Dangerous Waters, GIS and the Management of Shipwrecks and Marine Disposal Sites from the Second World War

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As the distance between the Second World Wars and our current time continues to increase, the need to record the locations and conditions of the various ships lost during those wars and those disposed of afterward, especially those containing chemical weapons and explosives, begins to become an issue of more significant concern.

Technology in the Second World Wars had advanced to where warships were far larger than prior wars in both size and capabilities.[1] They also used materials that can be used and are in limited supply today, such as low-background steel. (Lin, 2020) The ships also contained asbestos, fuel oil and diesel, and various explosives that directly hazard navigation and the environment. (Monfils et al., 2006) In the immediate post-war era, the Allied nations disposed of most of their own and their former enemies' chemical and biological weapons stores by placing them in excess shipping and sinking them off the coast. (Rapp Learn, 2020) Many of the vessels also contain the remains of crew and passengers, numbering into the thousands in some cases. (Grządziel, 2020) As a result, ships, such as the USS Arizona, are war graves and environmental hazards. (Smith, 2004) This complex set of circumstances means developing an overall plan to handle the management of the sites. The complication of the need to preserve the graves of the men who died with them has become an international and multi-discipline issue with research already done in fields from psychology (Kirsner, 2015) to archaeology (Brennan et al., 2018) and, of course, GIS. (Bartoli et al., 2012) By looking at shipwrecks, and the dumping of chemical weapons in the immediate post-war era, we can get an idea of the scope of the issue.

[1] For a quick example the HMS Victory that was the flagship of the Royal Navy during the Napoleonic wars displaced just over 3500 tons, by the time of the Second World War, the HMS King George V, was listed at just 40,000 tons and by 1942 the IJN Yamato was over 72,000 tons (Crawford, 1999)

Then we can look at legal and moral issues before looking at the role of geospatial technologies in three areas. First, we will review the struggles of a small pacific island nation to manage the wrecks left from the war, second, how a single ship may cause big trouble in a major waterway, and finally get answers on the dangers of chemical weapons dumping in the Baltic. When these issues occurred, the problems they now have created were not considered. Using geospatial technologies to help solve issues like these shows how versatile this technology can be and shows that no matter when the issue occurred, geospatial technologies can help us correct the issues of the past.

An Overview of Sunken Ships from the Second World War

The number and locations of ships lost and dumping records during the Second World War era is challenging to quantify. Sailors abandoning ships in the middle of a battle often did not keep complete, accurate records of where and when their ship sank. When the war ended, Japan and Germany often destroyed their records from the conflict to prevent the Allies from obtaining them. (Skulski, 1988) The looming start of the Cold War caused even the western allies to not fully document or share their records, the Soviet Union (and today Russia) being especially reluctant to work with researchers. (Wilkinson, 2017)

Nevertheless, we do have some estimates of ships lost. The major naval combatants, the United States, United Kingdom, Japan, Germany, and Italy, lost over 1600 warships of all sizes during the conflict and thousands of other ships. Estimates range from 7807 (Monfils, 2005) to over 10000 total ships lost during the conflict. (Ellis, 1993)

Country	Carriers	Battleship/ Battlecruisers	Cruisers	Destroyers	Submarines
Nazi Germany	0	3	8	27	765
Imperial Japan	19	11	37	134	130
Italy	0	1	11	84	84
United Kingdom	8	5	30	110	77
United States	11	2	10	71	53
Totals by Ship Class	**38**	**19**	**96**	**426**	**1109**
		Total Warship Losses			**1688**

Table 1-Major Warship Ship Losses by Combatant (Ellis, 1993)

To give a sense of the scale, the U.S. Navy currently has 170 ships of the types shown in the table above (NAVSEA, 2021); during the war, they lost over 140 ships of the same types, nearly the total amount they have today. (Ellis, 1993) Japan, in particular, lost heavily 11 of 12 battleships, 37 of 43 cruisers, 137 of 169 destroyers, and all 15 of its fleet carriers between 1942 and 1945. (Dull, 1978)

Losses occurred in every corner of the globe. In the Pacific theater of operation, warships were lost as far north as the Aleutian Islands and as far south as the Coral Sea.

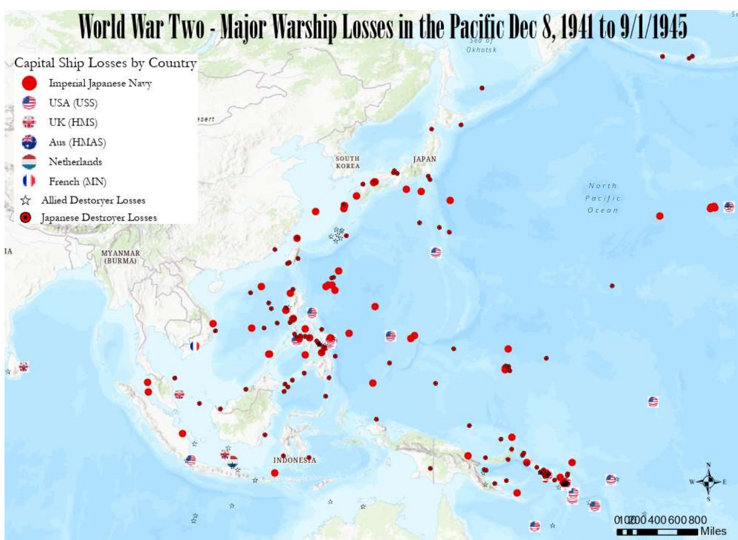

Figure 1- Major Warship losses in the Pacific (see Appendix 1 for sources)

The losses in the Pacific Ocean alone cover a vast amount of area without even considering losses across the rest of the globe during the conflict. With the ships rapidly deteriorating (or being illegally salvaged), the areas where these ships are and what threat they possess are becoming more of a focus for both government and researchers. (Monfils et al., 2006)

The Risks

So, what risk do these sunken ships pose? The most likely risks could be from any of the following, either singly or in combination: (Monfils, 2005)

- Explosive
- Fuel Oil
- Chemical

The first risk most people think of is that from explosives. World War Two naval vessels carried an enormous amount of firepower. A typical destroyer would have between 800-1000 rounds of 5in ammunition, weighing around 45 pounds per round, and smaller weapons ranging in size from 20mm to 40mm with even more ammunition and 8 to 10 torpedoes along with depth charges and other weapons. (Reilly & Johnson, 1983) When looking at ships the size of a battleship, the amounts ramp up quickly. Battleships had 8-12 guns sized from 14" to 18" in diameter, with around 800-1000 shells, along with as many 5in guns as four to five destroyers combined, and some ships had an additional 200 smaller guns as well. (Crawford, 1999)

For the Yamato Class battleships of the Imperial Japanese navy, each shell weighed in at an enormous 3200 pounds, which is about the standard weight of a modern Honda Accord, and they carried 900 of them. (Skulski, 1988) Carriers had not only gun armaments equal to several destroyers but also carried anywhere between 30-100 aircraft and their load outs a well. An

Essex class carrier of the U.S. Navy carried around 325 tons of ammunition for its aircraft, not counting the stock for the other firepower on board. (Dunnigan & Nofi, 1996) One would think that after nearly 80 years on the seafloor, these would be rendered inoperable, but as shown in Poland in October of 2020, World War Two explosives still do pack a punch, a 12,000 Tallboy bomb exploded while being defused in a Polish canal. No one was hurt, but the blast still sent a column of water into the air and forced the evacuation of residents within a 1.25-mile radius of the site. (Tanno, 2020)

Figure 2 - Tallboy explosion -Still from Polish Defense Ministry video (CNN, 2020)

Various fuels are also a significant concern. Ships carried anywhere from several hundred tons of fuel up to in the thousands along with more fuel if they carried aircraft. (Dunnigan & Nofi, 1996) Tankers were an especially high-value target.[2] (Potter, 1976) Overall, 801 tankers were sunk in the war, and enough records can be pieced together to show that around

[2] The US Navy made a concerted effort to sink Japanese tankers, and by the end of the war most surviving Japanese ships didn't have enough fuel to train must less fight. The lack of fuel for training was a factor in the decision as well to resort to Kamikaze tactics for the last year of the war. (Parsons, 1975)

79 in the Pacific were still full or carrying significant amounts of fuel oil and survived the sinking experience relatively intact. (Monfils, 2005) On those ships, they together carried around 248 million gallons of fuel oil. To try and give that some context, the Exxon Valdez spill in 1989 was around 11 million gallons. (US EPA, 2013) This estimate is a conservative calculation and does not include tankers with cargos other than oil, like benzene. (Monfils, 2005) One example of the risk they still have is that a 2001 leak from the sunken USS Mississinewa after a typhoon moved the sunken vessel caused damage to both the environment and the local community from the 20,000+ gallon spill and a six million dollar clean-up bill. (Gilbert et al., 2003)

The final risk is that from chemical munitions. The Second World War used almost every weapon imaginable, except widespread chemical and biological attacks. (Tucker, 2007) However, all nations involved manufactured the weapons, and at the end of the war, the victorious allies began to dispose of these in any way they could think of, including dumping them at sea. (Sanderson et al., 2009) This has led to several issues, primarily where dumping occurred in shallow water areas, like the Baltic Sea or the Japanese coast. However, those dumped in deeper water have no guarantee of staying there, as currents, storms, and even deep-sea fishing can move or transport them back towards the coast. (Bowers, 1995)

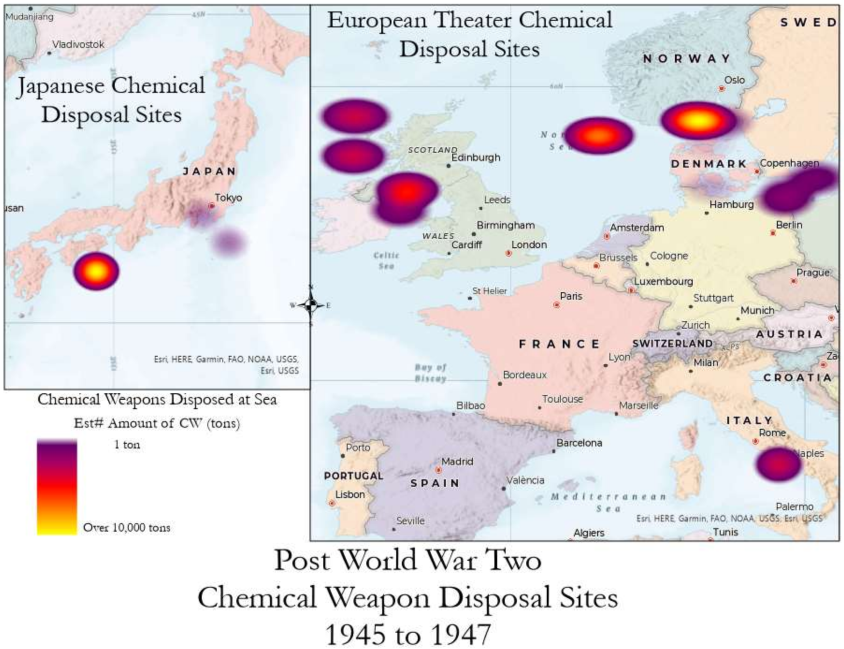

Figure 3 - Post War Chemical Dumping Sites (Appendix 2)

Chemical weapons react differently to the sea, many of the nerve agents break down in the water and pose no threat, but some, like those based on mustard agents, are not affected by water and can pose a severe threat when washed ashore or found in a fishing net. (Bowers, 1995) In 2010 several crewmen of a New York-based fishing boat reported injuries after finding several shells filled with Mustard Gas while fishing for clams. (Lindsay, 2010)

Current Management Efforts using Geospatial Technologies

Organizations ranging from the private sector to national and international government agencies have begun to work on projects to locate, record, and manage the sites and risks they contain. These efforts all use various geospatial technologies, including GIS databases and tools, many on advanced research ships, have begun to provide a framework for managing the issue.

The most famous of the private efforts is that of the R/V Petrel, a research vessel that the late Microsoft founder Paul Allen purchased to find historic shipwrecks, especially those from the Second World War. (LoProto, 2019) Equipped with the latest geospatial technologies, including autonomous and remotely operated undersea robots and multibeam echosounders on both the ship and the ROV's, give the R/V Petrel an ability to search as deep as 6000 meters(3.2 nautical miles) beneath the ocean surface. (Jaycen, 2017) As a result of the technology, since 2015, the ship has found over 30 ships lost during the war, including one, the USS Johnston, the deepest wreck ever found at 6200 meters (20,406 ft) below sea level. (Morelle, 2021)

Efforts to find the ships also come as organizations are developing GIS databases that record the sites of the sinking's and the potential risks for each location. (Masetti, 2008) Two significant efforts focused on the Second World War are the Pacific Regional Environmental Programme (SPREP) WWII shipwreck database and the Atlantic, Mediterranean, and Indian Ocean Database (AMIO), both developed in the last 20 years. (Monfils, 2005)

The United Nations SPERP organization consists of 26 members from around the Pacific, ranging from the United States to the Solomon Islands, and works to protect the environment of the Pacific region. (SPREP, 2021) The impetus to create the database was the major oil leak from the USS Mississinewa in the Federated States of Micronesia in 2001 mentioned above. Their database currently contains over 3800 wrecks, and the study has identified 53 wrecks that are the most in need of review and action. (Talouli, 2019) The AMIO database is of similar size, with nearly 4000 vessels of 1000 tons or larger, and has around 500 plus tankers as well in its tables. (Matika & Barić, 2016) It focuses on the areas not coved by the SPERP database, the Atlantic, Mediterranean, and Indian Oceans. In the United States, the National Oceanic and Atmospheric Administration (NOAA) also has shipwreck information, but only for U.S. waters. (NOAA, 2021)

GIS tools are also being used to determine the risk and locations of shipwrecks. In 2014 images from Landsat 8 were combined with elevation models on two wrecks off the coast of

Belgium. The wrecks had sediment plumes that were detectable by Landsat 8. By following similar sediment plumes back to their sources, this technique could find wrecks in coastal areas up to 50 feet deep and in areas where high sediment levels make use of LiDAR difficult. (Baeye et al., 2016)

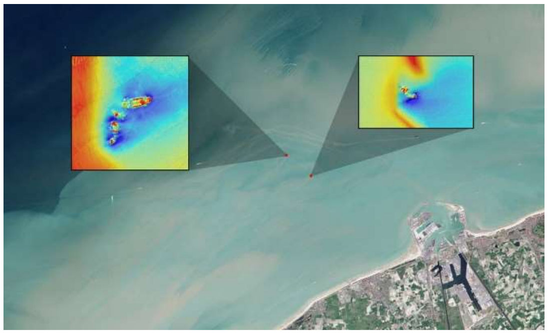

Figure 4 - Sediment Plumes from shipwrecks (Baeye et al., 2016)

GIS-based risk management and analysis for the wrecks are also occurring. The development of a Marine Site Risk index using an S-100 compliant GIS database allows for management and reduces the environmental and economic impacts of the wrecks. (Masetti et al., 2012) This GIS database would contain the location of the wreck, the risk to the environment, what level of risk, and keep track of other concerns, like national ownership and if the location is a war grave. Standardizing this information would give managers what sites need work now or in the future while providing a georeferenced set of records of sites and risks. (Masetti et al., 2012)

Other Complications

Of course, there are complications in how shipwrecks are analyzed outside the environment and technical limitations. Primarily outside the purview of this review, understanding them helps with the overall comprehension of the issue. These come in two significant areas, legal concerns and the issue of war graves.

As it is currently enforced and understood, the law of the sea holds that the wreck is the property of the nation that last owned it. A view that the United States, Japan, the United Kingdom, and others all vigorously defend. (Forrest & Corrin, 2013) While this works for wrecks located in deep water, for those located in the sovereign territories of another nation, this can bring complications to the study, salvage, or even mitigation of dangerous materials on the wrecks themselves. (Browne, 2019) The stance that the owning nation should not only be able to approve but then also have to pay for damages caused has left many of the sites in a sort of odd limbo, with the owning nation proclaiming ownership and rights to salvage but not wanting to pay for expensive remediation that could be needed. (Forrest & Corrin, 2013)

The other major issue is that of the human loss that occurred when the ship sank. Although no legal precedence has been clearly defined, many maritime laws avoid the human remains issue entirely. As a result, the issue of these sites as graves is highly contentious. (Varmer, 1999) Many of the Second World War shipwrecks are the graves of up to several thousand. (Skulski, 1988) Many western nations, the United Kingdom being the primary example, feel the sites should remain untouched due to the presence of those remains. (Browne, 2019) The stance is further strengthened by illegal salvage and treasure hunting, which often destroys the wreck and has items sold as souvenirs. (Torpy, 2015)

The worst loss of life in the war was the sinking of the German liner Wilhelm Gustloff by a Soviet submarine on January 30, 1945, with the loss of over 9000 lives, mostly civilians being evacuated from areas threatened by the Soviet army. (Prince, 2013) The Gustloff, rumored to have parts of the Amber Room looted by the Nazis, has since become a target of treasure hunters and other salvagers. (James Sidney Lucas, 2000) When the ship's bell was removed by sports divers and used a seafood restaurant centerpiece, the resulting international fallout was so extreme that the current Polish government has placed a 500m radius off-limits order to protect the wreck and those remains. (Petruskevich, 2021) Along with the legal complications, the issue around war graves gives another layer of complexity in determining the risk and the best way to fix issues posed by the Second World War shipwrecks.

Specific Case Studies

A few examples will be reviewed to explain the risks and how geospatial technologies are used to monitor, manage, and provide information on some of the complicating factors in dealing with the issues. Examples will include risks contained at the site of a significant naval campaign, the dangers posed by a single ship in a high traffic area, and finally, how chemical weapons dumping has impacted a region.

Guadalcanal – Ironbottom Sound The battle for the island of Guadalcanal was one of the pivotal campaigns during the Second World War in the Pacific. (Potter, 1976) In the first Allied offensive of the war, both sides poured men and material into the battle. From August 8, 1942, when the Allies invaded the island, until February 7, 1942, when the Japanese evacuated the island, there were seven major, and dozens of minor naval battles fought in the waters around the island along with a land campaign that involved nearly 100,000 troops from both sides. (Frank, 1990) So many ships sank in the small area that sailors referred to the waters around the island as "Ironbottom Sound." (Cox, 2020)

Figure 5 -Major Losses in "Ironbottom Sound" (Appendix 1)

Overall, losses were extreme for both sides; 111 total ships, including three carriers, two battleships, nine cruisers, and 14 destroyers, were sunk, many with nearly all hands[3]. (Maharaj, 1999) 1400 aircraft were also lost, and the human cost of between 14000 – 20000 deaths make the island one of the primary battlefields of the war. (Maharaj, 1999)

The government of the Solomon Islands, the world's 19th most impoverished country, is not well equipped to deal with the environmental and other issues posed by the leftovers of the war. (IMF, 2021) Being a member of the United Nations, Commonwealth, and SPERP, among other organizations, has enabled them to request assistance on what impact could occur from the wreck off their coasts. (Maharaj, 1999)

The first report was requested in 1999 from the U.N. using geospatial technologies like bathymetric data and first-generation GIS systems (MapInfo) to identify several risks present, the most prominent being oil and fuel leaks and the leaching of metals from the wreckage and munitions. (Maharaj, 1999) The report also stated that the records for what each ship carried

[3] The most famous of these may be the Sullivan brothers, all five of whom were lost on the USS Juneau when she was sunk by a torpedo after the 1st Naval Battle of Guadalcanal, only 10 of the 670 crew survived. (Cox, 2020)

were incomplete. Without that specific information, the report stated it was challenging to make any further risk assessments and recommended further study. (Maharaj, 1999)

In 2002 the Solomon's requested further help, noticing that coral reefs near some wreck areas were beginning to die. (UNESCO, 2010) This request, along with the previously mentioned incident with the USS Mississinewa, moved SPERP to start seriously developing strategies to deal with the wrecks of the Second World War. (Monfils et al., 2006) It also led the SPERP to develop the SPERP Shipwreck Database and adopt a regional strategy for dealing with the issues. (SPREP, 2019) However, implementation has been complicated as some member states prefer to make deals outside of the agreement framework due to economic concerns. (RNZ, 2017) For many Pacific island states, diving on the wrecks is their primary tourism attraction and main economic generator. (RNZ, 2017)

In the end, while the Paul Allen Foundation missions with R/V Petral have identified more wrecks and their locations in the area, little more has been done to mitigate the threat and issues they cause. (SPREP, 2019) Contributing to this is the complications of international law, noted earlier, which holds that the shipwrecks are still the property of the state that originally owned them. So those nations would be responsible for the clean-up and cost associated with them. (Forrest & Corrin, 2013) The Solomon Islands and other small nations in the Pacific have to rely on the United States, Japan, and other major powers to want to take action and be willing to pay for it, a situation that rarely leads to much action, well, until a tragedy occurs. (Browne, 2019)

SS Richard Montgomery – On August, 8th 1944, convoy HX-301 had completed crossing the Atlantic with little trouble. The 130 ships had left New York harbor on July 25 and arrived in Liverpool with no losses. The ships then moved to unload or wait for further orders at various locations. One of these ships was the fully loaded Liberty Ship SS Richard Montgomery. (Hague, 2021) She was sent to the Thames estuary to await another convoy that would take it to Cherbourg, France. However, fate intervened at that moment. (Alexander, 2019)

On arrival at the estuary, the Harbormaster ordered her to drop anchor and wait for the convoy to France. The location for the ship to anchor in only had about 10 meters of draft, and the Montgomery was, due to her fully loaded status, sitting at 9.45 meters. (Rowland, 2010) The Assistant Harbormaster protested, seeing the danger that this posed, and refused to give the orders to ship unless he got it in writing! (Alexander, 2019) He was to be proved correct, and he also worried, for he knew what the cargo was on the ship, over 6,000 tons of bombs and explosives[4]. (Alexander, 2019)

On August 20, a force-eight gale assaulted the anchorage. The SS Richard Montgomery's anchor came loose. She ran aground on a sandbank; her captain having slept through the grounding as no one dared wake him! (Alexander, 2019) The ship cracked in two, and despite some attempts at salvage and succeeding in removing about half the cargo. Salvage stopped on September 25, 1944, after the ship broke in half, leaving over 3500 tons of explosives on board, nearly 1.4 megatons. (Atkinson et al., 1972) After operations stopped on the ship, very little else happened as, for the next 20 years, the wreck and its contents were an "Official Secret of the British Government." (Alexander, 2019)

[4] For his troubles he was sent to another posting two days later. (Alexander, 2019)

Explosives still Onboard Estimates	Total Remaining On-Board	Weight in Tonnes
250 lb Bomb	2021	215
500 lb Bomb(General Purpose and Semi-Armor Piercing)	3332	714
1000 lb Bomb(General Purpose and Semi-Armor Piercing)	4022	1636
2000 lb Bomb	206	249
Cluster Fragmentation Bombs	2618	159
Phosphorus Smoke Bombs	1429	97
Pyrotechnical Devices	638	21
Fuses	225	11
Totals	**14491**	**3102**

Figure 6 - Explosives Remaining on the SS Richard Montgomery (Atkinson et al., 1972)

Marked on charts as a navigation hazard, with parts of the masts visible, she and her cargo remained. In the years since the United States offered several times to help remove the wreck and the hazard, nothing came of those inquiries. A clerical error resulted in the ship getting sold to a salvage group for a short period, and then the United States repurchasing it and claiming it had cleaned up the wreck, despite nothing being done. (Alexander, 2019) In the sixties, people would fish off the wreck, and fishing boats were told that if they found World War Two munitions to dump them on the site. Several near misses occurred as well as the wreck is located near major shipping lanes. (Alexander, 2019)

Figure 7- LNG Tanker passing the Wreck (Rowland, 2010)

The wreck sits near two main shipping lanes; one lane feeds the main Grain Liquefied Natural Gas terminal for the United Kingdom, a large petroleum farm, an electrical plant, and Sheerness, with a population of nearly 12,000. (Alexander, 2019) The other is the main shipping lane for

London, and estimates have over 5000 ships a year passing near the site on both lanes. (Rowland, 2010) Several proposals for a new airport for the London area include human-made islands near the site as well, though most have been denied to the presence of the wreck. (Airports Commission, 2014)

Reports began to wonder about the security and safety of the site. The first significant report written in 1970 directly contrasted the official stance that all was well. The Royal Military College of Science speculated that if the entire cargo went at once, a 3000-meter tall column of water and debris would occur, wiping out Sheerness and the LNG and petroleum installations nearby and that a wave, perhaps as tall as 50ft would travel up the Thames into London itself. (Hawkins, 1970) As a result, the government established a 100-meter exclusion zone that was finally put in place in 1973. (Rowland, 2010) By the mid-90s, a decision to conduct an annual survey of the wreck approved after much discussion. (Alexander, 2019)

While not all in agreement, these studies all have noted the significant risk the ship and its deterioration pose. The explosion of all or part of the estimated 1.4 megatons onboard has ranged from a local danger to one that might impact communities as far away as London. (Alexander, 2019) More recent studies reduce the effects of an explosion and place the danger zone between 2.5 and 5 miles, which would still encompass much of Sheerness and the surrounding areas. Other studies also show that to make the ship and its cargo safe, an estimated 50,000 people would need to leave their homes for perhaps as long as six months for the work to happen safely. (Britcher, 2021)

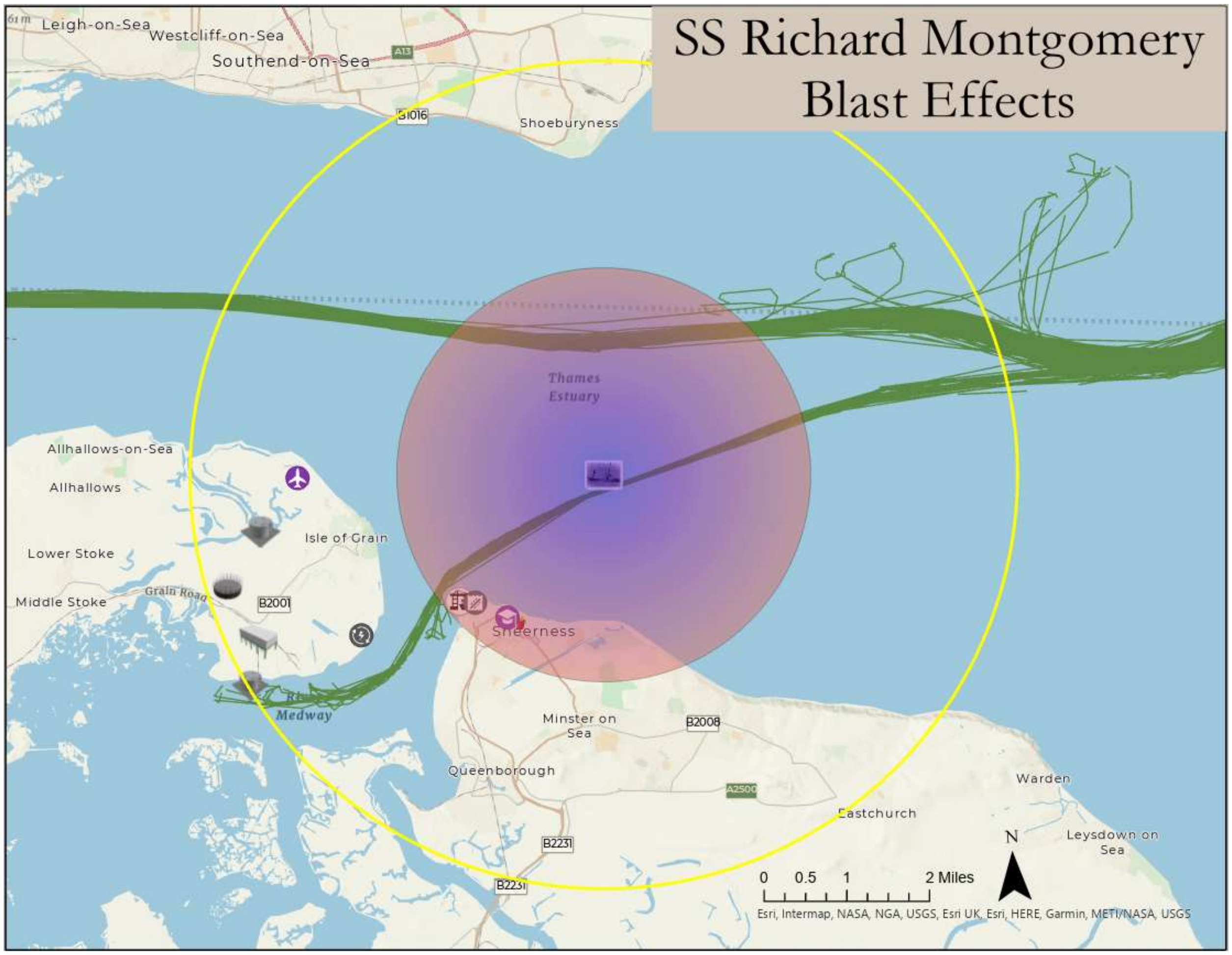

Figure 8 - the Wreck of the SS Richard Montgomery and the major sea lanes. (Appendix 3)

Using geospatial technologies to support research into the ship's condition and if her cargo is still a threat has taken several forms, from the analog to the digital. The first attempts involved a wooden model in a box of sand. (Alexander, 2019) Sonar, Multibeam echo sounders, laser scanning, GNSS positioning systems, and GIS software are a few of the technologies used since that attempt. (Alexander, 2019) One sonar survey in 2006 used the latest technology and a purpose survey vessel to produce high-quality images which showed the vessel, broken in two, and detail sharp enough to show safety railings and gunwales. (Rowland, 2010)

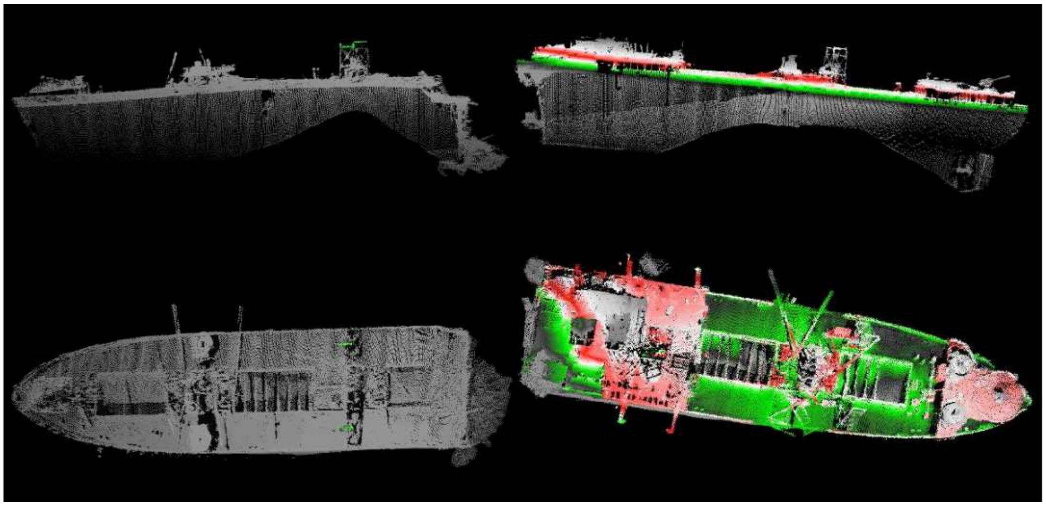

Figure 9 - the SS Richard Montgomery (Rowland, 2010)

By 2016 surveys advanced to where the detail was so precise to be able to show the exact positions of everything not inside the wreck are now surveyed. Ninety-six survey points are monitored and show that cracks continue to develop, and a minor collapse occurred on one of the decks in 2015. (Alexander, 2019) Surveys continue on the Montgomery every year, but the wreck continues to be a hazard in one of the most traveled and famous waterways on the planet.

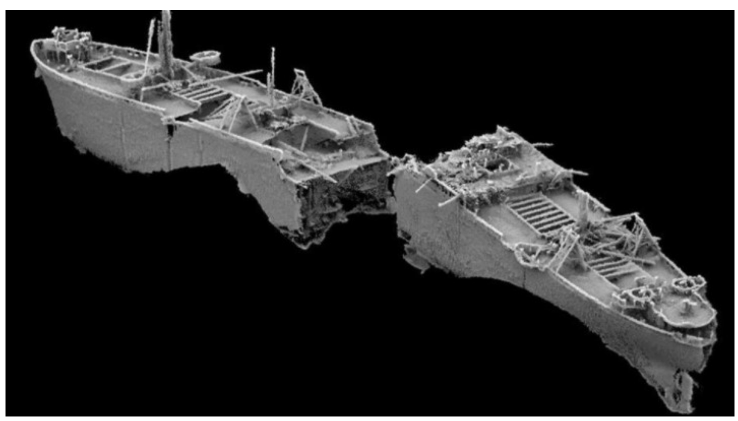

Figure 10 SS Richard Montgomery 2019 Crown Copyright

The Baltic, Chemical Weapons Dumping Ground

At the end of the Second World War, the victorious Allies faced a new issue, what to do with the fallen Nazis and Japanese empire's stocks of chemical weapons. (Vanninen et al., 2020) With science yet unable to safely dispose of the weapons with any methods other than burning, the Allies came up with a cheap and straightforward solution, load them on the remains of the Kriegsmarine and Imperial Japanese navy and scuttle the ship and the chemical weapons at sea. (Lastumäki et al., 2020) Alternatively, they just filled barrels, crates, boxes, even wicker baskets (with the thought they would absorb the Mustard agents if the shells cracked) and threw them overboard. (Chepesiuk, 1997) From 1946 to 1948, Operation Davy Jones Locker was the primary U.S. Army effort to dispose of the stockpile, and over 30,000 tons went into the Baltic, often with little or no documentation. (Vanninen et al., 2020)

Now, according to some scientists, the nations of the Baltic are heading for an ecological disaster. The shells are corroding, and some estimates say that they will crack open over the next 50 to 100 years and let loose the chemical weapons within. (Glasby, 1997) For some water-soluble agents, that is not going to be an issue, but for others like sulfur mustard-based agents, which polymerizes and floats as thick tarry globs that stick to fishing nets, it will be. (Missiaen et al., 2010) Over 200 cases in the Baltic of injuries to fisherman and beachgoers from the blobs, and those mustard glass blobs could remain dangerous for decades. (Rapp Learn, 2020)

Researchers use various geospatial technologies to support the research and evaluate the risk for the Baltic. Side-scan sonar and other technologies like acoustic-based sonar, swath-bathymetry sonar, and multibeam sonar is mapping the floor of the Baltic Sea to help find sites and evaluate if the sites have been disturbed. (Curry, 2016) Many have found fishing nets and lines entangled with the bombs. (Curry, 2016) Once a site is confirmed, a remote submersible records the site's condition and takes measurements on the chemicals in the water and sediment. (Curry, 2016)

GIS Datasets are also getting developed to help manage the issue. A custom GIS was built to help the MERCW (Modelling of Environmental Risks related to sea-dumped Chemical

Weapons) project. The GIS not only helped integrate the data that the project had accumulated to date but gave it the ability to add new data. (Goncharova et al., 2007) This allowed for several advantages, including risk assessments and planning for future studies is simpler due to the tools a GIS provides. (Goncharova et al., 2007)

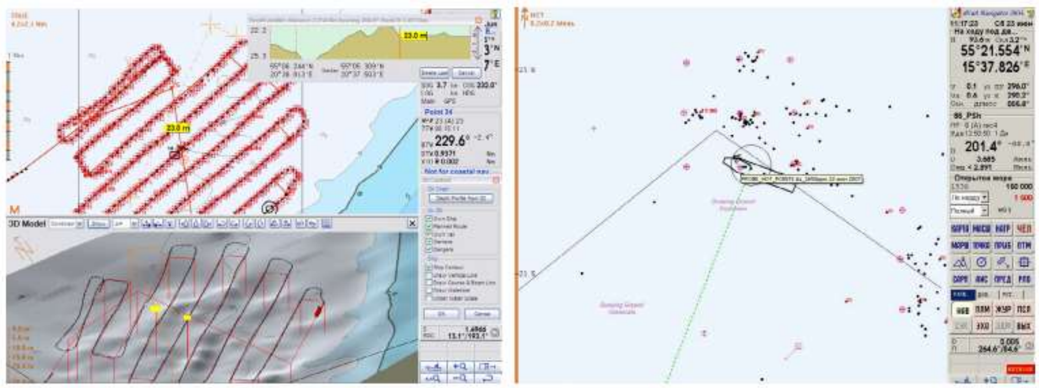

Figure 11- Images from the GIS developed for the MERCW Project (Goncharova et al., 2007)

The Baltic is just one area where scientists are using geospatial technologies to gauge the risk, extent, and location of the issue develop solutions for this complex issue. (Bełdowski et al., 2017) While research and debate continue on the threat caused by the dumping of chemical munitions into the sea after the Second World War, all agree more research is required, and geospatial technology will help get the answers. (Greenberg et al., 2016)

Conclusion and the Future

The above represents only a glimpse into the legacy of the Second World War at sea regarding shipwrecks and chemical dumping. The use of geospatial technologies continues to evolve and grow as new and better technologies are developed. (Honkavaara et al., 2019) Traditional forms of Information Science can contribute as well. Managing archives, assisting with research, ensuring access, and communication give Information Sciences a role in almost every issue but could be particularly valuable here given the history of poor record-keeping around the issue. (Lagerstrom & Grothkopf, 2011) The geospatial scope of these issues also allows for Student/Teacher/Scientist partnership opportunities to advance geospatial skills. Students researching this subject can help with a real-life issue as it provides a framework for the student to learn geospatial skills. (Hedley et al., 2013) Working with GIS technologies in this way could also help students learn more about historical events and even gain skills that help the community and themselves. (Masucci et al., 2016) Public and Academic libraries, especially those in coastal areas where chemical dumping may have occurred, could play a role by encouraging awareness of the issue through outreach events, including hosting workshops from experts on the issue and building lists with links to GIS resources. (Theobald & Vrbancic, 2016)

These underwater hazards are not going away anytime soon. Some estimates have the issue of chemical weapons dumping from the Second World War reaching an apex in this century, and that is not even dealing with dumping that occurred in other periods. (Curry, 2016) The issue of the dangers of just a typical wreck, like the SS Richard Montgomery or those in lagoons and islands of the Pacific, will remain as well. Difficulties in assigning responsibility for the wrecks, along with cultural differences about the human remains and the cost of mitigating the hazards, will keep researchers busy. (Rogowska & Namieśnik, 2013) Geospatial technologies will be needed, as will those who understand how they can be leveraged and adapted for the situations described above for many years to come.

Geospatial technologies use in managing the situation for shipwrecks and chemical dumping sites of the Second World War, from searching for the location of the sites, risk assessment, and data management, continues to grow as the technology grows and evolves. The examples above are just a few of the more compelling stories, but GIS and Geospatial technologies have a significant role in keeping the seas safe for all, despite the hazard beneath the waves.

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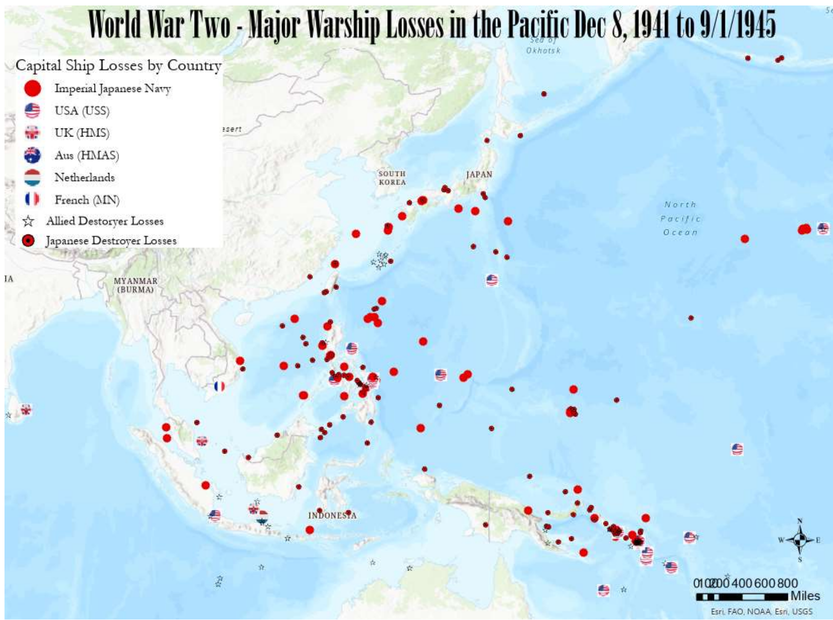
Appendix 1 Major Warship Losses in the Pacific and Major Ship Losses Guadalcanal Campaign



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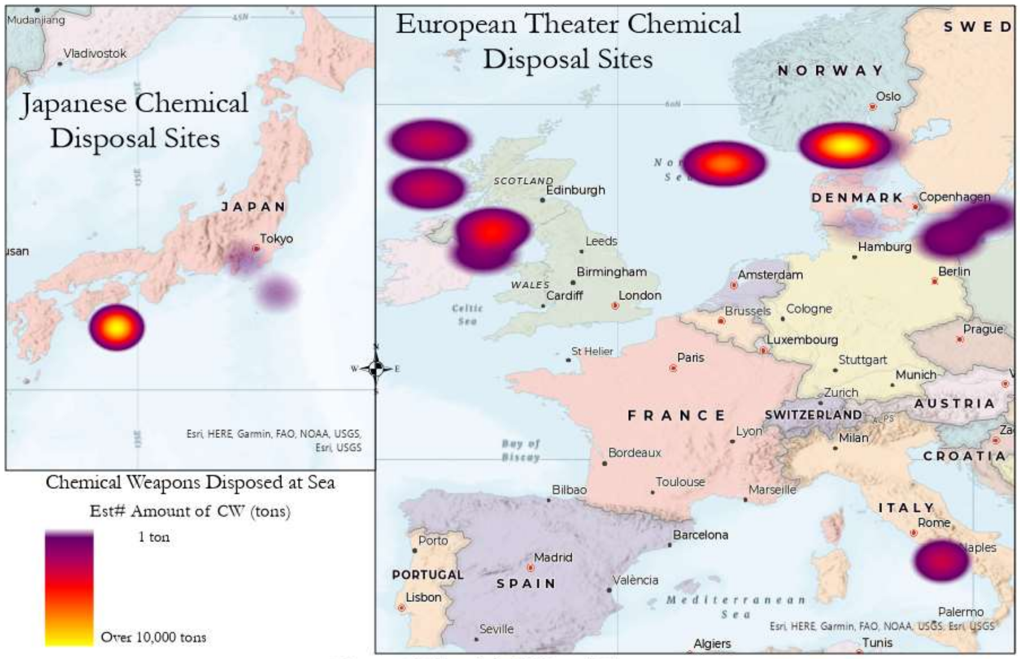
Appendix 2 Chemical Weapons Dumping Ground Maps



Post World War Two
Chemical Weapon Disposal Sites
1945 to 1947

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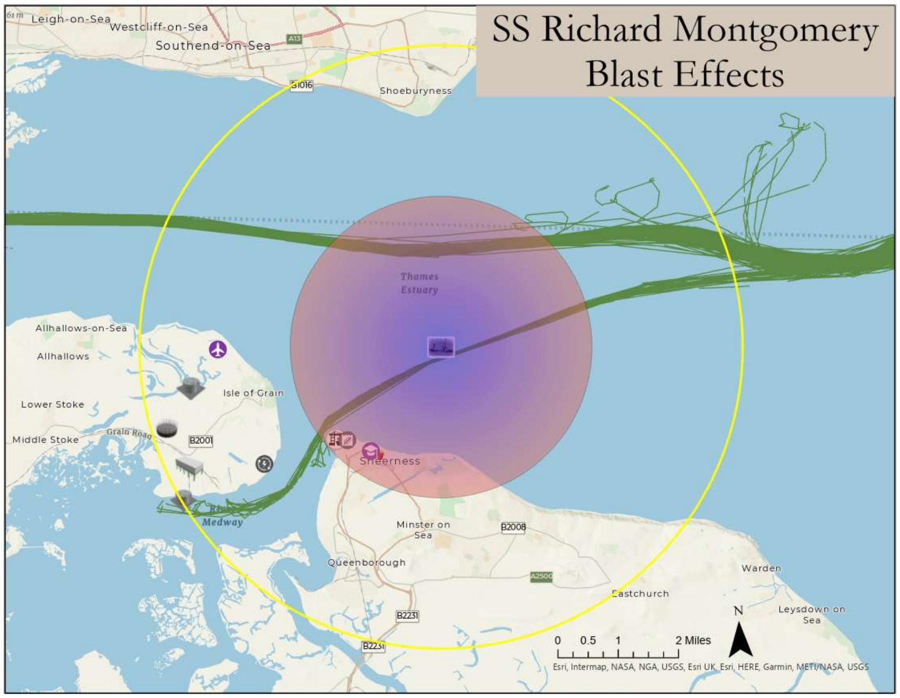
Appendix 3 SS Richard Montgomery Maps



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