosion and silting processes in adjacent submerged areas, and also increase the risk of flooding upstream of the estuary and interfere in mangrove areas (CPEA, 2004; Santos *et al*., 2017).

- *Water quality*

The release of contaminants present in sediments disposed in CAD can cause changes in the chemical forms of some metals, increasing their bioavailability (Chen *et al*., 2009; Wasserman *et al*., 2016; Méar *et al*., 2018).

Such impact has a strong magnitude and high importance, seen by the sensitivity of the estuarine environment, since contaminants can dissipate in the water column and be transported by sediment to surface waters (Bridges *et al*., 2010; Wasim *et al*., 2017; Manap and Voulvoulis, 2015).

The level of contamination associated with the sediment will reflect on the change in water quality. It can occur through the release of contaminant into surface water, through the discharge of effluents, through runoff, and also through infiltration and leaching, it is an impact of medium magnitude and high importance (Goes Filho, 2004; Bridges *et al*., 2008). Resuspension of sediments implies changes in the chemical parameters and the quality of the water column, mainly due to the release of contaminants, causing this impact to present medium magnitude and medium importance (Roberts, 2012). Since in suspension, the action of currents can increase the dispersion of contaminants and cause ecotoxicological effects beyond the area originally affected (Bach *et al*., 2017).

3.2.2 Impacts on the biotic environment

Contaminants released in the estuary affect organisms by different routes, such as direct contact with sediment, or contact with sediments suspended in the water column, incorporating them as part of food, leading to bioaccumulation and trophic transfer within a chain to feed (DelValls *et al*., 2004; Buruaem *et al*., 2013). It has a strong magnitude and high importance, as many compounds can be absorbed by mucous membranes and biological membranes, so their concentration becomes much higher in organisms than in water itself, reaching harmful levels for consumers at the top of the chain, including man (Wasserman *et al*., 2016; Goes Filho, 2004).

- *Pelagic communities*

The interference in the ichthyological community already occurs due to the great movement of vessels in the Port of Santos, however, due to the activity of dredgers and equipment, there is a spacing of fish in the areas close to the disposal site.

The impact has weak magnitude and high importance, since the Santos estuary is still an area where fishing is practiced together with port activity, being an indication that this distance, although it occurs, does not significantly decrease the density of fish who reside there (Parizotti *et al*., 2015).

Pelagic organisms suffer from the increased amount of particulate matter in suspension, in addition to direct exposure to contaminants released from CAD (CPEA, 2004). In addition, photosynthetic organisms, such as planktonic microalgae, show reduced photosynthesis due to light obstruction caused by the turbidity of suspended particulate matter (Bridges *et al*., 2010; Da Silva and Gomes, 2015). Thus, this impact has little significance, with weak magnitude and low importance.

- *Benthic communities*

Benthic communities are adversely affected by physical disorders such as burial and suffocation at the time of disposal (Chen *et al*., 2018). This impact presents itself with a medium magnitude and high importance. However, the benthic communities in the dredged areas and in the vicinity are little diverse and numerous, since the dredging practices and local contamination history seem to contribute to the structure of the communities in the Port of Santos (Buruaem *et al*., 2013).

3.2.3 Impact on the socioeconomic environment

The change in water quality caused by the disposition of dredging increases the degradation of the estuary, resulting in areas of exclusion or restrictions on fishing activity (Silva Junior *et al*., 2012).

It is an impact of medium magnitude and high importance, since the effects of dredging and the disposal of sediments cause the decrease and/or disappearance of some species of fish, negatively affecting the fishing and living conditions of the fishermen who depend this source of income, which results in a change in the cultural habits of artisanal fishing in the region (Wasserman *et al*., 2016; Wenger *et al*., 2018; CPEA, 2004).

The effects caused in the Santos estuary by the construction and activity of the CAD reflect on the quality of life for the fishing community in the vicinity. The disposal activity in CAD affects the community "Vila dos Pescadores", in Cubatão (São Paulo), with an impact of strong magnitude and high importance (CPEA, 2004). The layout in the pit results in numerous implications for the environment and health of these residents.

In addition to making it impossible for these fishermen to practice their activities with higher quality and to acquire their main source of income.

Fishermen also suffer direct exposure to contaminants, mainly due to the consumption of fish from this degraded environment, since riverside communities have these subsistence as the basis for their food (Santos and Sartor, 2019).

According to Article 4 of Federal Law nº. 12.651/2012, it is defined that mangroves and estuaries are classified as Permanent Protection Areas (APP).

Thus, this legal instrument is applied in the CAD locality, demonstrating that the choice of the region for the construction of the underwater pit, no longer considers the legislation, being considered an impact of interference in the preservation area, with strong magnitude and high importance (Santos and Sartor, 2019; Quiala *et al*., 2015).

3.3 Assessment of the Degree of Significance

As previously presented in the methods used, in subtopic "2.3 Significance assessment of impacts", the degree of significance of the impacts of the oceanic and confined disposal techniques was assessed based on the relationship between their magnitude and importance, obtaining the results presented in Table 2 and 3, the follow.

Assessing the significance degree of the impacts of the ocean disposal technique (Table 1), the result obtained and presented in Table 2 shows that the largest number of impacts was corresponding to Very Significant Impacts, totaling 7 impacts.

Four of the impacts were in the category with levels of magnitude and importance Strong/High. The other 3 impacts are in the category with levels of magnitude and importance being Medium/High. Six significant impacts were accounted, 2 with levels of magnitude and importance Medium/Medium. And 4 significant impacts with levels of magnitude and importance

Weak/High. The less significant impacts were 2, in the category of magnitude and importance Weak/Medium. Regarding the degree of significance of the impacts for the confined disposal (Table 3), 9 impacts of Very Significant category were observed, being 5 of levels of magnitude and importance Strong/High. Another 3 impacts also Very Significant with levels of magnitude and importance as Medium/High.

Two impacts were considered to be significant. With level of magnitude and importance Weak/High. And in the Medium/Medium category, only the impact of resuspension of sediments was observed. And one less significant impact was identified with Weak magnitude and High importance.

Thus, from the interrelationships, it is possible to affirm that the oceanic and confined dispositions presented the same number of very significant impacts for the physical environment.

However, the underwater confined arrangement showed a greater number of very significant impacts in relation to the ocean in the biotic environment, with the impacts of bioaccumulation, interference in the benthic, ichthyological and pelagic communities.

And also, in the socioeconomic environment, with the impacts of interference in the fishing activity; loss of quality of life for residents of Vila dos Pescadores; interference on protected areas.

4. DISCUSSION

The adaptation of the Leopold Matrix proved to be a meaningful approach for this study, since it allows a simple evaluation and clarity in the presentation of the results obtained, as well as the use of essentially qualitative data in its elaboration.

The matrix has a relevant basis to make data on environmental impact of dredged material disposal from the Port of Santos more interpretable, serving as a material that can support the decision-making analysis into most sustainable management actions. The importance of this method has already been highlighted, as it is used to associate the impacts of a given activity with the various environmental characteristics of its area of influence.

From the analysis of the matrices it was possible to observe that the main difference between disposal methods is the level of sediment contamination that characterizes the dredged

Table 2. Degree of significance of the impacts of the oceanic disposition. Strong magnitude impacts are evidenced by the full circle - ● - a medium magnitude impact is represented by a circle semi-full - ◐ - the weak one is represented by an empty circle - ○ -. The arrows indicate whether the impact is high (↑), medium (↔), or low (↓). Impacts considered to be very significant are represented in red, impacts considered significant are represented in yellow, and impacts in green are the least significant.

Impacts Oceanic Disposition		Magnitude	Importance	Significance
physical	Hydrodynamic changes	◐	↑	red
	Bathymetric changes	○	↑	yellow
	Changes in the quality of the bottom sediment	◐	↔	yellow
	Dispersion of sediments	◐	↑	red
	Resuspension of sediments	◐	↑	red
	Change in the quality of the water column	●	↑	red
	Increase in the turbidity of the water column	◐	↔	yellow
biotic	Bioaccumulation	●	↑	red
	Changes in the fauna composition	●	↑	red
	Interference in the demersal communities	○	↑	yellow
	Interference in the ichthyological communities	○	↑	yellow
	Interference in pelagic organisms	○	↔	green
	Interference in plankton organisms	○	↔	green
	Interference in benthic communities	●	↑	red
sc.	Interference in fishing activity	○	↑	yellow

material classes, associating each one with the appropriate management option (Alvarez-Guerra *et al*., 2007). Although sediments designed for ocean disposal have a lower content of contaminants, when relocated to the ODP they directly affect the environment, altering bathymetry, speeds and flows of the currents and the quality of the water column by the load of contaminants and sediments in suspension. The impacts in CAD are more related to the potential effects of contaminants on the environment, since they exhibit high concentrations of nutrients, heavy metals, polychlorinated biphenyls (PCBs), aliphatic and aromatic hydrocarbons (PAHs), in concentrations far above of the values established in CONAMA Resolution nº. 454/12 (Buruaem *et al*., 2013). Thus, as shown, the confined disposal presented a higher number of very significant impacts on the biotic and socioeconomic environments. For both disposal techniques, the environmental impacts of the physical environment are related to the impacts of the biotic environment leading to ecological losses. The ecological effects of these impacts may be the result of an isolated disposal event, or its frequency, depending also on the natural environmental stress regime of the habitat (Bolam *et al*., 2006; Bolam and Rees, 2003; Roberts, 2012).

Overall, impacts identified in the biotic environment showed greater relevance to the effects of permanent changes in biological characteristics in the disposal environment, such as contaminants bioaccumulation and interference in local fauna communities. However, long-term studies on the bioaccumulation of persistent compounds are still insufficient, especially in the upper trophic species, considering that most studies have not yet measured the impacts that may occur in the food chain, considering greater temporality after the end of dredging (Su *et al*., 2002; Roberts, 2012).

Research is highly needed to better measure the impacts on the food chain that can occur long after the end of dredging events.

Interference in the benthic community is a recurring and very significant impact for both dispositions. Demersal and pelagic communities, including the ichthyological community, suffer less influence from the effects of the dredged material in relation to the benthic community as they can move due to the greater capacity of locomotion. Thereby, there is a loss of abundance and change in composition in all the mentioned communities (Bemvenuti *et al*., 2005).

Findings of this study suggest that impacts on the socioeconomic environment clearly highlight the differences in the intensity of socio-environmental effects between the two disposal techniques. The construction of the underwater pit in the Santos Estuary failed to meet and consider the state, federal and international legal apparatus related to the theme, focused on the conservation and sustainable use of estuarine, mangrove and wetland ecosystems (Santos *et al*., 2017; Santos and Sartor, 2019; Brasil, 2012; PNUD, 2019). The underwater pit imposes an environmental liability of toxic pollutants and

Table 3. Degree of significance of the impacts of contained aquatic disposal. Strong magnitude impacts are evidenced by the full circle -●- a medium magnitude impact is represented by a circle semi-full -◐- the weak one is represented by an empty circle -○-. The arrows indicate whether the impact is high (↑), medium (↔), or low (↓). Impacts considered to be very significant are represented in red, impacts considered significant are represented in yellow, and impacts in green are the least significant.

Impacts Contained Aquatic Disposal		Magnitude	Importance	Significance
physical	Hydrodynamic changes	◐	↑	red
	Changes in the morphology of the estuary	●	↑	red
	Release of contaminants	●	↑	red
	Change in water quality	◐	↑	red
	Resuspension of sediments	◐	↔	yellow
biotic	Bioaccumulation	●	↑	red
	Interference in ichthyological communities	○	↑	yellow
	Interference in pelagic communities	○	↓	green
	Interference in benthic communities	◐	↑	red
soc.	Restrictions on fishing activity	◐	↑	red
	Interference in traditional community	●	↑	red
	Interference in a preservation area	●	↑	red

risks associated with their rupture, with irreparable effects for the ecosystem, for estuarine species and for local communities (Santos *et al*., 2017; Santos and Sartor, 2019). Recently, the Commission for the Environment and Sustainable Development of the Chamber of Deputies of Santos approved in October 2019 the Law nº. 3285/2019 which prohibits the construction of new underwater pits in oceans, rivers, lakes, ponds, or estuaries in the city Santos. Although relevant by reducing future ecological risks, such approval does not resolve historical environmental passive caused by the installation and maintenance of an underwater pit in the estuary, granting the license for its development (Santos *et al*., 2017; Santos and Sartor, 2019). This is a highly controversial point.

There is a substantial need for harmonization of environmental agencies performance and competence about licensing processes for dredging activities in the Port of Santos. However, in the current national political context, the restrictions imposed by environmental licenses in infrastructure projects, as in the case of dredging, may suffer significant reductions in applicability as they are considered as obstacles to economic development (Abessa *et al*., 2019). In contrast, the sustainable management of dredged material is a priority in the legislative and political structural context of countries such as the United States and members of the European Union that foster integrated plans for the planning of port infrastructures, strengthening the concern with the environment, urban ordering and social impacts (Manap and Voulvoulis, 2014, 2015).

Findings of this study suggested that dredging and disposal of the dredged material implies modifications of extremely sensitive environmental components, causing substantial changes in the functioning of marine ecosystems. Although it is an activity with a totally economic bias, it is impossible to disassociate it with the environmental context in which the Port of Santos is inserted, advocating for sustainable port management. Thus, contaminated sediments from dredging operations must be treated with the use of sustainable technologies instead of dumping in confined disposal sites. Complementary studies are urgently needed to find more sustainable alternatives ways to dispose dredged sediments, particularly for those that have some level of contamination (Santos and Sartor, 2019).

It is imperative that decision makers have less detrimental alternatives for sediment management. Innovative research must be carried out with the focus of determining technologies that improve the performance of this activity, so that losses are increasingly mitigated, and dredged sediment is reused as a valuable and no harmful resource (Gustavson *et al*., 2008).

5. CONCLUSIONS

Dredging is an activity intricately linked to coastal environments since harbour and coastal waterways need periodic dredge for maintenance of navigable waterways to allow continuous traffic flow. Coastal disposal of maintenance dredged material constitutes one of the most important dilemmas in coastal zone management and in some coastal areas represents the major anthropogenic disturbance to socioenvironmental systems.

The elaboration of the degrees of significance allowed an analysis of the impacts by type of affected environment and integrates the main recurring failures in the disposal of the dredged material. Our review of the literature shows that contained aquatic disposal technique presented a higher number of impacts of great significance in the socioeconomic environment. This was pointed out not only by the high load of contaminants associated with dredged sediments, but also the locational alternative for its disposal, conflicting with the different uses of the Santos estuarine system.

Additionally, the selection of an underwater pit in harbour waters leaves an enormous environmental liability in a sensitive ecosystem as an inheritance highlighting the importance of studies to assess environmental impacts in the elaboration of dredging plans.

Port of Santos exemplifies a situation of how important is to have sound science and an integrated approach to dredging management in guiding decision makers actions. Sediments will continue to be dredged so that the largest port of Latin America remains an important transport hub for the country.

It is necessary that dredging projects implement evaluations of effectiveness for management strategies to mitigate the impacts of the disposal, through environmentally friendly and financially viable techniques. It is time to consider dredged sediments as important mineral resources and traded commodities to identify options for the reuse of contaminated materials, or with remnants of contaminants after treatment.

Nevertheless, alternatives should contemplate site-specific evaluations and the natural variability of local conditions. Detailed studies are recommended to in order to plan effective scenarios of dredged sediments management.

6. AUTHOR CONTRIBUTIONS

Lorena Rosa: Design of the work, development of the methodology, collection and analysis of data, writing of the manuscript, Débora

Martins de Freitas: Design of the work, review of data analysis, suggestions and supervision of the work, writing of the manuscript. Both authors contributed to the acquisition of funding, and writing (revision and editing) of the manuscript.

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