Marine Environmental Research 169 (2021) 105345

Contents lists available at ScienceDirect

Marine Environmental Research

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

Short communication

Marine debris from the past - Contamination of the Brazilian shore by a WWII wreck

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ARTICLE INFO

Keywords:
Marine debris
Tropical atlantic
Shipwrecks
Rubber bales

ABSTRACT

In 2018, unidentified packages appeared along approximately 1600 Km of the Brazilian coastline causing widespread pollution to beaches and danger to society. The packages were found to be bales of raw rubber ranging in size from 0.06 m^3 to 3.4 m^3 and weighing up to 200 kg. A few bales were marked with the stamp "Product of French Indochina" and colonized by the barnacle *Lepas anatifera*, an oceanic species. We found that unidentified packages are from a Second World War (WWII) shipwreck, and that the source is almost certainly the SS *Rio Grande* found at 5,762 m depth. Numerical simulations show that currents can carry out the bales from the SS *Rio Grande* to the beaches. We highlight transnational measures to study and protect the WWI shipwrecks because they represent an overlooked environmental risk.

1. Introduction

In October 2018, hundreds of mainly square-shaped packages began washing up onto Brazilian beaches from Sergipe to Maranhão States (northeastern region). They reached an extensive area of this tropical coastline covering approximately 1600 Km (Fig. 1). The appearance of these unidentified packages caused considerable public and media concern because their origin and chemical composition was unknown (Gama, 2019; G1, 2018). The packages were generally seen to represent an unrecognized environmental risk and as a potentially harmful source of marine pollution (Avio et al., 2017; Frias and Nash, 2019) to the poorly known South Atlantic ecosystems (Soares et al., 2017). Also, due to their relatively large size and weight, the packages were a serious risk to vehicle traffic on the beaches, which was tragically demonstrated when a night-time collision between a dune buggy and a package reportedly led to the death of two women and the serious injury of a third passenger resulting in amputation of his leg (Gama, 2019). In August 2020, what looks like the same kind of bales were reported on Ambergis Caye in Belize and Palm Beach (Florida) in USA, (Miller, 2020).

A further worry was that the area where the blocks came ashore was later impacted by the most extensive oil spill ever recorded in the South Atlantic Ocean basin at the end of 2019 (Soares et al., 2020 a, b). This raised additional questions whether the pathway and offshore source of the two different polluting events was the same.

In this article, we present several different lines of evidence allowing us to conclude, the probable source of the packages found in Brazil. Our evidence about the packages includes: 1) their chemical composition; 2) the history of raw rubber from the Far East; 3) an oceanographic particle-tracking model to demonstrate the probable source and the paths of these packages from a South Atlantic location; and 4) identification of the colonizing barnacles. This multi-disciplinary approach allowed us to make the initial analysis of this case and the associated environmental problems and management measures to minimize the damage. We also assessed whether the unidentified packages were connected with the worst oil spill disaster ever recorded in Brazil.

2. Material and methods

The precise number of packages that drifted to the beaches was not

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https://doi.org/10.1016/j.marenvres.2021.105345
Received 27 January 2021; Received in revised form 14 April 2021; Accepted 24 April 2021
Available online 29 April 2021

recorded by the government. We estimated the total number of packages based on numbers that appeared on media reports (Gama, 2019; G1, 2018; Souza, 2018). Twenty-two packages were measured and photographed in the field, and four packages brought to our laboratory to be weighted and the material analyzed.

At the time the packages were coming ashore (October 2018–March 2019), the Brazilian authorities were unaware of their origin although it was generally understood the contents were layers of raw rubber (Gama, 2019; G1, 2018; Souza, 2018). To test this hypothesis non polar solvents (ex: hexane) were add to small pieces of the packages.

We did a historical research to identify the meaning of the stamps found in the packages (Benedict, 1947; Miller, 1947). Based on the results about the packages material and its manufacturing place, we did an online research about possible shipwrecks caring this kind of cargo (Sixtant, 2020; US Navy Department, 1968).

After identifying two shipwrecks as the source of the packages the particle-tracking model OpenDrift (Dagestad et al., 2018) as used to simulate the dispersion of the packages in the ocean. OpenDrift uses a Runge–Kutta fourth-order time-stepping method whereby particle positions were calculated hourly based on ocean circulation data provided by an ocean model. We used 1/12° spatial resolution, daily mean currents data from the CMEMS PSY4QV3R1 Global Ocean Physics Analysis and Forecast (Mercator) produced by the Mercator-Ocean system (Lellouche et al., 2018) as the hydrodynamic source to the OpenDrift Model. A total of 10,000 virtual particles (i.e. simulated bales) were released in the SS *Rio Grande* and SS *Burgenland* shipwreck positions and the particle trajectories were tracked for 90 days based on daily outputs. The particles were released in a 10 km radius around the shipwreck sites on the 20th of August of 2018. This date was chosen based on tests performed for having the particles to arrive on the coast around 15th of October of 2018 to coincide with the same time the unidentified packages began arriving on the Brazilian coast (Gama, 2019; G1, 2018; Souza, 2018).

Marine crustacean species inhabiting one of the packages were photographed and collected to be identified. Specimens were identified based on Pilsbry (1907).

3. Results

We estimate the number of packages to be between 150 and 200 with most appearing by the end of 2018. The packages measured at the field vary in size from 0.4x0.4 × 0.4 m (0.064 m^3) to 1.5x1.5 × 1.5 m (3.375 m^3) and weigh up to 200 Kg.

The first evidence from the source of packages was provided by their chemical composition. The material from the bales becomes soft and sticky when warmed by the sun and is soluble in nonpolar solvents; both characteristics of natural rubber (Brydson, 1988). Consequently, the material in the bales is probably crude rubber and is not synthetic material. This hypothesis is supported by evidence found in one of the bales, which was visibly stamped "Product of French Indochina" (Fig. 2A) as well as the word "SBIAK" (Fig. 2B). "SBIAK" is a word from the Khasi people, an indigenous ethnic group of Meghalaya in northeast India who lived in French Indochina (Benedict, 1947). This region was a French colony (actually Vietnam, Laos and Cambodia) that became independent in 1953. The climate and soils of French-Indochina are well adapted to the growth of rubber trees (Miller, 1947) and the region was a large producer of rubber, especially during WWII. French Indochina was dominated by the Japanese during WWII, which resulted in cargoes of natural crude rubber being carried by German ships. In this context, we hypothesized that the packages are rubber bales that came from French Indochina.

The second line of evidence was provided by the marine crustacean species inhabiting the rubber bales. The packages were colonized by adult individuals of the goose barnacle *Lepas anatifera* Linnaeus, 1758, a pelagic oceanic species worldwide distributed (Fig. 3A–C). This species is usually found on floating objects in tropical and subtropical oceanic waters. Individuals of *L. anatifera* become adults and reach sexual maturity when the capitulum reaches around 2.5 cm across and approximately 30 days in warm waters (Patel, 1959; Anderson, 1994).

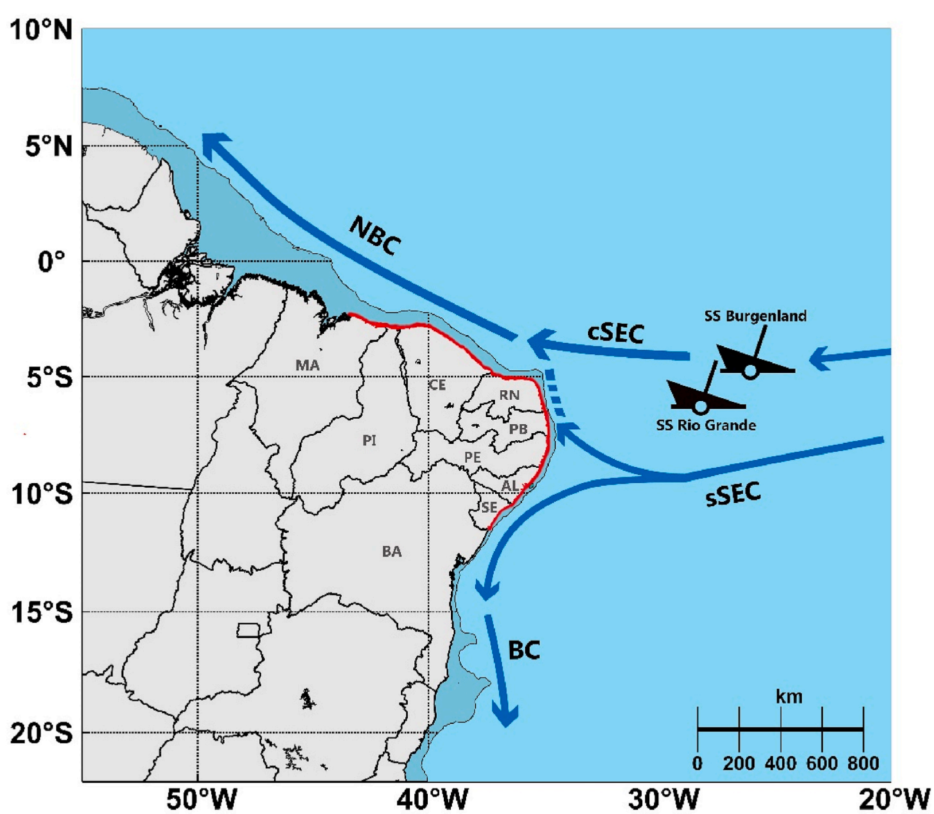

Fig. 1. Distribution of rubber bales on the tropical coast of north-eastern Brazil (red line) and shipwrecks position (SS *Burgerland* and SS *Rio Grande*). MA = Maranhão State, PI = Piauí state. CE = Ceará state; RN = Rio Grande do Norte state; PB = Paraíba state; PE = Pernambuco state; AL = Alagoas state; SE = Sergipe state, BA = Bahia state. NBC = North Brazil current. BC = Brazil current, sSCE = south South Equatorial Current, cSCE = central South Equatorial Current. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

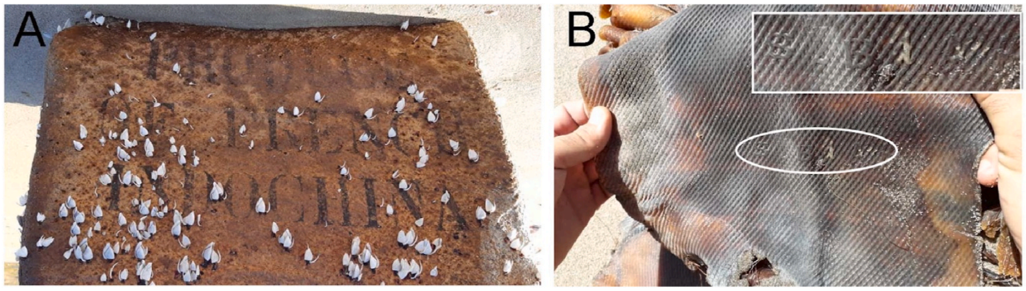

Fig. 2. Historical evidence about the origin of the packages: (A) rubber bale found in northeast Brazil with the stamp "Product of French Indochina"; the Southeast Asian colony (actually Vietnam, Laos and Cambodia) that ceased to exist after 1953. (B) The word "SBIAK" in one of the packages. This word came from the Khasi people, an indigenous ethnic group of Meghalaya in northeast India who lived in French Indochina.

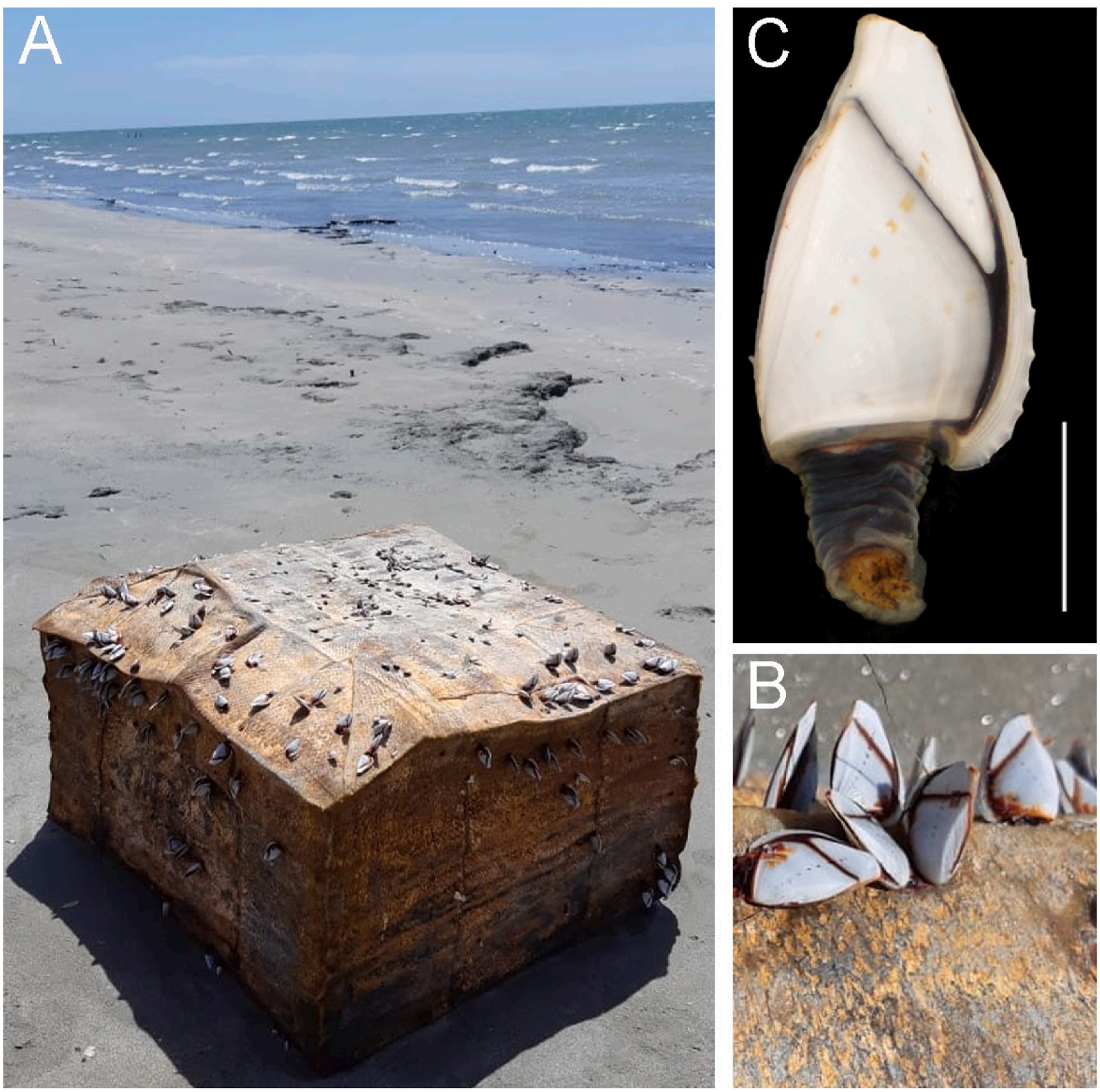

Fig. 3. Biological evidence about the origin of the packages. A. Crude rubber in bales on the tropical coast of Ceará (northeastern Brazil) – size (60x70 × 40 cm); B. Detail of presence of the oceanic species *Lepas anatifera* attached to the package; C. *Lepas anatifera*, a barnacle not found on coastal regions. Scale bar: 1 cm. The voucher material of this species was deposited in the Crustacean Collection of the Departamento de Zoologia of the Universidade Federal do Rio Grande do Sul (catalogue number UFRGS 6847).

This fact indicates that the bales had been floating on the sea surface for at least one month. No other coastal organisms were found on the bales. The French Indochina stamps discussed above indicate that the rubber bales were made prior to 1953. Moreover, since no coastal organisms were found attached to the rubber bales we hypothesized that the bales possibly originated from a deep shipwreck located beyond the limits of the continental shelf. Our hypothesis was that the bales, contained within the shipwreck that carried them as cargo, was somehow released and subsequently floated to the surface of the ocean whereby they were then transported by oceanic currents towards the Brazilian tropical coast. During the time they drifted in the surface waters the packages were colonized by the oceanic species *L. anatifera*.

Third, looking into the history of ships sunk in the South Atlantic, we found two WWII shipwrecks that were carrying large cargoes of crude rubber; the SS *Rio Grande* and SS *Burgenland* (Sixtant, 2020; US Navy Department, 1968). These two shipwrecks were German blockade runners intercepted by the Cruiser USS *Omaha* (CL-4) and Destroyer USS *Jouett* (DD-396) on 4th January 1944 in the vicinity of 06° 41"S, 25° 57"W and 05° 25"S, 25° 00"W, respectively. It was reported they were carrying a vital cargo of 500 tons of Tin, 2370 tons of Copper, 311 tons of cobalt and crude rubber in bales with French Indochina markings (Sixtant, 2020; US Navy Department, 1968). These shipwrecks are approximately 1000 km (~540 nautical miles) off the Brazilian coast and, consequently, in the high-seas (>200 nautical miles) outside the Brazilian Economic Exclusive Zone.

The wreck of the SS *Rio Grande* was first discovered on 28 November 1996 by the British company Blue Water Recoveries (BWR) using side-scanning sonar technology (BWR, 2020). Two days after the initial discovery BWR positively confirmed the identity of the shipwreck as the Rio Grande using a remotely operated vehicle, that investigated the shipwreck to confirm its cargo and to recover a sample artefact (David L Mearns; personal communication). The extreme depth where the SS *Rio Grande* was located (5,762 m) was later independently recognised by Guinness as an official record for the world's deepest shipwreck (Guinness World Records, 2006) ever visited. At the time of the discovery in 1996, the hull of SS *Rio Grande* was broken in two (David L Mearns; personal communication). After 86 years in the water, its current corrosion status is unknown.

Finally, numerical models provide the last evidence to support the hypothesis of the origin of the crude rubber bales from one of these WWII shipwrecks. The particles released at the surface from the SS *Rio Grande* position followed the south branch of the South Equatorial Current (sSEC) towards Brazil and arriving in the shelf-break region around 6.6° S. From this region, the particles were then transported north-westward and southward and reached the coast in many places from Alagoas State to Maranhão State (Fig. 4 – upper panel), showing that bales released in the vicinity of the SS *Rio Grande* shipwreck can reach the places where the bales were reported (Fig. 1). From the shelf-break region around 6.6° S, the bales can also be transported southward by the circulation within the shelf (Fig. 1).

The particles released at the surface from the SS *Burgenland* position also followed the South Equatorial Current (SEC) towards Brazil, but since the shipwreck is located further north than the SS *Rio Grande,* it took the central branch of the SEC (cSEC) and arrived at the coast in the Maranhão and Pará States (Amazon coast), westward from where most of the bales where found (Fig. 4 – lower panel). The mean shelf circulation westward from the Rio Grande do Norte State is always towards the west, driven by the trades winds, so the bales that arrived in the Maranhão and Pará States coast will always be driven in this direction by the currents. This modelling does not match with the distribution of the rubber bales actually found along the Brazilian coast (Fig. 1).

Altogether, despite the uncertainties about the dates the rubber bales

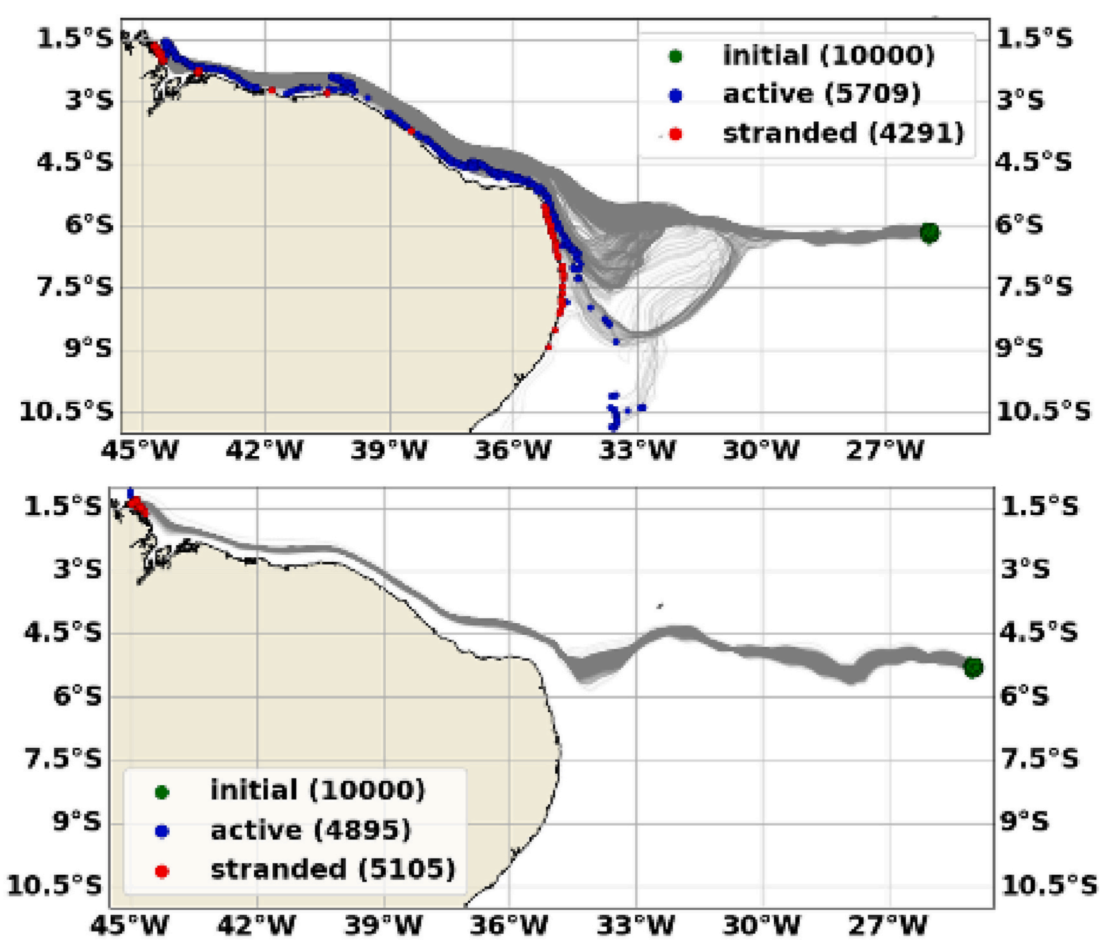

Fig. 4. Numerical modelling evidence about the origin of the packages: Trajectory modelling showing the releasing position at the shipwreck SS *Rio Grande* (upper panel) and SS *Burgenland* (lower panel) (green dots) and the dispersion of the simulated 10,000 particles (rubber bales). Red dots denote particles that arrived on the coast and blue dots particles that are still active at the end of the simulation. Particles released on 20th of August of 2018 and followed for 90 days. The SS *Rio Grande* numerical modelling (upper panel) match with the distribution of packages along the Brazilian coast, while the SS *Burgenland* simulations (lower panel) do not match (see Fig. 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

arrived in the ocean surface, the simulation with the particles released at the SS *Rio Grande* position matches with the distribution of the WWII rubber bales actually found on the coast. However, the simulations from the SS *Burgenland* position does not match with the site of the impacted beaches.

At this point, we are not sure what the real cause of the bales release is. Corrosion at deep ocean sites is expected to be small, due to the low temperature, high pressure and small current velocities. Based on laboratory and field measurements Kuroda et al. (2008), estimated the corrosion rates to be between 0.04 and 0.06 mm/yr at 5000m. However, these rates can be increased by microbiologically influenced corrosion (Moore, 2015), like the metal-eating, species of bacteria that are expected to reduce the wreck of RMS Titanic to rust in decades (Cullimore and Johnston, 2008). Also, iron in contact with a less active metal like the SS *Rio Grande* cargo (tin and copper) corrodes more rapidly than when alone (Herdendorf and Robbins, 2020). We do not have information about the current corrosion state of the SS *Rio Grande*, but that could lead to the bales release. There is also evidence that unauthorised salvage of metal cargo from the SS *Rio Grande* (almost $32 million worth cobalt cargo in 2018 prices) was taking place at the same time the unidentified packages arrived upon the Brazilian coast (David L Mearns; personal communication). While this salvage would cause the hull of the wreck to be opened up and the rubber bales to float to the surface due to their natural buoyancy, the rubber itself would have no commercial value and thus would not be recovered by the unauthorised salvors.

We suggest SS *Rio Grande* are also the origin to the bales are that appeared in Belize and Palm Beach in 2020 (Miller, 2020) since the Atlantic Ocean circulation is able to transport the bales from the Brazilian Coast into this Caribbean region. However, further investigation is needed to confirm the same origin.

4. Discussion

Shipwrecks around the world are cryptic sources of oil and other hazardous substances (e.g., mercury and polycyclic aromatic hydrocarbons) which, if discharged, could have a long-term effect on the health of oceans and coastal zones. Thus, they are a potential threat to the marine environment and local people who depend on it for their sustainability and/or livelihoods (Landquist et al., 2013, 2014). Shipwrecks deteriorate through a variety of causes, and with time the probability of leaking increases (Landquist et al., 2014). As they age their metal structures deteriorate, thus threatening the release of their contents into the sea (Council of Europe, 2012). During World War II (1939–1945) the largest loss of ships in a relatively short period of time, which produced shipwrecks that have been submersed in marine conditions for almost 86 years (Monfils et al., 2006; Landquist et al., 2014) like the present case of the German ship SS *Rio Grande*.

Due to the concerns about the health of the marine environment and the need to protect the oceans from pollution, sunken ships have recently been receiving increased attention as an emergent threat worldwide (Monfils et al., 2006; Council of Europe, 2012; Ndungu et al., 2017). Unfortunately, this is not the case in the South Atlantic Ocean. Recently, tools for quantitatively estimating the potential risks from polluting shipwrecks have been discussed (Carter et al., 2021; Monfils, 2005; Monfils et al., 2006; Landquist et al., 2013) in order to support remediation by governments and other potential actors. More than 500 shipwrecks from WWII are known to exist in the South Atlantic Ocean (Sixtant, 2020). However, no risk assessment has not been conducted. Not only chemical substances can originate from these shipwrecks. The present case of rubber bales shows that they can be an important source of marine debris in the world's oceans.

In this way, in 2012, rubber-like blocks, known as "*Tjipetir*", washed beaches across Europe (Spain, France, Netherlands, United Kingdom, Denmark and Sweden). The blocks were made of gutta-percha: the gum of a tree found in the Malay Peninsula and Malaysia that probably came from a Japanese ship, the *Miyazaki Maru*, which was sunk on 31 May 1917 by the German submarine U-88 west of the Isles of Sicily (Cacciottolo, 2014). "*Tjipetir*" was the name of the rubber tree plantation (Cacciottolo, 2014). Similarly, some rubber-like packages found on Britain's coast had the inscription "Prey Estate", which indicated the name of the rubber tree plantation. Similarly, rubber packages marked with the name "*Senawang*" were found in Cornwall (UK) in 2016 (Fenwick, 2016). These similar inscriptions also helped us to provide historical evidence to hypothesize the origin of the rubber bales from French Indochina.

There is an emergent threat of global marine pollution from over 7800 sunken WWII ships, including over 860 oil tankers, that have been corroding for more than 80 years at the bottom of the sea (Monfils, 2005). In this way, the paths followed by the bales released from the SS *Rio Grande* are somehow similar to the oil spill that reached the Brazilian coast at the end of 2019 (Magris and Giarrizo, 2020; Soares et al., 2020a). These two events (oil spill and rubber bales) are probably unrelated because the total amount of oil that reached Brazil is larger than the volume of fuel oil carried by the SS *Rio Grande* (US Navy Department, 1968). However, the hypothesis that the source of the largest oil spill ever recorded in Brazil (Soares et al., 2020b) may be from a shipwreck cannot be excluded until further geochemical analysis is conducted. Moreover, other WWII shipwrecks have coal and mineral-based oil in their cargo (Landquist et al., 2014; Faksness et al., 2015; Ndungu et al., 2017) and represent a permanent and overlooked risk of new oil spills disasters in the South Atlantic Ocean.

5. Conclusion and final remarks

Using a multi-disciplinary approach whereby multiple lines of evidence were assessed (chemistry, marine biology, history and oceanographic modelling), we found that unidentified packages that appeared along an extensive stretch of the Brazilian coastline are bales of raw rubber from the second World War (WWII), and that the source is almost certainly the SS *Rio Grande* shipwreck. This is also the origin to the bales are that appeared in Belize and Palm Beach in 2020. Our findings highlight the importance of analysing the ecological and human risk of these old vessels sunk in the South Atlantic basin.

We call for the urgent adoption of three main management and scientific outreach measures. Firstly, remove the bales from the coast and give examples to national museums to provide environmental and historical education about this important period in human history (Huang, 2014) and the wreck-borne pollution on the world's sea floor (King 1995; Monfils et al., 2006). This measure is important in order to avoid human disasters like the collision of vehicles and to stop the fragmentation of these rubber bales and consequent release of microplastics in the oceans (Andrady, 2017; Frias and Nash, 2019). The second important measure is the creation of a database of these WWII shipwrecks in the South Atlantic (their location, high-resolution mapping, cargo, current state of conservation and pollution potential) (Monfils, 2005; Landquist et al., 2014). Finally, we call for international collaboration to protect these numerous and understudied vessels such as the shipwrecks that are outside the Exclusive Economic Zone of the countries (Monfils et al., 2006; Lin, 2020).

These three measures require the adoption of national, international, transnational, public and private policies due to the fact that many of these shipwrecks have sunk on the high-seas and are thus outside the economic exclusive zones of the countries bordering the Atlantic oceans. The laws and policies of the coastal States in whose waters the shipwrecks are found are not adequate. Moreover, as the States concerned generally lack the capacity to protect such wrecks, bilateral arrangements have to be urgently made (Monfils et al., 2006; Lin, 2020). Despite being located in international waters these shipwrecks represent a time-bomb for contamination to bordering countries in this ocean basin (e.g., Brazil). Most of these old vessels have hazardous material (e.g., crude oil, radioactive waste, ordnance, and plastics), which represents an environmental and human health risk to South Atlantic ecosystems, human communities and their bordering low-income countries. These shipwrecks represent underwater cultural heritage and human history (Pater and Oxley, 2014; Lu and Zhou, 2016) and they can no longer be left unattended.

Authors' contributions

CEPT and LEAB conceived and coordinated the study and found the Historical evidence about the origin of the packages. FBR and LEAB analyzed barnacle species. CEPT did the numerical simulations. RMC did the chemical analysis. MOS discussed the environmental risks. All authors helped to write and have read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

MO Soares thanks the Conselho Nacional de Desenvolvimento Científico e Tecnológico—CNPq (Grant Numbers 307061/2017-5, 313518/2020-3, 442337/2020-5), CAPES PRINT Programme, I-plastics (JPI Oceans Consortium), and FUNCAP (Chief Scientist Program) for the financial support. This research was carried out under inctAmbTropic phase II (CNPq Process 465634/2014-1) linked to MCTI Emergency Action to combat the oil spill. RM Cavalcante thanks CNPq (Research Productivity Fellowship, 315281/2020-0). FB Ribeiro thanks to CAPES postdoctoral fellowship (PNPD, proc. n° 88887.470134/2019–00). Carlos Teixeira thanks the FUNCAP/PRONEM PNE-0112-00007.01.00/16 for the financial support. LEA Bezerra thanks CNPq Research Productivity Fellowship (Number 310165/2020-2).We also thanks David L Mearns from Blue Water Recoveries (BWR) for the discussions about the SS *Rio Grande* Shipwreck.

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