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Historical shipwrecks in international waters contributes to coastal pollution

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Abstract

In 2021, rubber bales appeared along the Brazilian coastline, causing environmental impacts. In this research paper, we identified a Second World War shipwreck that was associated with this event. Numerical simulations provided robust evidence to support the hypothesis that the origin of the 2021 bales was the MV *Weserland*. Moreover, it was sunk to a depth of approximately 5,000 m with a cargo containing rubber, tin, and wolframite. Tin is currently considered a strategic metal, with prices rising from USD 13,375/t in March 2020 to USD 34,462/t in May 2021. We provided evidence that the departure of rubber bales from the wreck and the increase in the price of its metal cargo were temporally associated; this reinforced the hypothesis of deep-sea unauthorized salvage in international waters (areas beyond national jurisdiction). The novel results demonstrate that historical shipwrecks are ticking time-bombs with risks of high and unmapped pollution in oceans worldwide.

Keywords: Rubber debris, Shipwrecks, Second World War, Brazil, Marine pollution

Shipwrecks have been recognized as a threat to the world's oceans due to oil and other substances they carry, as well as uncertainty over the probability and time of release (Landquist et al., 2013; Carter et al., 2021). Moreover, shipwrecks also serve as stepping-stones to increase the distribution of invasive marine species (Soares et al., 2016; 2020). In this regard, various methods of environmental risk assessment of shipwrecks have been proposed, helping to support decision-making about mitigation measures (Landquist et al., 2013; MacLeod, 2016).

Every shipwreck is unique regarding its potential environmental risk, proximity to vulnerable marine environments, and the probability of discharges (Monfils, 2005; Landquist et al., 2014; 2017). Even worse are the cases of historical shipwrecks in international waters, currently located in deep areas (> 3,000 m) of the ocean floor that are beyond national jurisdiction (Shi, 2020; Ma and Zhou, 2021). In such cases, the exact location and associated risks are practically unknown by countries and society, and financial costs of mitigation are likely to be correspondingly greater (Monfils et al., 2006).

The Second World War (WWII) witnessed the largest loss of shipping in a relatively short period

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(six years) that the world has ever known (Monfils, 2005; Renzi et al., 2017). Wrecks from this period have been submerged under marine conditions for approximately 80 years, implying that leakages could occur due to natural corrosion and biological activity on the iron structures (Faksness et al., 2015, Teixeira et al., 2021). Moreover, they may have recently been exploited by salvage companies owing to their economically valuable cargo (e.g., tin, copper, and cobalt) (Teixeira et al., 2021), lack of enforcement in international waters, and non-compliance with strict environmental regulations, considering that these are outside national jurisdictional areas (Ma and Zhou, 2021). Despite the large number of WWII shipwrecks and their risks, few mapping studies (Lin, 2020; Carter et al., 2021) report on impacts of cargo release from them.

One of the most extensive and inadequately studied oceanic regions containing shipwrecks is the South Atlantic, located between Africa and South America (Foltz et al., 2019). Despite the low military involvement of developing countries in this region, this zone was the target of intense military activity for geopolitical reasons and access to Europe, the Caribbean, and North America (Hudson and Urquhart, 2022). More than 500 shipwrecks from WWII have been reported in the South Atlantic (Soares et al., 2020), most of them along the coasts of Brazil and Africa, and in international tropical waters due to a strong naval blockade between the Allies and the Axis countries (Sixtant, 2021; Teixeira et al., 2021). However, information on environmental risks from WWII shipwrecks that remain on the seafloor in this large oceanic region remains inadequate despite statements such as those in the Declaration of Belém (1988), which aimed to expand research and environmental policies in this unique ocean basin region.

In 2018 and 2019, unidentified packages were found along 1,600 km of the Brazilian coastline, north of Sergipe State. Some of these rubber bales were also found in Florida, USA, in 2019 and 2020 (Teixeira et al., 2021). Teixeira et al. (2021) identified them as crude natural rubber in bales from French Indochina (before 1943). Moreover, based on numerical modeling on the impacted area, they identified that this marine debris came from a deep (approximately 5,762 m depth) WWII shipwreck (MV *Rio Grande*) (Teixeira et al., 2021). However, this was not the first record of rubber bales in this region. Throughout 1944, many local fishers in northeastern Brazil earned money salvaging and selling floating rubber bales from cargoes of German ships that had been sunk near the coast by the United States planes and boats during WWII (Cutler, 1946). The present case demonstrated unknown risks of historic shipwrecks in international waters (in areas beyond national jurisdictions). In this baseline assessment, we identified a second WWII shipwreck associated with a more recent pollution event (2021) off the Brazilian coast. Moreover, our novel data reveal that these ships have high (and scarcely known) environmental risks due to private interests and their economic exploitation of these cargoes.

Examination of materials and their source

In July 2021, rubber bales were reported again, but this time along the coast of the states of Alagoas, Sergipe, and Bahia (approximately 300 km long), located further south from where MV *Rio Grande* had sunk (Figure 1). The large number of bales (more than 200) and their arrival in a different southernmost region drew attention to what could be a new leak, rather than those remaining on beaches from the MV *Rio Grande* leak that had been detected by Teixeira et al. (2021). Recently, from October 2022 to February 2023, rubber bales have been reported in the states of Rio de Janeiro, São Paulo, and Rio Grande do Sul, as well as in Uruguay.

In addition, rubber bales had a newer appearance than those of 2018 (Figure S1; Supplementary Material), which indicated that they had not been reworked by waves, tides, and sediment burials near Brazilian beaches during the three years since their appearance in 2018. In 2021, bill (rostrum) fragments taken from a rubber bale found on the coast of Sergipe were identified as belonging to the Blue Marlin *Makaira nigricans* Lacepede, 1802, based on Fierstine and Voigt (1996), Fierstine and Crimmen (1996), and De

Gracia et al., (2022) (Figure S2). This fish species lives in epipelagic tropical and subtropical ocean waters, with surface temperatures above 25°C and rarely recorded close to the continental shelf and islands, unless there are deep waters (> 1,000 m). Blue Marlin is the most tropical among billfishes and is considered an extremely migratory species, capable of trans-oceanic movements (Collette and Graves, 2019). Voracious and an opportunistic predator, the Blue Marlin uses its bill to strike and kill prey, mainly large fishes and squids, frequently in near-surface waters (Shimose et al., 2007; Collette and Graves, 2019). This showed that the rubber bales came from the open sea (Cutler, 1946), where shipwrecks are found in deep areas and outside national jurisdiction areas (Figure 1).

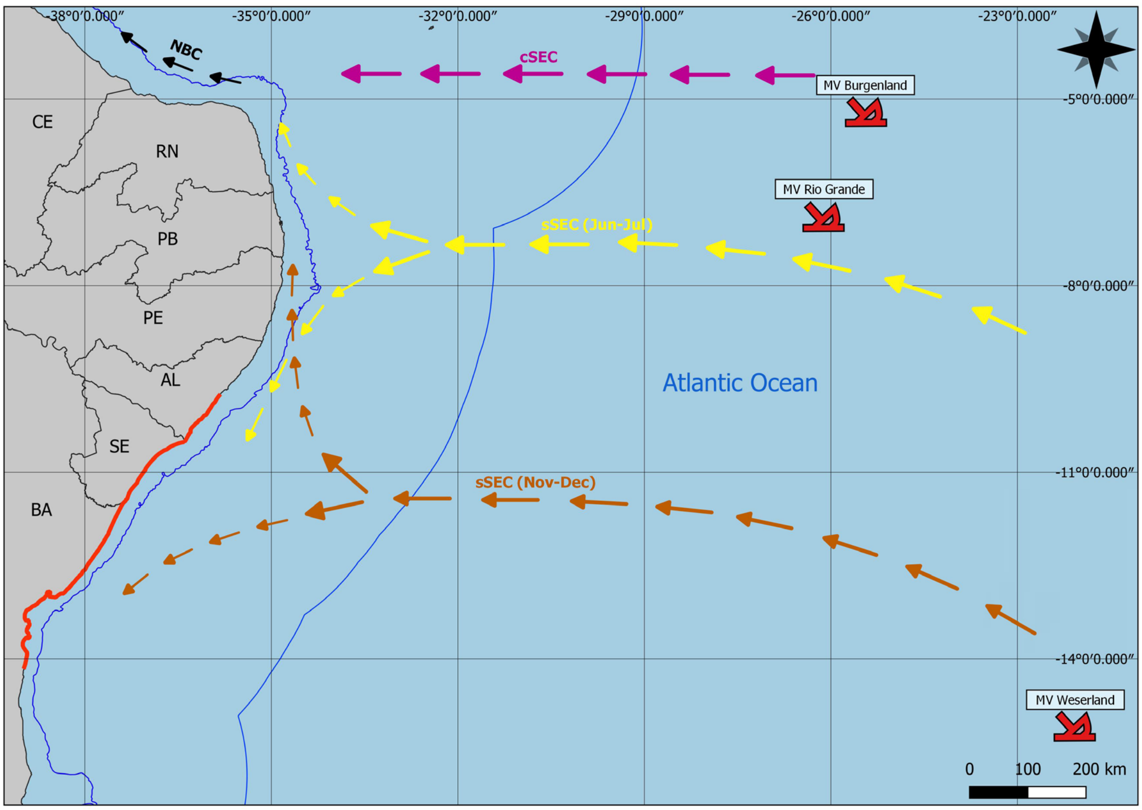

Figure 1. Spatial distribution of rubber bales in 2021 (in red at the coast), which differs from areas affected by the 2018 and 2019 event (whose origin was the MV Rio Grande, according to Teixeira et al. 2021). The arrows denote the ocean circulation in the region: NBC = North Brazilian Current (black); cSEC = central branch of the South Equatorial Current (purple); sSEC =south branch of the South Equatorial Current southernmost position (Nov-Dec) (brown) and northernmost position (Jun-Jul) (yellow). Brazilian states denoted by: CE (Ceará), RN (Rio Grande do Norte), PB (Paraíba), PE (Pernambuco), AL (Alagoas), SE (Sergipe), BA (Bahia). The blue line near the shore shows the limits of the continental shelf and the one far from the coast shows the limit of the Brazilian Exclusive Economic Zone. Thus, the three cited shipwrecks (MV Burgenland, MV Rio Grande, and MV Weserland) are in international waters.

The Blue Marlin is known to impale sea turtles (Frazier et al., 1994; Fiedler et al., 2022), oceanic sharks (Fierstine et al., 1997), cetaceans (Oshumi, 1973), and even small boats (Fierstine and Crimmen, 1996), so this record of a bill in the rubber bale is not surprising. Using the evidence discussed above, we evaluated the hypothesis that a new leak from another WWII deep-sea shipwreck from international waters occurred. In this regard, we used historical, biological, and numerical modeling to verify the origin of this recent leak and the potential shipwreck source.

The first evidence to support this hypothesis of a new WWII shipwreck/leakage was the absence of writing in the language of the former French Indochina, as had been found in the 2018 bales that belonged to MV *Rio Grande* (Teixeira et al. 2021). In contrast, the analysis of the 2021 bales revealed the novel presence of Japanese Kanji ideograms, which have not been recorded in any of the rubber bales (> 200) that appeared in 2018 (Figure S3). In addition, after translating the content written in Japanese, the term "Great Japan" was found, which was used during World War II for newly occupied territories outside the current islands of Japan.

This historical evidence (Figure S3), together with the aspect of the bales (Figure S1), suggests that they were produced on Southeast Asian rubber plantations that were under Japanese control during WWII and were being transported by German ships to provide rubber for the war effort (Cutler, 1946). Based on this evidence, a search was conducted for WWII shipwrecks located close to the region of these previous bales (Sixtant, 2021). The wreck of a German ship, the MV *Weserland*, was identified as a potential source of the debris. Similar to the MV *Rio Grande* and MV *Burgenland* (Teixeira et al., 2021), the MV *Weserland* was a blockade runner that was carrying a large cargo of crude rubber (Sixtant, 2021; US Navy Department, 1968). However, the route of the last voyage of this WWII ship differed significantly from that of the MV *Rio Grande*.

The MV *Weserland* began its journey to Europe on October 26, 1943, from Yokohama, Japan, which matched the Kanji ideograms on flotsam found along the Brazilian coast in 2021 (Figure S3). On New Year's Eve of 1944, the ship was located by a reconnaissance squadron of PB4Y-1 Liberators based on Ascension Island in the South Atlantic. The destroyer *USS Somers* (*DD-381*) sighted the MV *Weserland* on January 2, 1944, and sank the German ship at 00:30 on January 3, 1944, at position 14° 55' S 21° 31' W. The MV *Weserland* was sunk with its cargo of rubber, tin, and wolframite (mineral from which tungsten is extracted) at a depth of approximately 5,000 m (Sixtant, 2021; US Navy Department, 1968).

Modeling of ocean dispersion

In addition to this historical and rubber bales evidence, we used a numerical dispersion model to evaluate whether loads released by the MV *Weserland* would reach the Brazilian coastal region affected by the 2021 event (Figure 1). Moreover, we also evaluated the alternative hypothesis that the cargo from the 2021 event could be from the MV *Rio Grande* or MV *Burgenland* (also sunk in the deep-sea region of the South Atlantic) (Figure 1).

The particle-tracking model OpenDrift (Dagestad et al., 2018) was used to simulate the dispersion of rubber bales in the region. This software uses the Runge–Kutta fourth-order time-stepping method to calculate hourly particle positions based on ocean circulation data provided by an ocean model. We used the 1/12° spatial resolution and daily mean current data from the CMEMS PSY4QV3R1 Mercator Global Ocean Physics Analysis and Forecast provided by the Mercator-Ocean system (Lellouche et al., 2018) and validated to the region (Lessa et al., 2021), as the ocean model source for the OpenDrift Model.

A total of 10,000 virtual particles (i.e., simulated bales) were released in the MV *Rio Grande*, MV *Burgenland*, and MV *Weserland* shipwreck positions, and the particle trajectories were tracked for 90 days based on daily outputs (Figure 2). Particles were released in a 10 km radius around the shipwreck sites on March 15, 2021. This date was chosen based on tests performed for particles arriving on the coast around the end of July 2021 and coincided with the time when rubber bales began to arrive on the Brazilian coast (Figures 1 and S1). The three WWII shipwreck positions were chosen because these ships were carrying rubber bales at the time of sinking (Sixtant, 2021).

Particles released at the MV *Weserland* shipwreck site were transported by the south branch of the South Equatorial Current and arrived at the states of Bahia, Sergipe, and Alagoas on the Brazilian coast. These matched the distribution of packages found along the Brazilian coast in 2021 (red color in Figure 2), while particles released from the MV *Burgenland* (gray color) and MV *Rio Grande* (green color) did not match (Figure 2). Rubber bales that surfaced around the MV *Rio Grande* and MV *Burgenland* shipwrecks in March 2021 would be transported by the central branch of the South Equatorial Current (Figure 1), which is positioned southward at this time of the year, reaching the Amazon coast (Brazil) (Figure 2). As no rubber bales records were identified in this low-latitude region in 2021 (Figure 1), our numerical modeling supported the hypothesis that the 2021 event was not caused by these two WWII shipwrecks. In this regard, the positions of particles that had been released at the site of MV *Weserland* at a depth of 5,000 m (Figure 2) in international waters provide robust evidence that this shipwreck was the origin of crude rubber bales that arrived in Brazil in 2021 (Figures 1 and S1).

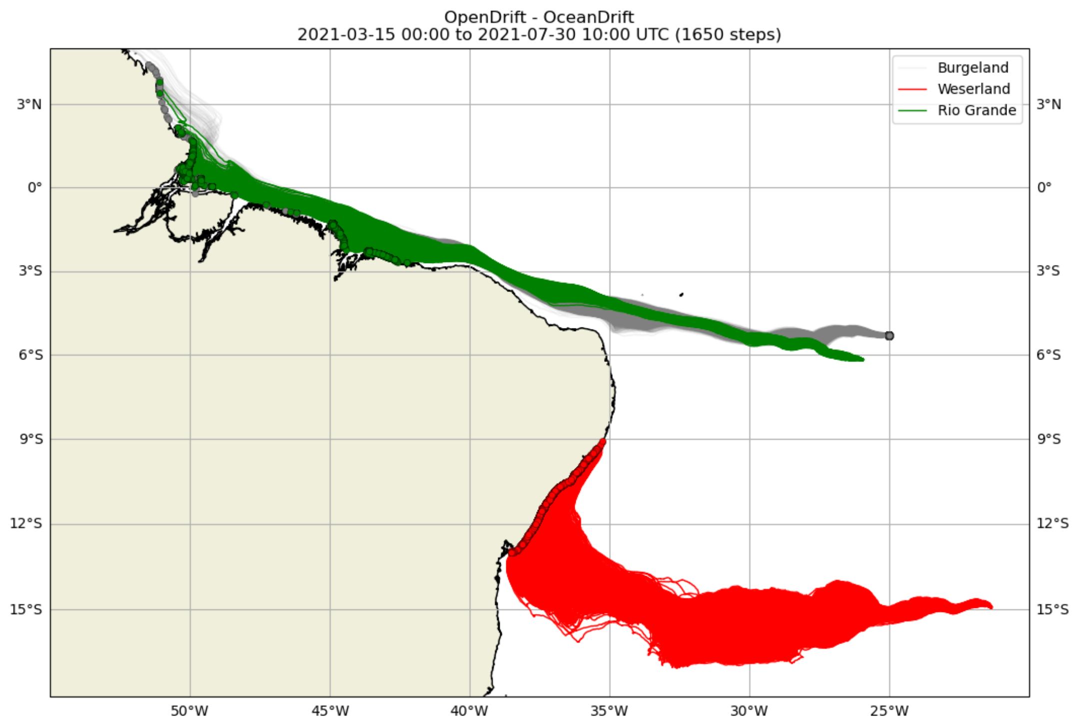

Figure 2. Numerical modeling provides robust evidence about the origin of the 2021 rubber bales. Trajectory modeling demonstrates the release positions (dots in ocean) and trajectories (lines) of the 10,000 particles simulating rubber bales released by the MV Rio Grande (green), MV Burgenland (gray), and MV Weserland (red). The dots on the coast denote particles that arrived on site. Particles were released on March 15, 2021, and followed for 90 days. The MV Weserland final destination (red) matches the distribution of packages found along the Brazilian coast in 2021, while the MV Burgenland (gray) and MV Rio Grande (green) trajectories do not match.

Hypothesis: Association with unauthorized salvage

As found for the MV *Rio Grande* (Teixeira et al., 2021), there is evidence that the unauthorized salvage of metal cargo from the MV *Weserland* took place in 2021, before the bales arrived on the Brazilian coast (David L Mearns; personal communication). Moreover, the MV *Weserland* held a tin cargo, which is currently considered a strategic metal (Lima, 2019) and is also one of the better-performing commodities on the London Metals Exchange (Figure S4). In fact, after a decline since 2015, global tin demand recovered strongly in the second half of 2020 and into 2021, driven by an increase in consumer electronic demand, which is set to continue beyond 2021, increasing prices from USD 13,375/t in March 2020 to USD 34,462/t in May 2021 (Roskill, 2021). The total amount of tin carried by the MV *Weserland* is unknown, but its cargo capacity (6,528 dwt) is comparable to that of other blockade runners of similar size, which are known to carry from 500 t (MV *Rio Grande*) to 2000 t (MV *Karin*) of tin (Sixtant, 2021; US Navy Department, 1968). Based on this cargo amount and the tin price in May 2021, the total cost of MV *Weserland* cargo could reach from 17 to USD 68 million.

The cost of running a salvage ship is about USD 35,000 per day (including staff), and the cost to haul the cargo to the surface can range from USD 5 million to USD 20 million (Burlingame, 2013). There is a debate if deep ocean salvage is profitable or not (Throckmorton, 1990; Kleeberg, 2013). The salvage costs can be reduced targeting specific vessels with known cargoes, whose coordinates are already reasonably well known. Companies have been doing this kind of salvage (ex: Odyssey Marine Exploration, Deep Ocean Search, Magellan Deep Water Specialists, Oceanic Research & Recover, etc) in recent years and cargo has been recovered deeper with time. In 1997, Blue Water Recoveries salvaged 179t of blister copper and tin ingots from the merchant vessel SS *Alpherat* from a depth of 3,770 m in the central Mediterranean (Blue Water Recoveries, 2022). Odyssey Recovery salvaged 110 tons of silver from the SS *Gairsoppa* from a depth of 4,700 m in 2011. The salvage SS *Gairsoppa* cost was USD 20 million and the cargo profit estimated at USD 76 million (Limsira, 2020). In 2013, Deep Ocean Search company salvaged 100 tons of silver coins worth almost USD 45 million, from the SS *City of Cairo* shipwreck located at a depth of 5,150 m (Deep Ocean Search, 2022).

These shipwreck metal cargoes have an extra profitable characteristic since they hold what is considered to be low-background metal, which is any steel produced prior to the detonation of the first nuclear bombs in the 1940s and 1950s (Jacobs, 2022). This kind of metal is used in devices that require the highest sensitivity for detecting radionuclides and in the microelectronics industry for microchips that require low-background lead components (Andrews, 2019). The scientific interest of pre-World War II steel from historical submarines and battleships has transcended its historical interest to be used in other domains, for example, medical research (Perez-Alvaro and Gonzale-Alba, 2015). In recent years, warships from the Second World War have vanished off the coasts of Malaysia, Indonesia, and Singapore, illegally ripped apart by salvage divers (Andrews, 2019).

Moreover, the departure of rubber bales from the wreck (Figure 1) and the increase in the price of their tin cargo (Figure S4) are temporally associated, which reinforces the hypothesis of deep-sea unauthorized salvage in international waters.

CONCLUSION

Other shipwrecks of blockade runners located in the deep waters of the South Atlantic Ocean, such as the MV *Karin* and MV *Burgenland*, also have valuable metal cargoes (Sixtant, 2021; US Navy Department, 1968). Since metals such as cobalt (MV *Rio Grande* cargo), tin, and tungsten (MV *Weserland* cargo) have increased in monetary value in recent years, deep-sea unauthorized salvage is expected to continue in these unmonitored areas, where there is also no enforcement beyond national jurisdictions. This opens a discussion on the need to regulate this type of cargo salvage (Fan et al., 2018; Lee et al., 2020) from historical wrecks in international waters (Shi, 2020; Ma and Zhou, 2021), whose cargoes, besides having great market value, also cause widespread pollution on adjacent and even distant coastlines (Lin, 2020; Carter et al., 2021). This occurred when rubber bales appeared on beaches off the coast of Brazil in 2018 and Florida (USA) in 2019 and 2020, causing environmental impacts and increasing risks to the physical wellbeing of people, including death (Teixeira et al., 2021). This novel record of a WWII shipwreck polluting South American beaches reinforces the notion that historic wreckages are ticking time-bombs for new pollution events in the world's oceans.

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AUTHOR CONTRIBUTIONS

L.E.A.B.: Conceptualization; Investigation; Writing – original draft; Writing – review & editing.

C.E.P.T.: Conceptualization; Investigation; Methodology; Software; Formal Analysis; Investigation; Writing – review & editing.

C.L.S.S.; R.M.C: Conceptualization; Investigation; Formal Analysis; Writing – review & editing.

M.O.S.: Conceptualization; Investigation; Formal Analysis; Writing – original draft; Writing – review & editing.

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