Marine Pollution Bulletin xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Potential oil spill risk from shipping and the implications for management in the Caribbean Sea

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Caribbean Sea
Oil pollution
Management framework
Potential oil spills risk (POSR) model

ABSTRACT

The semi enclosed Caribbean Sea is ranked as having one of the most intense maritime traffic in the world. These maritime activities have led to significant oil pollution. Simultaneously, this sea supports many critical habitats functioning as a Large Marine Ecosystem (LME). While the impacts of oil pollution are recognised, a number of management challenges remain. This study applies spatial modelling to identify critical areas potentially at risk from oil spills in the form of a potential oil spill risk (POSR) model. The model indicates that approximately 83% of the sea could be potentially impacted by oil spills due to shipping. The results from this study collectively support a management framework for minimising ship generated oil pollution in the Caribbean Sea. Among the recommended components are a common policy, surveillance and monitoring controls, standards, monitoring programmes, data collection and greater rates of convention ratifications.

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1. Introduction

Throughout history, maritime activities have been instrumental in promoting development and bridging civilisation, affording humanity a form of mobility whether for trade, transport or fishing among others. Into the twenty first century, these activities have evolved into a vibrant economic sector effectively linking economies worldwide and by way of maritime transport which accounts for over 90% of the global trade (IMO, 2012). Similarly regional and inter-regional shipping have also evolved especially in emerging economies growing at a significant rate. For example The Latin America and the Caribbean (LAC) region is classified as one of the fastest growing in terms of container trade (Sanchez and Ulloa, 2007). In some regions, shipping is critical to reliable supply of goods, for example in the Caribbean Small Island Developing State (SIDS), as much as 90–95% of all imported goods are transported through maritime shipping (Singh, 2008) and in the Eastern Caribbean region (OECS) as much as 96%.

Apart from the well-established economic benefits, shipping also brings tremendous environmental challenges such as pollution from ballast water, sewage, grey water, solid waste, noise, oil discharges and air emission (Singh and Mee, 2008; Singh, 2008; GESAMP, 2007). Ship related sources account for 51% of marine oil pollution in the marine environment with natural seepages commanding 49% (GESAMP, 2007). Studies have shown that oil pollution if not adequately managed, can have devastating effects, being harmful and potentially toxic to marine life. For example, the 1978 Amoco Cadiz incident resulted in the death of over 20,000 birds, millions of molluscs, sea urchins, benthic species, other shell and fin fisheries (Maritime Connectors, 2013). Oil with its inherent high concentration of polycyclic aromatic hydrocarbons (PAHs), when dispersed in an open sea environment either through accidental or operational activities, has the propensity to cause long term residual effects on marine biodiversity. Some of the noted observations include an increased susceptibility to diseases of certain species (Lafferty and Holt, 2003), reduced resilience (Loya, 2004) and abnormal reproductive cycles (Yanko et al., 2003). Further, the natural decomposition properties of oil makes it persist in the environment over a prolonged period, thereby having long term deleterious effects on critical ecosystems (Armentares et al., 2010; Pisanty et al., 2010) such as coral reefs (Norstrom et al., 2009), littoral forests (Peterson et al., 2003) sea grass (Kenworthy et al., 1993) and mangrove (Lewis, 1983).

Oil discharges occurring in semi or closed systems has the potential to magnify the concomitant environmental impacts aforementioned is a significant concern. One such area is the semi

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http://dx.doi.org/10.1016/j.marpolbul.2015.01.013
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enclosed Caribbean Sea covering an area of 2,515,900 km^2, with one of the most intense maritime traffic in the world and where 37 countries and territories exercise jurisdiction (Singh, 2008). In tandem, this sea supports many critical habitats and shared resources which classified it as a LME (Singh, 2008; Sherman, 2014). Field monitoring data indicated the presence of oil throughout the Caribbean Sea with high levels of Dispersed/Dissolved Petroleum Hydrocarbons (DDPH) recorded at various locations (Fernandez et al., 2007; Persad and Rajkumar, 1995; Atwood et al., 1987; Harvey, 1987). Further, data available for the Caribbean, shows that between 1960 and 1995, 28 vessel spills occurred where in each instance, in excess of 240 barrels (>10,000 gallons) entered in the sea's environment (Singh, 2005). However, the most significant was the *SS Atlantic Empress* which occurred off the coast of Trinidad and Tobago and is regarded as the largest shipping related oil spill in known maritime history (Visser, 2012).

Although the impacts of oil pollution in the Caribbean Sea are recognised, a number of management challenges remain which include (a) lack of information on potential oil spill risk from shipping, (b) little emphasis on management interventions using scientific modelling from a spatial standpoint and (c) effective utilisation of this information in policy decisions. Mainstreaming marine spatial mapping and planning into decision making is growing in usage, supporting better decision making in integrated management regime. In an environment such as the Caribbean Sea in the context of being an LME, the development of spatial mapping for pollution risk identification and control will provide a decision making tool which could be used for management. In view of these gaps, this paper seeks to apply spatial modelling to identify critical areas potentially at risk from oil spills. It also aims at utilising this information to support a management framework for minimising ship generated oil pollution and to provide recommendations for improved management of the Caribbean Sea in this regard.

2. Shipping in the Caribbean Sea

2.1. Shipping trends

The Caribbean Sea (Fig. 1) is ranked as one of the principal transit zones in the world, harbouring in excess of 90,000 port calls per year (Singh, 2008; Girvan, 2002). There is a huge inter and intra-regional and international shipping in this sea, moving various products from ports and refineries. Colombia, Mexico, Trinidad and Tobago and Venezuela are the major crude oil producing countries in the Caribbean Sea with a total production of 6,436,500 barrels per day in 2012 (OPEC, 2012).

There are 214 ports found within or bordering the Caribbean Sea (Fig. 2) in addition to a number of refineries found in various countries (Singh, 2005). The refineries throughout the Caribbean supply refined products to countries within the region, the Gulf of Mexico and beyond. Refined products are shipped into or through the Caribbean Sea via the Panama Canal to other destinations. Not only are other products such as crude oil and its refined products shipped from Africa, the Middle East, Argentina and Alaska into the Caribbean but also oil and its derivatives are shipped from Venezuela, Trinidad and Columbia to the USA and other parts of the region (Dillion, 1995; Singh, 2005). Large storage terminals in Saint Lucia, Aruba, Curacao, US Virgin Islands (USVI) and St. Eustatius are used as trans-shipment ports for crude oil, thereby contributing to the traffic intensity of the Sea.

The Panama Canal also plays a significant role in promoting the increase of traffic in the Caribbean Sea. Petroleum shipments represented approximately 28% of total canal traffic in 2013, of which about 60% of that sum went from the Caribbean Sea/Atlantic to Pacific Ocean (MEEM, 2013). The expansion of the Panama Canal scheduled to be completed in 2014 is projected to witness an increase in transit volumes of liquefied natural gas (LNG), petroleum and other related products, thereby increasing the marine traffic and potential oil pollution in the Sea. Further, the Nicaragua Grand Canal, similar to the Panama Canal when it becomes operational is predicted to add greater pressures to the Caribbean Sea.

Apart from commercial shipping, the Caribbean Sea plays a significant role in cruise ship tourism with over 70 cruise ships from approximately 24 cruise companies operating in the Caribbean Sea (Singh, 2005, 2008). Overall, the region is regarded as the most visited destination in the world, commanding over 45% of the world's cruise market (Ocean Conservancy, 2002). In 2012, it was estimated that over 1929.24 million USD were contributed by the cruise industry through tourist expenditure in the Caribbean countries (BREA, 2012). This large market coupled with the number of cruise ships has the potential to contribute to accidental oil spills thereby compounding the oil pollution issue which emanates from other types of shipping activity. Collectively, the shipping network

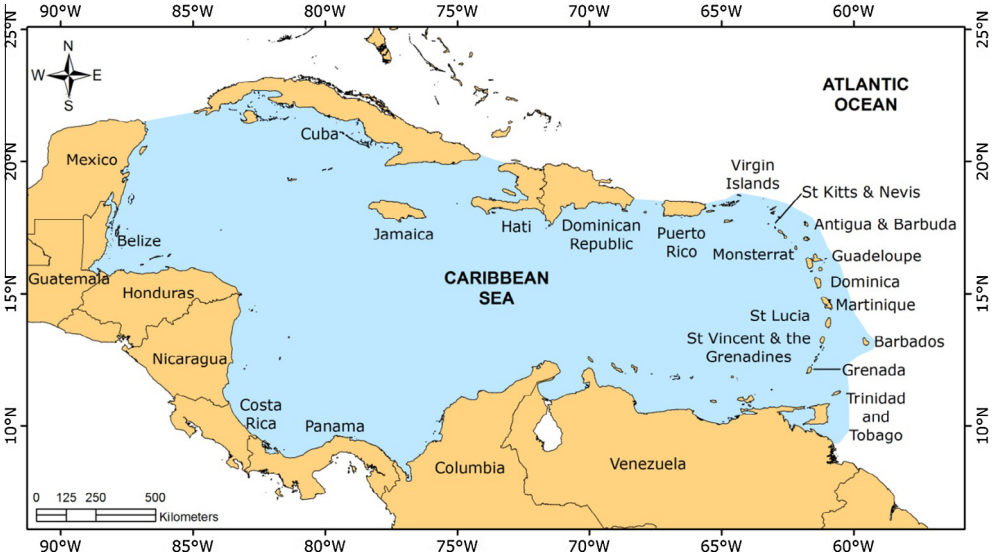

Fig. 1. The study area which includes the Caribbean Sea and the countries with jurisdiction over the sea. Adopted from Singh (2008).

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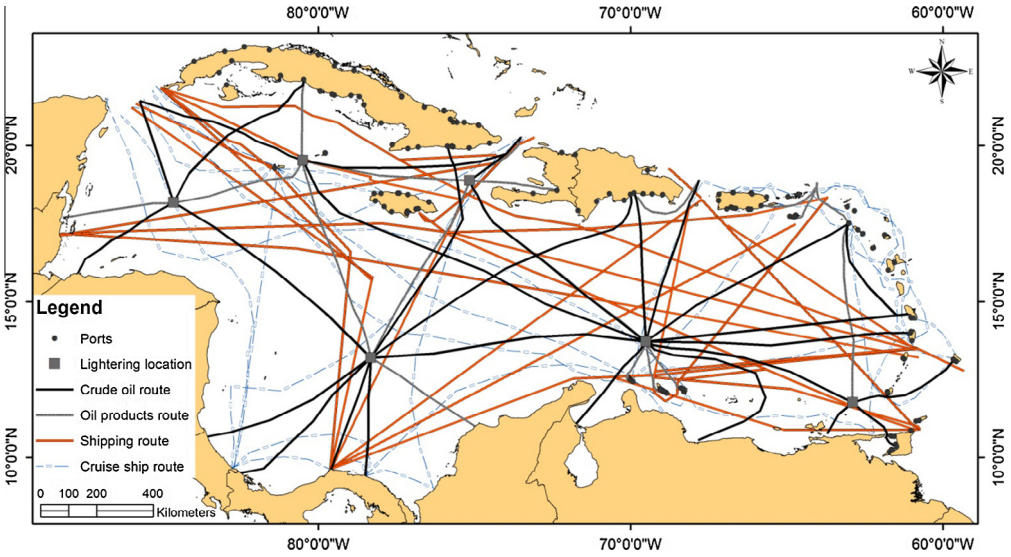

Fig. 2. Shipping network in the Caribbean Sea showing the designated route. Modified from Singh (2005).

suggests a complex pattern of traffic throughout the Caribbean Sea (Fig. 2), which includes oil tankers, chemical tankers, yachts, cruise ships, container/bulk carrier ships, ferries and large fishing vessels.

In terms of trade, the Caribbean Sea is one of the main transit routes for trade through the Latin American and Caribbean (LAC) region and by 2006 the trade had grown annually by 9.74%, in comparison with a global growth of 9.93% (UNECLAC, 2012). Collectively LAC registered the largest container movement between 2000 and 2006 which amounted to 1.7 million twenty-foot equivalent units (TEU). Data trends suggested that by 2010 it reached 2 million TEU for this region. Furthermore, the expansion of this region's economies grew by approximately 5.3% in 2006, with a rise in per capita GDP of 3.8%. Available data shows that between 2003 and 2006, the average annual rate of increase of 4.4% doubled the 2.2% recorded for 1980–2002 (Sanchez and Willsmeier, 2009). Recent statistics show that the region's 20 main container ports posted 12.3% growth, with just two of the 20 experiencing a slight decline compared to 2010 (UNECLAC, 2012). These statistics show a significant growth in the movement of goods and services in shipping driven by demand and strategic location. When placed into the context of oil pollution, what is evident is an expanding shipping industry which needs to be managed thus reinforcing the need for sound management of shipping in the Caribbean Sea.

2.2. Pollution trends

A cause for concern is the environmental pressures from shipping in the region. Ship generated waste is one of the major contributors of pollution in the Caribbean Sea, originating mainly from operational ballasting activities, tank washing and other discharges. Oil pollution is significant in this regard and according to UNEP (1994), it prevails throughout the Caribbean Sea and is classified as one of the most significant threats to marine life. In 1994, UNEP estimated that in excess of 50% of the pollution was caused by ballasting and emptying of bilges in the Caribbean region (UNEP, 1994). Similarly, in 1997, it was estimated that in excess of 700,000 barrels of oil were discharged annually into the marine environment from operational ballast activities and tank washing (Botello et al., 1997). Given the growing intensity, perhaps this is far higher or perhaps lower, as regulation and ship technology are evolving which supports a reduction in oil pollution, but whether such reduction exists in the Caribbean Sea, remains unknown. Data from the Office of Response and Restoration (2012) shows that between 1960 and 2010 there were 9 incidents where oil spills ranged from 7000 to 83,400 barrels. Given the increased shipping activities mentioned above, it is likely that this volume of discharge is currently higher with the potential to increase caused in part by the increase demands for products by emerging economies, reliance of maritime transport for movement of goods and increased globalisation.

The presence of oil in the environment changes the state of the environment in the Caribbean Sea. Oil pollution has resulted in loss and/or degradation of critical habitats. Studies off the coast of Panama after two major oil spills which occurred in 1986 and 1968 showed large scale damage to mangrove forest (Duke et al., 1997). From the time of the spill to five years after, it was found that the epibiota and the mangroves had not fully recovered (Garrity et al., 1994). Although the issue of oil pollution is well recognised, the scientific basis to establish trends and assess environmental status over long-term periods remain insufficient at best and this in part is due to a lack of data gathering regimes. However, what is known is that the Caribbean Sea plays host to a number of ecosystem and habitats, which are very vulnerable to oil pollution and therefore their presence can serve as a proxy for displaying and analysing to an extent, possible threats (Fig. 3).

2.3. Pollution response

An examination of the current responses geared toward minimising ship generated waste has revealed a number of initiatives. These include port reception facilities and co-operation through regional and international legislative frameworks. In an effort to minimise discharges accidental or otherwise, port reception facilities are seen as a viable option where discharge from ships can be safely disposed. Of the 214 ports in the Caribbean Sea, 62 (28%) handles oil and oil products, however, only 22 (10%) have oil or ballast reception facilities (Singh, 2005; Singh and Mee, 2008). In the absence of adequate reception facilities, there is a greater probability of unregulated discharges. Although oil pollution is controlled under MARPOL Annex 1, ballasting is viewed as operational discharge and therefore does not fall under the stipulations of the Convention but rather is now dealt with under the International Convention on Ballast Water Management (2010).

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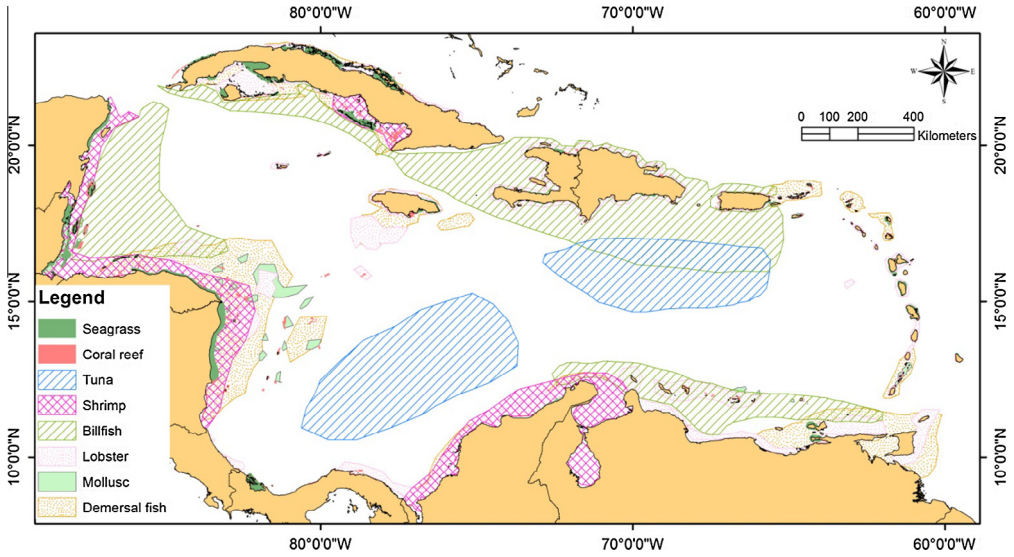

Fig. 3. Habitats and ecosystems in the Caribbean Sea. Modified from Singh (2005).

In terms of regulations, management of ship-generated pollution is sanctioned at the international and regional levels via conventions, treaties and programmes, which in some instances are translated to the sub-regional and national levels, enshrined in laws, regulations and programmes. An examination of the agreements reveals a total of 3 major international mechanisms that govern oil pollution from ships. An indicator of compliance of these relevant agreements is the number of state ratifications for the states with jurisdictions in the Caribbean Sea. What is evident is that the number of ratifications varies, depending on the agreement, with some agreements having a statically significant level of ratification while others are low (Table 1).

Overall, the analysis of the shipping activities in the Caribbean Sea shows its economic importance to the region, but also the issues faced and response taken regarding oil pollution.

3. Methods

3.1. Promoting spatial marine planning through Geographic Information System (GIS)

ArcGIS version 10.0 was used to conduct the spatial modelling and analysis for this study. A number of datasets were used to develop a Potential Oil Spill Risk (POSR) model. Geo-referenced datasets of the major routes for crude oil tankers, oil products tankers, container/bulk carrier ship and cruise ships were created using base data from Singh (2005). The model treated these transportation routes as possible sources of oil spills due to the aforementioned shipping activities. The major types of oil transported by the four shipping activities were determined by conducting a survey over 2 days of 60 ships in the Caribbean Sea using data from MarineTraffic.com. From this survey, three major types of oil were identified as having the potential to cause pollution through spills. These were crude oil, Bunker C and diesel. Both crude oil and oil products tankers transported crude oil and Bunker C but also had diesel on board that was used as fuel. The only major oil type present on container/bulk carrier and cruise ships was diesel that was used for fuel. Data was also sourced from the Hybrid Coordinate Ocean Model (HYCOM) from the United States Global Ocean Data Assimilation Experiment. This produces daily predicted current speed and direction for the entire globe. To model the expected movement of oil in the Caribbean Sea from a potential oil spill, the horizontal (u) and vertical (v) components of surface currents from 2011 HYCOM data was used (as it represents an epoch outside of the primary influence of El Nino Southern Oscillation (ENSO) and therefore is more representative of general oceanographic conditions in the study area). Due to computational constraints only the u and v components for every 20th Julian day were extracted which amounted to 18 days of data for both u and v components. For each dataset, current speed and direction were calculated and averaged to derive the current speed and direction matrix for each cell (approximately 9 km resolution) in the Caribbean Sea for 2011 (Fig. 4).

The speed of water flow through each cell of the study area was determined based upon the HYCOM current speeds. Treating the shipping activity transportation routes as potential sources of oil spills, the transit time and current direction were used to calculate the speed and direction of that spilled oil would travel. This produced a time based current flow surface that represents the amount of time taken for oil to propagate through the matrix for each type of shipping activity. Utilising the time based current flow surface and the oil decomposition values for the oil types; a fuzzy logic approach (Kainz, 2012) was employed to develop a spatially distributed gradient matrix of risk membership values for each of the major oil types for each shipping activity.

The oil decomposition rates were derived using the adapted values from National Research Council (2003). Crude oil was assumed to decompose 10 days after the spill event, Bunker C after 7 days, and diesel after 3 days (National Research Council, 2003).The risk membership functions ranged between "0" and "1", with "1" indicating a high potential oil spill risk, and "0" as no potential risk. Crude oil and oil product tanker shipping activities each had 3 membership value matrices, crude oil, Bunker C and diesel, while container/bulk carrier ship and cruise ship activities each only had a single membership value matrix which was diesel. The 3 membership value matrixes for crude oil and oil product tanker shipping activities had to be combined into a single membership value matrix for each shipping activity. To accomplish this, the major oil types, crude, Bunker C, and diesel, were empirically ranked according to the relative impact on the receiving environment, and equated to their percentage influence relative to each other. Crude oil was assigned an impact ranking of 50, Bunker C 30, and diesel 20 (National Research Council, 2003). The 3 major oil type membership matrices were combined into one risk matrix

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Table 1
The status of the various ship related conventions.

Agreements	Relevant articles to oil pollution from shipping	Ratification rate of a total of 37[a]
International		
United Nations Convention on Law of the Sea (UNCLOS)	Articles 36, 38, 211(5), 220	27
The International Convention for the Prevention of Pollution from Ships 73/78 (MARPOL)	Preamble, Article 3(b)(i)(ii) Annex 1	Annex I & II–26 Annex III-23 Annex IV-19 Annex V-27 Annex VI-7
The International Convention on Oil Pollution Preparedness, Response and Co-operation – OPRC (London 1990)	Preamble, Articles 1, 2, 3(2), 3(3), 7, 4(a)(i)	12
Convention for the Protection and Development of the Marine Environment of the Wider Caribbean (Cartagena Convention)	Articles 2	34
The Caribbean Environment Programme. Oil Spills Protocol	Preamble, Article 2	34
International Conference on Ballast Water Management for Ships Agenda item 8		
Regional political/diplomatic agreement		
Convention Establishing the Association of Caribbean States	Section 2 Articles 1 (a and b), 2(b) Article VIII (3b)	Governing ACS members
The Revised Treaty of Chaguaramas establishing the Caribbean Community Including Caricom Single Market Economy	Articles 135(1d), 141	Governing CARICOM members
Tegucigalpa Protocol to the Charter of the Organisation of central American states (ODECA)	Article 3(a)	Governing a group of Latin American countries
Revised treaty of Basseterre establishing the organisation of eastern Caribbean states economic union	Article 4.2(o)	
International and regional non-binding agreements		
United Nations Conference on Environment and Development. Agenda 21	Chapter 17 paragraphs 30(A), 33, 30(A)	Universal
Barbados Programme of Actions (BPOA)/MS	Article III(A)(ii)	Relevant to SIDS
Project		
Wider Caribbean Initiative for Ship Generated Waste (WCISW)	Only known initiative for shipping for the Caribbean Sea	Not relevant

Compiled using data and information from the IMO (2012).

[a] Countries are independent mainland countries: Belize, Colombia, Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, Panama, Venezuela; Independent Island States: Antigua & Barbuda, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St Kitts & Nevis, St Vincent & Grenadines, St. Lucia, Trinidad and Tobago. Overseas Territories (OTs) Islands: United States Virgin Islands (USVI), Puerto Rico (USA); Aruba, Bonaire, Curacao, St. Eustatius, St. Marteen (The Netherlands); Guadeloupe, Martinique, St Martin, Saint Barthélemy (France); Anguilla, British Virgin Islands (BVI), Cayman Island, Montserrat (United Kingdom).

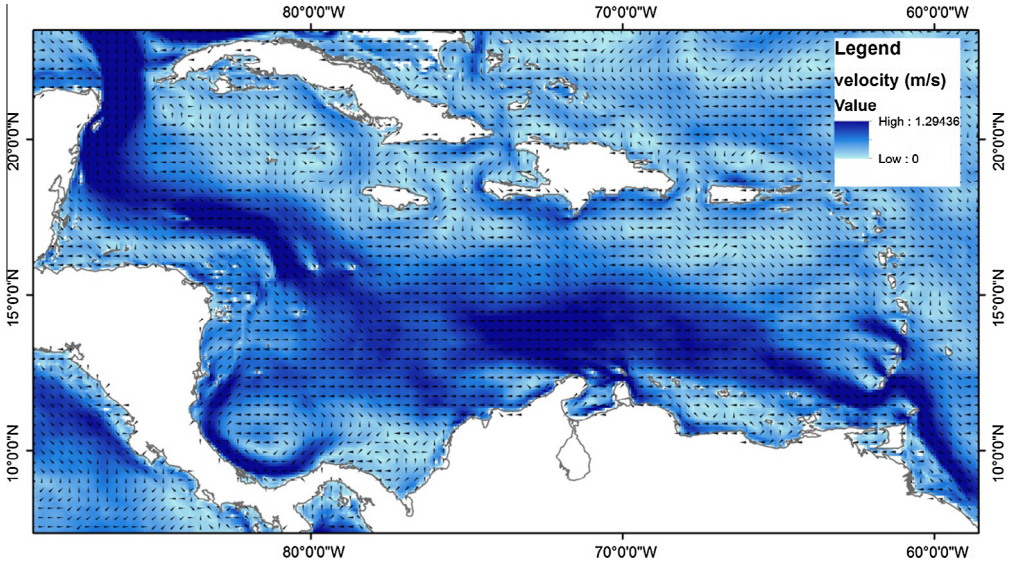

Fig. 4. Current speed and direction from HYCOM used for the potential oil spill risk model.

for crude oil and oil product tanker each by using the empirically ranked oil spill weightings corresponding to the different major oil types. An example of the calculation for a single cell for crude oil tanker shipping activity is presented in Table 2.

Container/bulk carrier ship and cruise ship activities each only had a single membership value matrix as these shipping activities only had one type of oil onboard (diesel). A combined shipping activities risk membership matrix was then developed. The oil type impact rating value for diesel was applied to the container/bulk carrier ship and cruise ship activity membership value grids. The membership risk matrix for each of the 4 shipping activities was summed and percentage normalisation conducted to reduce the membership risk values to be between 0 and 1. The derived combined oil spill risk matrix was reclassified into (a) no risk, (b) very low, (c) low, (d) medium and (e) high risk by performing quartile disassociation on the membership functions greater than "0". The

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Table 2
Single cell example of combination of major oil type risk membership matrices into a single risk membership matrix for crude oil tanker shipping (modified fusing values from National Research Council (2003)).

Oil type	Risk membership value for cell (x, y)	Oil type impact rating	Risk membership oil type impact rating
Crude oil	1	0.5	0.5
Bunker C	0.95	0.30	0.285
Diesel	0.86	0.20	0.172
Combined shipping activity risk membership value			0.957

results are presented in Section 4. Given that the Caribbean Sea is ranked as having the highest number of states per area in the world (Singh, 2005; Chakalall et al., 1998), the potential risk by state was calculated using the Exclusive Economic Zone (EEZ) and study area boundaries. The values of the membership functions calculated for each state were extracted. Based on the analysis, these values provide an indication of the potential oil spill risk to each nation state (Table 3).

3.2. Limitations and contribution of the POSR model

The POSR model has limitations. The derived speeds for surface oil transport do not consider the effect of waves, winds, extreme conditions and the effects of vertical mixing. Another limitation is the use of HYCOM modelled data. HYCOM like all models is the mathematical assimilation of several remotely sensed and in-situ observations used for the purpose of simulating reality and thus it is restricted in this aspect. It does however represent a marked improvement over the Miami Isopycnic Coordinate Ocean Model (MICOM) by integrating both an Isophycnic model for ocean interior with z-coordinate model for the near surface (Megann, 2004). While HYCOM is undergoing continuous refinement and calibration through in-situ measurements, to date no concise validation programme has been implemented for the Caribbean Sea and thus limits the effectiveness of the model. Despite these limitations, HYCOM has been extensively used all over the world with over 143 peer review publications, including Schiller and Kourafalou (2010), Yao and Johns (2010) and Zamudio et al. (2011). Therefore, its application is important and pertinent for the POSR model. The development of the POSR model through this study is valuable in its application in the Caribbean Sea as its value is its usage in informing in an indicative manner, the potential risk from oil spills. This information adds to the body of work that exists for this area and can be used to broadly support policy and management prescriptions. The study also presents a baseline model upon which further studies could be undertaken to build upon this type of research aimed at grounding policy making in science and incorporating marine spatial planning in management.

4. Results and discussion

4.1. Promoting the spatial marine planning through geographic information system

The spatial model revealed the varying degree of potential risk from oil spills in the Caribbean Sea. The main entry points for flows into the Caribbean are at Trinidad, Barbados and Grenada and exit between Cuba and Mexico. This corresponds to a general flow model trend as seen in Fig. 4, which is an east to west surface flow. Highest current speeds (1.29 m/s) are observed in the central region of the sea with large gyres with high speeds of 1.29 m/s occurring close to Panama. Small scale gyres of lower speeds are observed around the islands and South American Countries. Given the existing shipping lanes and shipping activities it is clear that oil has the potential to be dispersed along the routes but typically in an east to west direction along routes. Oil can circulate in these gyres and can spread outwards from point sources depending on oil decomposition rates which translate to risks ranging between low and high levels.

A qualitative comparison of the different shipping activities shows that crude oil and oil products tanker transport POSR exhibits the greatest threat over a large area (Fig. 5a and b). These activities produce oils spill patterns similar to the corresponding oil spill routes as shown in Fig. 2. The extent of the oil spill pattern is affected by surface currents and extends over larger areas of the Caribbean Sea when compared to the impact due to container bulk and crude ships. The influence of wind on surface transport can exacerbate this potential for oil spill however the impacts could not be quantified due to limitations of the model. Crude oil, on board crude oil an oil products tanker transport, with its low decomposition rates results in persistence in the environment for an extended period of time. This is the primary reason for the ability for currents to transport the oil over larger areas. Comparatively, potential risk from container/bulk carrier and cruise ships is not as extensive, given diesel is the only type of oil onboard for these activities and it has a relatively faster decomposition rate. This produces smaller extents potentially affected by pollution from these types of transport (Fig. 5c and d).

Upon visual inspection it is clear that the South American countries and islands are at high risk from potential oil spills from all types of transport, mainly crude transport which affects large areas of the Caribbean sea (Fig. 5a). The islands are not at high risk of pollution from oil products transport (Fig. 5b). Container/bulk transport does not pose a high risk of pollution to the Greater Antilles (Fig. 5c).

Further, when all the risk from the 4 classes of shipping were combined and classified into 5 potential risk categories, what is evident is that 83% of the total area of the Caribbean Sea is exposed to some level of risk. Qualitative analysis shows that the islands have a low to moderate risk despite being exposed to all types of shipping activity. These levels along with the spatial area and corresponding percentage risk are provided in Table 3 and spatially illustrated in Fig. 6.

The main contribution of this spatial modelling is the visual products which can be used to support targeted management which is very applicable to the Caribbean region given the limited financial resources for environmental management. Further, when the spatial areas in the form of the potential Exclusive Economic Zones (EEZ) of the jurisdictions within the study area are superimposed over derived potential oil spill risk, a number of observations with management implications are evident.

Quantitative analysis shows that for crude oil tanker transport, the islands EEZs and Central/South American countries EEZs are at

Table 3
Spatial area and % of the Caribbean Sea by ranges of potential oil spill risk.

Oil risk ranked quartiles	Membership values	Risk category	Area (km^2)	Percentage (%)
0	0	No risk	495355.77	16.85
1	0.01–0.26	Very low risk	527771.88	17.95
2	0.27–0.51	Low risk	421621.59	14.34
3	0.52–0.79	Moderate risk	616593.17	20.98
4	0.780–1	High risk	878103.82	29.87

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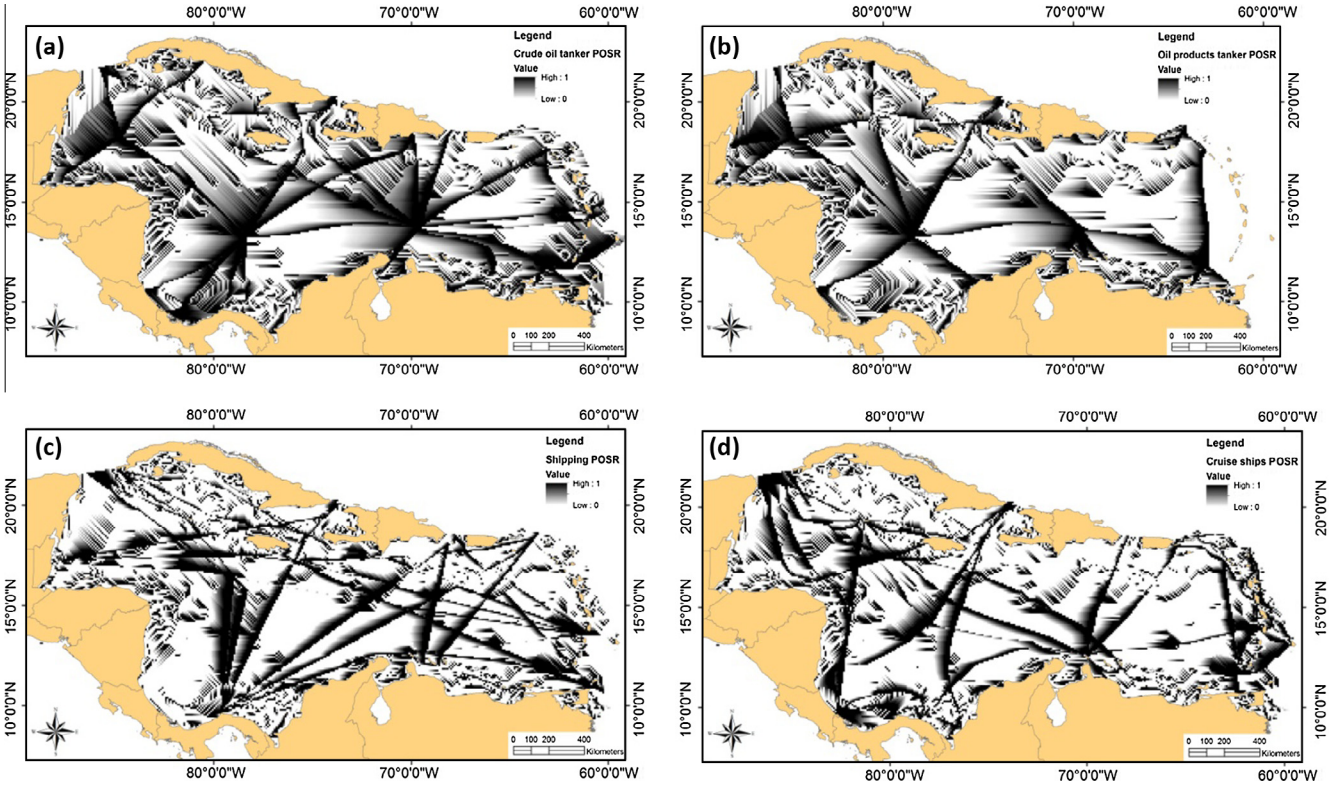

Fig. 5. The potential oil spill risk from (a) crude oil tankers, (b) oil products tankers, (c) container/bulk carrier ship and (d) cruise ships for 2011. Darker shades indicate higher potential oil spill risk, while lighter shades indicate lower potential oil spill risk.

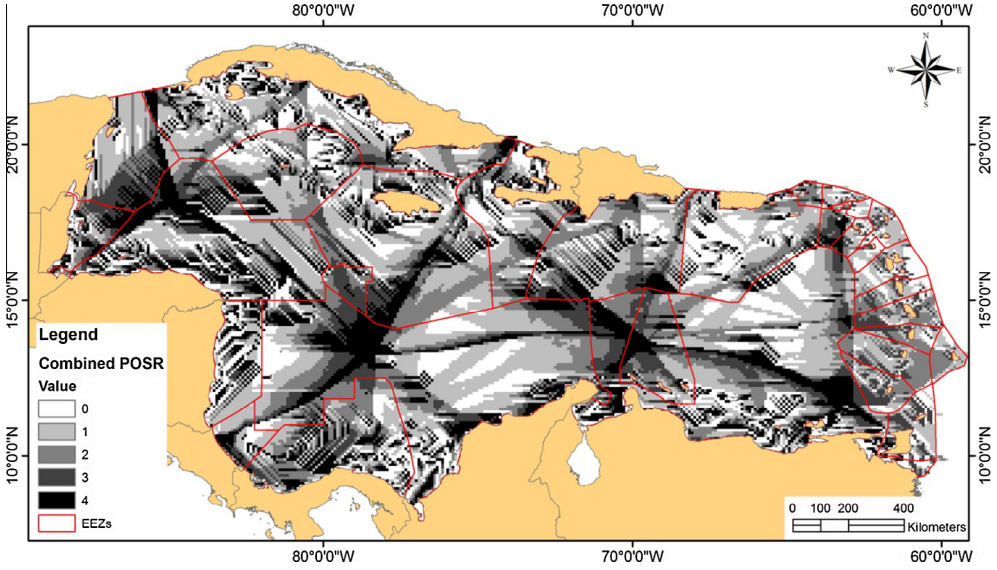

Fig. 6. An illustration of the potential oil spill risk within the context of countries EEZs* and study area for 2011. *The EEZ boundaries are an academic illustration, and do not represent the agreed boundaries agreements by countries.

moderate to high levels of risk (Fig. 7a) with the Martinique, Sint Maartan and Grenada being the top three highest risk islands exhibiting more than 50% of the EEZ at high risk for pollution. Honduras, Panama and Guatemala are also the top three South American countries having similar risk. For oil products transport, the islands EEZs are generally at low risk levels (Fig. 7b) while South American countries are low to high risk. South American countries, for example, Belize and EEZ of the British Virgin islands and the areas between Columbia and Jamaica, require close attention as these show very high risk for pollution. On examination of container/bulk carrier shipping the POSR model shows that the risk ranges from low to high for the islands and Central and South American countries but there is low impact on the Greater Antilles (Fig. 7c). In this case, the EEZs of Netherlands, Saint Lucia and area between Columbia and Jamaica show high risk for pollution. In terms of cruise ship, the islands EEZ risk levels are generally higher

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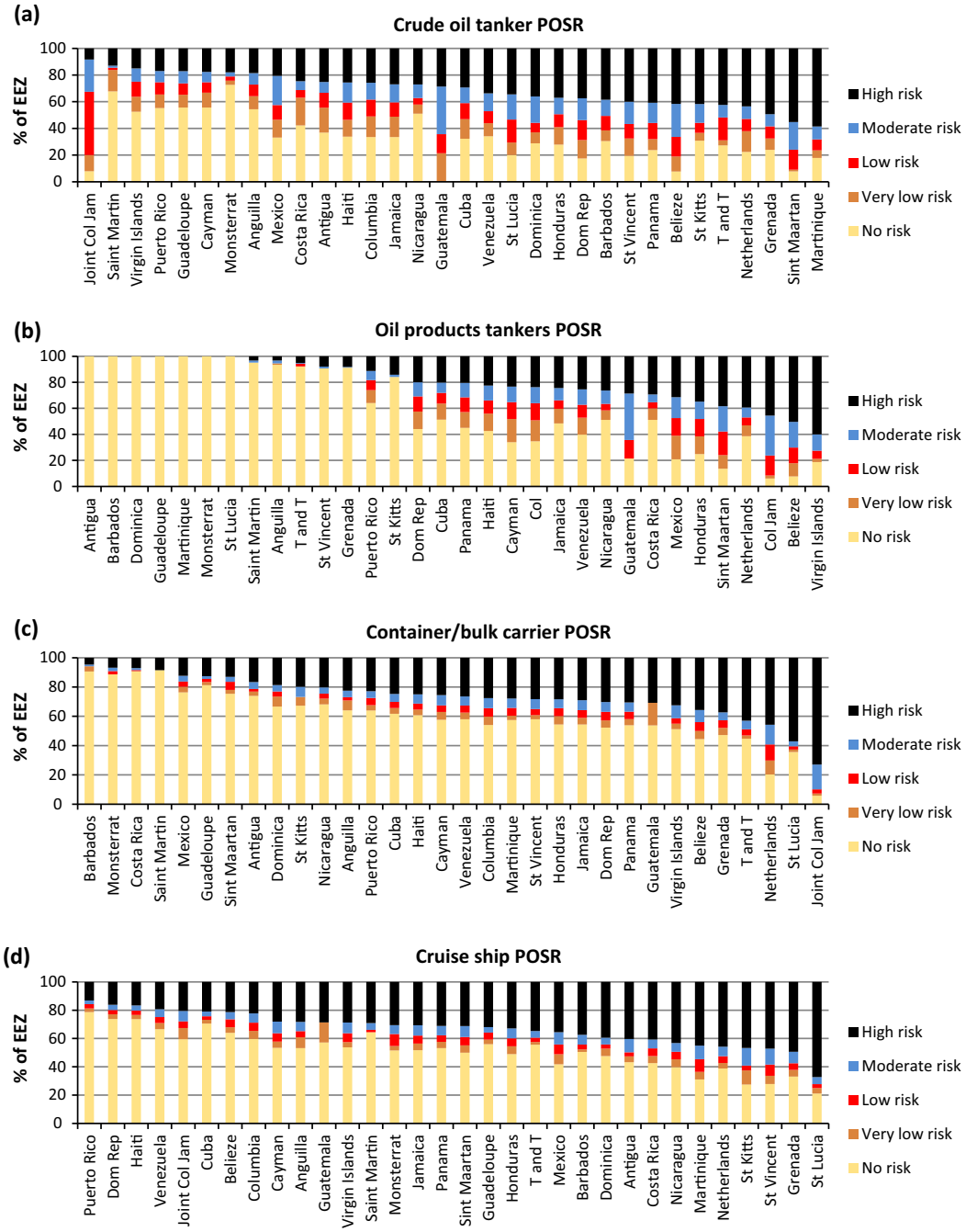

Fig. 7. Percentage of countries EEZs potential oil spill risk by type of shipping activity.

than the Central and South American countries which exhibit more than 50% of the EEZ being affected (Fig. 7d). Overall, these findings further elucidate the importance of an oil spill contingency plan for the region and targeted management interventions.

Having analysed the compiled potential oil spill risk the impact of independent shipping activities pose high risk to EEZs' of islands but the combined impact from all four shipping activities, shows that the Caribbean SIDS such as Trinidad and Tobago and Saint Lucia among others have a lower propensity to the high risk category. The presence of these risks points to potential threats oil pollution can pose to the economies of the countries (especially tourism based economies) (Fig. 8). The high risk areas due to combined shipping activities are the South American countries, with Belize, Honduras and Guatemala being the top three high risk countries as more than 70% of their EEZ potentially affected.

The outcome of this model gives an indication of the level of potential risk emanating from these four shipping activities and this information could be used for informing targeted area management within the Caribbean Sea, if more practicable. For example (Fig. 5) shows that the impacts in the Lesser Antilles are from cruise ship activities, while there is no risk from oil product tanker shipping activities. This information is crucial given the significant role that the cruise industry plays to the economic sustenance of this region. According to the Florida Caribbean Cruise Association, for the year 2011–2012, over 1535 million USD were earned from cruise tourism for 20 countries in the Caribbean of which Sint Maartan grossed the highest with 356.50 million USD. Further, this information on potential oil spill risk can be used in management decisions to ensure that the cruise industry does not negatively affect the very resources that it relies on, for example coral reefs,

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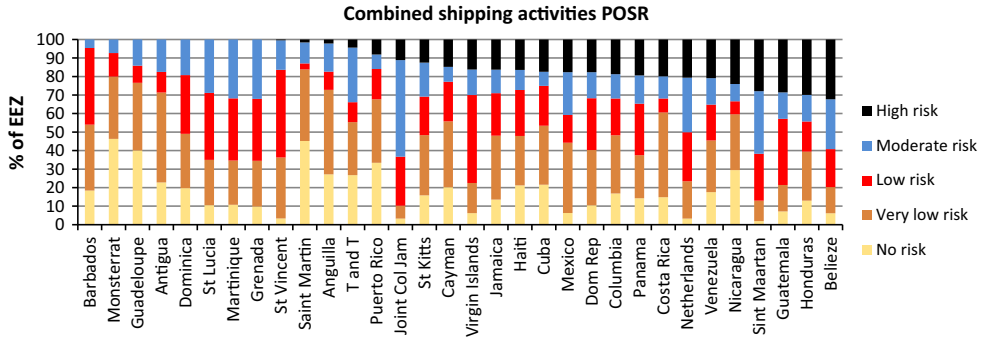

Fig. 8. Compiled potential oil spill risk by percentage of Caribbean Sea states EEZs.

sea grasses and white sand beaches which are integral to the tourism sector. Additionally, what is evident is the greatest oil spill risk to the open waters of the Caribbean Sea is from the transport of crude oil. Therefore, as maritime growth continue to trend upward; such information derived through this study can assist in supporting a regime for the crude oil transport 'sector.'

5. Recommendations

The proposed framework for minimising oil pollution from shipping in the Caribbean Sea

The proposed management framework seeks to enhance information on oil spills, encourage the use and incorporation of spatial analysis and use this information to inform policy decision. Based on the findings, the following management regimes are proposed for consideration.

5.1. Support research and information data management on shipping activities in the Caribbean Sea

The region requires a regime for data collection to inform oil spill related activities that will assist in improving the POSR model which is envisaged to respond to the data deficit that defines the current situation. One challenge for this study was acquiring data indicating vessel traffic for each type of shipping activity and types of fuel onboard for ships. These types of information can prove vital for risk analysis and should be logged at all ports throughout the Caribbean. The increasingly high and predicted maritime traffic in the Caribbean Sea suggests that water quality monitoring should be a priority. To ensure that these monitoring studies are useful, standards for environmental quality relevant to oil pollution from shipping should be developed and implemented to support sound governance. These data collection will form a critical component in monitoring as it lends to trend analysis thereby gauging environmental changes, for example, remotely sensed data could be useful. To compliment this process, the development and use of indicators could be advantageous. Additionally, applied research on various elements relating to oil pollution could support the framework for example, pollution risk assessment and sensitivity mapping for the Caribbean Sea. Within this proposed regime, efforts could be made to support greater data gathering to improve the POSR model to make its contribution more definitive rather than being solely indicative. Increased scientific data ensure that policies are not developed in a vacuum.

5.2. Early warning and surveillance

In this present era of increased access to satellite technology where real time imagery is easily accessible and affordable, there is an opportunity for the region to consider the establishment of a surveillance and early warning system for oil spill in the Caribbean Sea. A surveillance and early warning system would allow for more efficient management including better response in the event of spills. In addition, a region-wide surveillance and monitoring programme with a number of defined sub-regional hubs would ensure that the entire sea or the strategic points are being monitored. The incorporation of sub hubs will encourage efficiency with regard to resource allocation and policing. This proposed programme can serve as a deterrent and forces more effective compliance from both flag and coastal states. Additionally, information gathered could foster greater accountability and transparency. Pilot projects can be started in areas which have been identified as high risk. Consider for example, in islands such as Grenada, Sint Maartan and Martinique which are at high risk for crude oil pollution. Alternatively, pilot studies can be set up in South American countries which are at high risk for pollution from all shipping activities. While at present pockets of such initiatives exist in the region such as in Regional Activities Centre for the Regional Marine Pollution Emergency Information and Training Center for the Wider Caribbean (REMPEITC-Caribe) under the auspices of the Oil Spills Protocol of the Cartagena convention what remains absent is a regional surveillance mechanism that encompasses the entire Caribbean Sea.

5.3. Mainstreaming marine spatial planning in management interventions

The Caribbean Sea as a large marine ecosystem with varying economic uses would be better managed with greater emphasis on marine spatial planning. Spatial planning has a rightful place in management and its use and recognition is growing worldwide. Spatial analysis for example shows that Panama is high risk for oil spill pollution from the shipping activities analysed therefore the canal must have an effective, management plan to deal with risk specific to oil spill pollution. Monitoring of water quality should be made compulsory, particularly along transit routes as they have a significant role on the potential for oil spills. Also in cases where there may be developments in shipping activities, consider for example, the shipping of oil products amongst the islands, proper analysis must be conducted to determine the potential for oil spill. Currently there is very low risk to these islands from this activity, but oil spill management can be incorporated into existing plans. For example the Organisation of Eastern Caribbean States (OECS) Ocean policy, (OECS, 2013) can consider this incorporation given that one of the priority goals is marine spatial planning for maximising economic and environmental benefits.

By employing the spatial analysis approach, it is highly probable that stronger connections could be made between the various

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activities, which could foster greater engagement among stakeholders that could translate to greater synergies.

5.4. Continual streamlining of governance mechanism for effective management

One of the foundations to effective governance is the legal framework which makes management a responsibility. Within this realm, multilateral agreements and laws are very important, as they provide the necessary impetus for sound management. However their success hinges on the commitment from national governments and in the case of international agreements, to implement the principles and standards set forth within. These conventions have the propensity to support policy and management options. Therefore, efforts should be made by countries in the region to include agreements relating to ship generated oil pollution into in their governance framework, where necessary, particularly if they are at known risk for oil spills due to shipping related activities. Such actions would strongly support the regional management mechanism. Further this could be mainstreamed into national and regional oceans policies. Overall, these areas need to be supported by an effective institutional structure in order to ensure that the framework is iterative and informed by the agreements and programmes at all levels. One notable example of such use already in the Caribbean region is the OECS ocean governance initiative which operates with a regional framework policy called the Eastern Caribbean Regional Ocean Policy – ECROP (OECS, 2013). Such an approach if expanded to the Caribbean Sea can be valuable.

5.5. A common policy

Ad-hoc approaches to managing oil pollution from shipping need to be overcome through cooperation from all countries that have a vested interest. One approach is the formulation and implementation of a common policy. The basis of such a policy is one that considers the relationship between the economic contribution of shipping and the resulting environmental issues. Common policies should be adopted for countries which more than 50% of their EEZ being at high risk for pollution from shipping activities. Consider for example, countries such as Belize, Honduras, Guatemala and Sint Maartan should be managed adopting stricter regulations as these EEZs are at a high risk for pollution. These regulations may include, increased port facilities required at these ports and vessels being checked routinely.

5.6. Regulatory compliance

There is recognition that oil pollution and potential risk from spills is an issue in the Caribbean Sea but efforts are being made to manage this activity through a number of initiatives such as ratification of international agreements and regional projects. Conventions such as MARPOL provide a legal basis for the nation states in the region to collectively formulate enforcement strategies which can act as a deterrent in oil pollution. However, one of the major weaknesses is the varying level of ratification of the relevant agreement among countries in the region coupled with the lack of implementation of these agreements. Countries ranked as high risk as shown in Fig. 8, can utilise the results of POSR model to determine which of the oil pollution conventions need to be considered for ratification or in cases where this already occurred, to promote effective implementation.

While efforts have been made to improve port infrastructure through the establishment of port reception facilities, inventory shows that in light of the present and projected traffic increase these are inadequate to accommodate discharges.

6. Conclusion

The POSR model is a preliminary attempt at mapping potential oil spill risk for the Caribbean Sea. While there exists a myriad of contributing factors that determine risk, this study forms a valuable baseline for future work, and provides some basis for informing policy and management of the Caribbean Sea. The general consensus from this study, is that the risk of oil spills/pollution from shipping activities in the Caribbean Sea is present and although it may be complex to address because of the wide expanse of marine area and the many jurisdictions, the risk of inaction seems consequential, given, the presence of vulnerable and critical habitats coupled with competing and often conflicting economic interests which are occurring in the same space. This study elaborated a number of recommendations which can be considered as an approach aimed at moving away from the present status quo on the regional management efforts in terms of oil pollution within the realm of the maritime sector.

Acknowledgements

The authors would like to thank Mr. Colin Young, Mr. Anne Reglain and Mr. Adam Jehu for the insightful reviews, suggestions and comments. Further, funding for the development of HYCOM has been provided by the National Ocean Partnership Program and the Office of Naval Research. Data assimilative products using HYCOM are funded by the U.S. Navy. The 1/12° global HYCOM + NCODA Ocean Reanalysis was funded by the U.S. Navy and the Modeling and Simulation Coordination Office. Computer time was made available by the DoD High Performance Computing Modernization Program. The output is publicly available at http://hycom.org.

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