Potentially Polluting Shipwrecks

Spatial tools and analysis of WWII shipwrecks

Michael J. Barrett

Dr. Patrick N. Halpin, Advisor

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MJB58@Duke.edu / MBarretts20@Hotmail.com

Abstract

The sinking of thousands of ships during the Pacific Theater of World War II has blanketed the South Pacific region. These potentially polluting wrecks present a major environmental danger to the region in the form of oil spills and unexploded ordnance. As a major center of biological diversity, including World Heritage sites, the continued deterioration of these wrecks could destroy the rich marine life in these areas.

This study provides geospatial analysis of these wrecks, based on data from the United States and Imperial Japanese Navy. Wrecks have been mapped within ESRI GIS software and a variety of spatial and data analyses have been performed to address questions of environmental and geopolitical concern. A risk index has been developed to prioritize the most dangerous vessels. This index accounts for both characteristics of the ship, as well as the surrounding environment. Further, spatial tools have been designed to offer resource managers a basic method to predict sensitive ecosystems at risk from a wreck-based oil spill. For the first time, wreck data will be available for conservation groups and researchers to conduct their own risk planning.

Faculty

Dr. Patrick N. Halpin, Gabel Associate Professor of the Practice of Marine Geospatial Ecology and Director of the Geospatial Analysis Program at the Nicholas School of the Environment.

Dr. Christopher M. Reddy, Senior Scientist, Marine Chemistry and Geochemistry and Director of the Coastal Ocean Institute at Woods Hole Oceanographic Institution.

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Introduction

Right now, nearly 4,000 WWII shipwrecks are threatening the center of marine biodiversity with oil spills. The lasting legacy of WWII in the Pacific is found in millions of gallons of oil and unexploded ordnance onboard these vessels. While many ships lost their fuel reserves during battle, a considerable (but ultimately unknown) number still contain fuel on-board.

World War II erupted in the world scale like few events in history. The mass mobilization of men, supplies and machines to wage this war was unprecedented, and allowed the United States to climb out of the largest economic downturn in its history. As one researcher has put it, WWII put more people at sea than any other human event (Orbach, 2010). Pacific island nations found themselves between two giants, as these islands allowed nations to advance across the vast Pacific. In the aftermath, thousands of ships remain at the bottom.

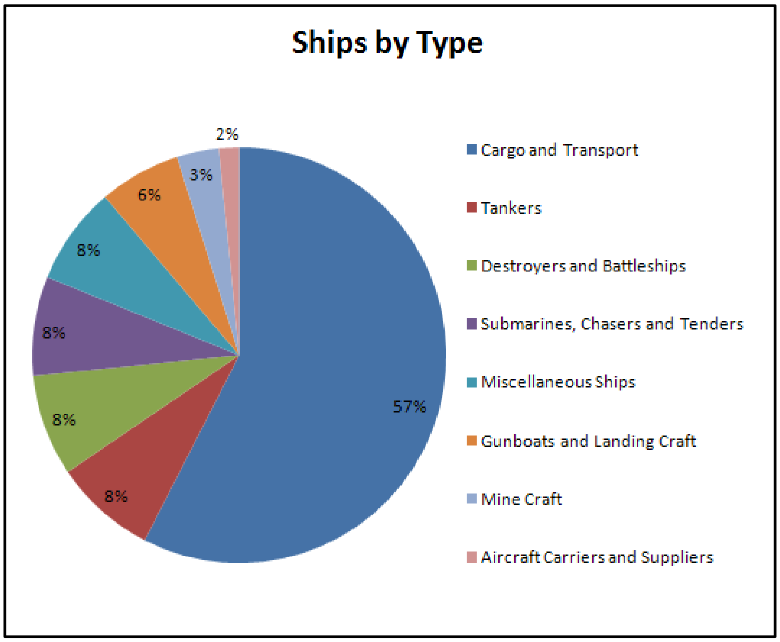
Today, the wreckage of WWII threatens to destroy the beauty of the Pacific. Home to hundreds of species of coral and thousands of fish species, including important tuna habitat, the Western Pacific is the most prolific ecosystems on the planet. For the last sixty-five years, the marine environment has slowly corroded the steel of their hulls, their interior compartments and their ordnance. In some cases, less than 40% of the original material remains, and management decisions are urgently required.

Oil tankers, each carrying millions of gallons of oil, were the primary target of naval warfare. Sinking a single tanker disabled hundreds of vehicles indefinitely. In 2006, I documented a sunken World War II oil tanker leaking fuel into a coral rich lagoon. The damage from this spill—and many more like it—is unknown. The implications of this single ship's leaking are dramatic, but to scale, this is only one of 250 tankers lost in the region. The wrecks of WWII are already releasing fuel into the environment, with no research teams studying the impact. The goal of this project is to provide relevant and objective data to address this problem. By mapping and prioritizing thousands of potentially polluting wrecks in the region, governments may use their resources most effectively and may avert an environmental disaster.

Shipwreck Data

In order to understand this threat to the environment, wreck locations were needed. For this study, the Joint Army-Navy Assessment Committee report, "Japanese Naval and Merchant Shipping Losses During World War II by All Causes" from 1947 was used as a primary source. This report, compiled from 13 other sources from both the United States and Japan, provides loss locations to the minute scale for ships of the Imperial Japanese Navy, as well as conscripted ships in the service of Japan during the war. Dr. Robert Neyland of the Naval Historical Center agreed that this would be the finest scale data available, as locations were taken during the actual battles (2010).This report provides the locations for the majority of the wreck dataset.

Lost ships of the United States Navy were found in "The Official Chronology of the U.S. Navy in World War II" by Robert S. Cressman, also of the U.S. Navy Historical Research Center, released in 1999. During WWII, a number of ships shared the same names. To determine the correct vessel, further data was gathered from the "Dictionary of American Fighting Ships" an online resource, and the "United States Naval Chronology, World War II", released in 1955 by the Naval History Division of the U.S. Navy Department. A number of other sources were consulted for individual ships. All ships in the dataset list their primary information source.



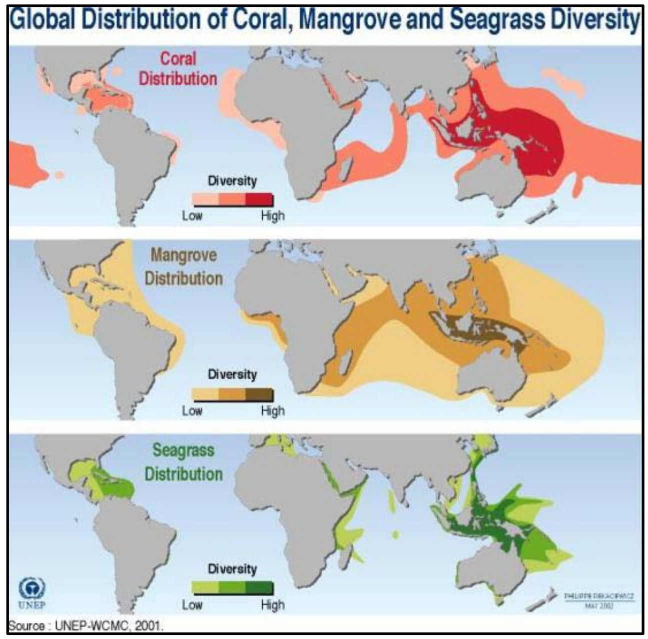
Wreck locations are quite varied. Some ships grounded ashore, while others sank in remote parts of the Pacific. The wrecks' condition is based on the amount of damage it received during battle and accumulated environmental exposure. While decades of corrosion threaten a ship's structural integrity, disturbance events; tsunamis, earthquakes and volcanoes, all common in the "Ring of Fire"; each hasten collapse.

3,100 wreck locations were identified across the Pacific region. Wrecks comprised dozens of different classes of vessel, and ranged from 24-ton patrol vessels to the immense Yamato and Musashi battleships, which displaced more than 60,000 tons. The majority of wrecks were conscripted merchant ships from Japan serving as cargo vessels. Approximately ten percent of all lost wrecks were oil tankers.

Environment

Known for its pristine environment, the Western Pacific is home to the greatest diversity of any marine ecosystem (Roberts et al 2002). A World Wildlife Fund report cites the importance of the Pacific region as "the world's richest fishing ground, the most extensive and diverse coral reefs, the world's third largest area of tropical rain forest, many species not found anywhere else on earth and strong cultural and economic links between people and the environment" (WWF, 2010).

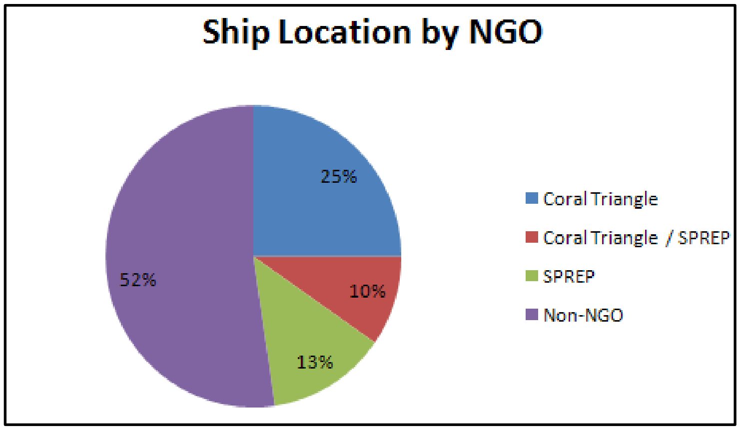
An area roughly the size of the United States known as the Coral Triangle contains ten times the coral diversity of the Caribbean (WWF, 2010).The Coral Triangle is also the center of global mangrove diversity (Burke, 2001). Mangroves are essential to coral reef survival by stabilizing shorelines to prevent sedimentation of shallow reefs, harboring endemic species and filtering terrestrial pollution (National Ocean Service, 2010).



These two ecosystems join, creating a "grown" environment where mangrove trees and corals create structure, physically building the ecosystem. While these two ecosystems work to produce globally high biodiversity, they are also among the most threatened (Roberts et al, 2002). Coastal mangrove forests are particularly susceptible to marine oil spills, and ranked as the most sensitive tropical habitat in global oil spill response (NOAA, 2002). Loss of mangrove habitat creates a cascading decline in broader marine systems. An oil spill could threaten the backbone of this ecosystem with both acute and decades-long chronic effects. While not discussed in this paper, the explosives used in "dynamite fishing" throughout the region often comes from these sunken vessels.

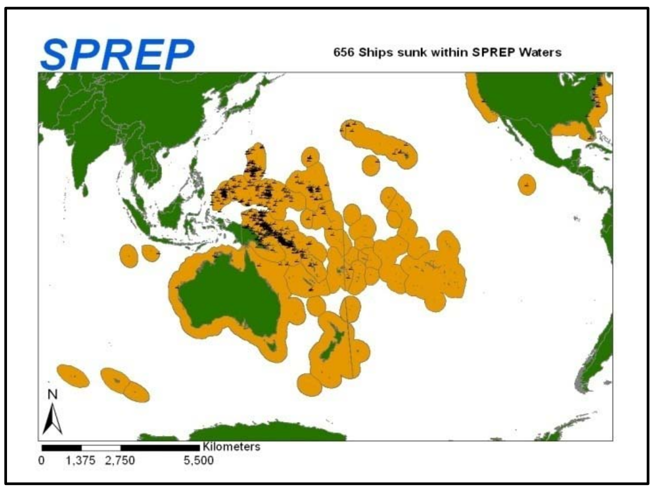
Stakeholders

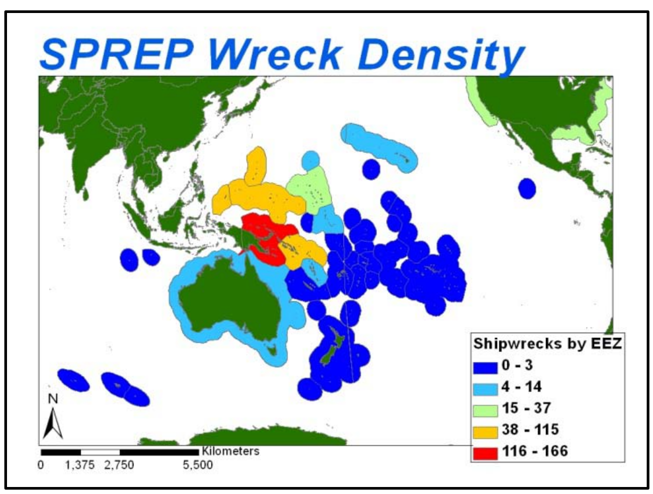
Host States



Small island developing states (SIDS) continue to endure the most impact from WWII, more than a half-century later. Often idealized because of their tropical setting, SIDS are challenged by limited resources, often reflected in their economies. These nations are dependent upon healthy seas for survival; their cultures, religions and diets are based on the sea. Currently, there are two large development and conservation initiatives at work in the Pacific region, the Secretariat of the Pacific Regional Environment Programme (SPREP), and the Coral Triangle Initiative (CTI).

SPREP

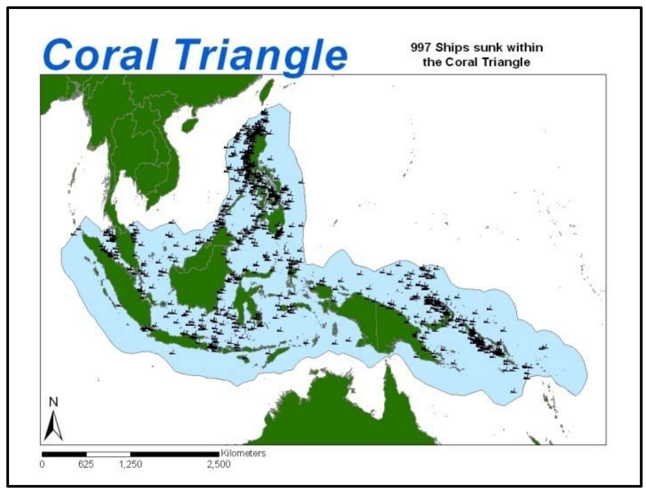


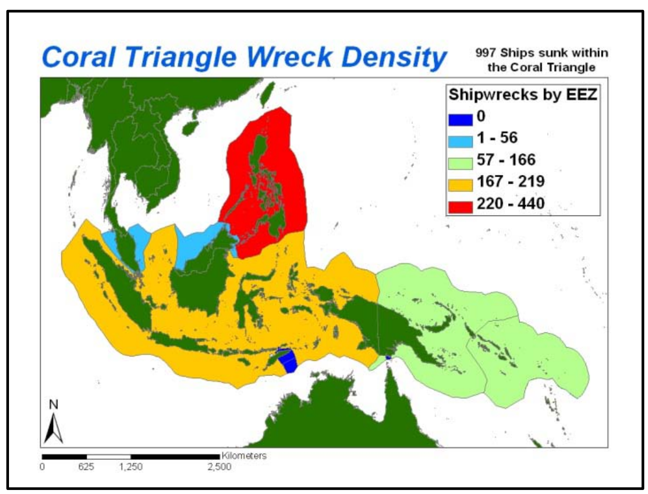


SPREP, a regional alliance of Pacific states and donor countries, works to ensure responsible and sustainable development of the Pacific environment. Comprised of 21 nations, including the United States and France, SPREP is the largest regional organization focused on environmental issues. SPREP's mandate is "to promote cooperation in the Pacific islands region and to provide assistance in order to protect and improve the environment and to ensure sustainable development for present and future generations" (SPREP, 2010).

Through the office of Marine Pollution, SPREP has created several work plans to address the threat of potentially polluting wrecks after the *USS Mississinewa,* an war-era oil tanker, began leaking. The most significant plan came in 2002, when a regional strategy was proposed at the SPREP Annual Meeting to assess these threats on a regional scale and determine responsibility and remediation potential (SPREP, 2002). SPREP was told not to pursue a regional strategy during this meeting. Currently, according to protocol, SPREP may only respond to specific calls for assistance from member states. SPREP is currently following this mandate with focus on the leaking tanker, *Hoyo Maru*, in Truk Lagoon in the Federated States of Micronesia (SPREP, 2010).

Coral Triangle





To sustain the biodiversity of the Coral Triangle, President Susilo Bambang Yudhoyono of Indonesia invited neighboring countries to join in protecting the vast resources of the region through sustainable development practices (CTI, 2007). The other five nations, the Philippines, Malaysia, Timor-Leste, Papua-New Guinea and the Solomon Islands consented and signed an international agreement with Indonesia in September 2007. The Coral Triangle Initiative, backed by international conservation groups such as the World Wildlife Fund and Conservation International, also receives funding and support from the United States, Australia, the Asian Development Bank and the Global Environment Facility (CTI, 2010).

The goal of the Coral Triangle Initiative is to preserve the natural environment and collectively address threats to both the resources and people of the region (CTI, 2010). While the CTI has resulted in positive changes for the management of marine resources, they have yet to address the significant danger posed by sunken wrecks, nor have these nations requested assistance from flag states. More than 800 vessels are found within the Exclusive Economic Zones of CTI member countries.

Legal Considerations

In considering these ships, one must distinguish them from sunken commercial or personal vessels. Unlike commercially owned wrecks, which frequently change ownership, nations have retained sovereignty of their state craft. Vessels on military service receive particular protection and treatment within the international community. The U.S. Supreme Court ruling on the schooner *Exchange* in 1812 found that ships operating on behalf of a nation are considered sovereign property and must not be disturbed in any manner. (*The Schooner Exchange v. McFaddon*, 1812).

Since 1812, sovereign immunity has been upheld throughout the international community and is listed explicitly in Article 95 of the Law of the Sea (UNCLOS, 1982). It is customary under maritime law that all state craft, sunken or not, retain their immunity (Roach, 2001) Unless a nation expressly abandons these vessels, they remain under the veil of immunity in perpetuity, and no passage of time, act of neglect or inaction may serve as an act of abandonment (Neyland, 2001). As war graves, ships are further considered under the protection of the flag state (Roach, 2001).

To reiterate the U.S. position on sunken state craft, President Clinton issued a Statement on United States Policy for the Protection of Sunken Warships in 2001:

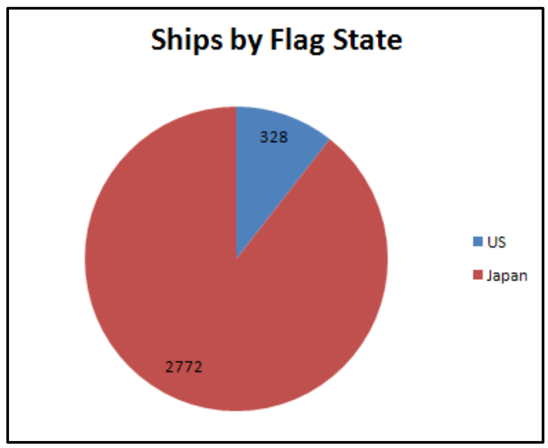
> *Pursuant to the property clause of Article IV of the Constitution, the United States retains title indefinitely to its sunken State craft unless title has been abandoned or transferred in the manner Congress authorized or directed. The United States recognizes the rule of international law that title to foreign sunken State craft may*

> *be transferred or abandoned only in accordance with the law of the foreign flag State.*
>
> *Further, the United States recognizes that title to a United States or foreign sunken State craft, wherever located, is not extinguished by passage of time, regardless of when such sunken State craft was lost at sea.*

The Statement continues, prohibiting any unauthorized disturbance of state craft (Office of Ocean Affairs, 2004). Several nations with significant naval histories were consulted in drafting this Statement, and France, Germany, Japan, the Russian Federation, Spain and the United Kingdom submitted consenting positions.

Flag States

While flag states of sovereign wrecks continue to assert ownership, no country has begun a proactive method to assess or monitor potentially polluting vessels outside their own waters. Where remediation has occurred, the "host" state of the vessel identified the problem after the spill began and requested assistance from the flag state through diplomatic channels (Woodward, 2008).



United States

In 2001, the *USS Mississinewa*, an oil tanker in Western Micronesia began leaking fuel after a cyclone moved through the area (U.S. Navy, 2004). Shortly after the spill was reported, the Navy responded by investigating on site, and patching areas with escaping oil. When the seeps continued, the Navy conducted a lengthy environmental assessment, and recommended for the complete removal of onboard oils, completed in 2003 (U.S. Navy, 2004).

While the United States Navy has successfully offloaded oil from ships in a few cases, it has explicitly stated that these cases do not set precedence for responsibility of leaking wartime wrecks (UNESCO, 2010). The Navy has also declared that it will handle requests for assistance on a "case-by-case" basis, and will not pursue a proactive approach (Woodward, 2008). Admiralty Counsel to the Supervisor of Salvage for the U.S. Navy, Richard Buckingham, reiterated this sentiment at the First International Corrosion Workshop in 2010. Buckingham described the Navy's approach as conservative, and felt it was both environmentally and fiscally responsible to proceed this way.

Japan

There are approximately 2,500 sunken Japanese wartime vessels in the Pacific representing more than two-thirds of sunken vessels in this survey. Since the war, Japan has consistently claimed sovereignty over these wrecks, preventing private firms from salvage activities (McCarthy, 1998). Japan has also defended sovereign immunity for wrecks within the international community by contributing to the 2001 U.S. Policy on Sunken State Craft. Japan's statement reads:

> *According to international law, sunken State vessels, such as warships and vessels on government service, regardless of location or of the time elapsed remain the property of the State owning them at the time of their sinking unless it explicitly and formally relinquishes its ownership. Such sunken vessels should be respected as maritime graves. They should not be salvaged without the express consent of the Japanese Government.*

Japan, like the U.S., has maintained sovereignty over their wrecks, but now appears willing to offer more assistance than it has in the past. When told about the leaking vessel *Hoyo Maru* in Truk Lagoon, Micronesia, the Japanese Minister of Foreign Affairs said that Japan recognized the issue and are "always ready to listen to our friends in the Pacific" (Johnson, 2008).

Remediation Options

As both host states and flag states come to terms with how best to manage and mitigate these potentially polluting wrecks, there is a range of response options. These choices follow a continuum from allowing the vessels to rupture and release the fuel, to a complete—or near complete—cleanup of the polluting wreck.

"The Do Nothing Approach"

With no international agreement to direct remediation efforts, allowing these vessels to corrode and release their fuel reserves into the environment is the current approach. Governments may not be aware of the oil onboard or its potential impact, environmental protection may not be a priority, or simply, they are not aware of wrecks in their waters.

Japanese Tanker *Hoyo Maru* leaking fuel, Micronesia 2006.

Only recently have nations begun investigating the potential of pollution from wrecks within their own waters. The United States was unable to trace the source of a series of oil spills in San Francisco Bay for years. At the time, these mystery oil spills were the "largest killer of sea birds in North America" (Basta, 2010). Only after several years of collecting oil samples and ruling out modern vessels did government researchers identify the culprit as the wreck of the *S.S. Jacob Luckenbach*. In 1952, the freighter *Luckenbach* struck another ship and sank 17 miles southwest of San Francisco, near the future Gulf of the Farallones National Marine Sanctuary (Monterrey Bay National Marine Sanctuary).

Upon discovering this wreck as the source of multiple oiling events in the Bay, and as a wreck capable of significant environmental damage (the ship sank with 457,000 gallons of bunker fuel), the Office of

National Marine Sanctuaries began the Resource and Under Sea Threats (RUST) database "to find the next *Luckenbach"* (Basta, 2010). This database now comprises thousands of wrecks, and aims to catalogue data on the more than 150,000 sunken vessels in U.S. waters (Zelo et al, n.d.). Japan, the UK and France have also begun cataloguing their wrecks.

Offloading

Technology offers solutions to prevent these ships from releasing their oil. Once the integrity of the hull has been established, a process called "hot tapping" is used to drill into sunken vessels and remove the oil. Hot tapping is usually used to access pipes and plumbing that cannot be taken out of service but require repair. Used on the USS Mississinewa, this process allowed the U.S. Navy's Supervisor of Salvage teams (SUPSALV) and contracted salvage teams to drill through the hull and install valves for a controlled removal.

A number of taps were drilled to speed offloading of the *Mississinewa*, with each tap taking 15 minutes to install (U.S. Navy, 2004). Once a valve is in place, a hose is attached and the oil is vacuumed to containment barges at the surface (SPREP, 2002). Oil collection booms are placed at the surface in the event of an accidental release. Once the oil is removed, seawater and other impurities are filtered out and the oil may be reused. In the case of the *Mississinewa*, the Navy sold the oil in Singapore (U.S. Navy, 2004). More than 2 million gallons of oil was removed from the *Mississinewa*, with only 5 gallons accidentally released into the environment (U.S. Navy presentation, n.d.), proving that removal can be an effective and environmentally safe option.

According to Devon Grennan, President of Global Diving and Salvage, Inc., while these salvage operations have already proven successful in defusing potential disasters, the U.S. Navy and the private salvage community continues to improve techniques and equipment with each deployment, reducing costs and minimizing risk to both ecological resources and the dive crew. After the successful unloading of the sunken tanker, *Prestige*, at a depth of 3,500 meters, Remotely Operated Vehicles have also proven capable of this work (Michel, 2005).

This process takes significant planning and operational management. The Navy conducted an environmental assessment in conjunction with NOAA, performed a full year in advance (U.S. Navy, 2004). For the *Mississinewa*, five ships and a crew of more than 150 people was required, with equipment coming from as far as Williamsburg, VA. While similar operations in more coastal waters tend to be far simpler in size and scope, due to the number of ships in the Western Pacific, the *Mississinewa* is a realistic case study for other remote vessels.

Costs

In the case of the *Mississinewa*, despite the large amount of equipment and personnel mobilized, the operation had a total cost of $4.5M, or $2.25 a gallon (U.S. Navy, 2004). The *Luckenbach*, on the other hand, cost $20M to offload approximately 100,000 gallons at a cost of $200/gallon (Marine Law Association of the United States, 2009). According to Devon Grennan, the wreck of the *SS Catala*, a grounded wreck in Washington State, cost approximately $225/gallon, while the *Princess Kathleen*, a passenger vessel that sank in Alaska in the 1950’s cost approximately $100/gallon (Grennan, 2010). The cost of removing oil varies greatly depending upon the amount of oil, the depth of the sunken ship, and the availability of equipment.

Entombing

A third option exists, but has yet to be used. Entombing entails covering the wrecks in sand and concrete in order to contain dangerous or toxic pollutants. Entombing potentially polluting wrecks has been discussed as an option for cases that require extensive clean up operations or where remediation could pose significant hazards. As with all war wrecks, unexploded ordnance is a serious consideration that could justify entombing. Entombing has been suggested for the *USS Montebello* in Monterrey Bay(Basta, 2010) and the wreck of a German U-boat, U-864. This submarine has released several kilograms of mercury a year into important Norwegian fishing grounds (Mammoet, 2008). This appears to be the least likely action plan, as the public is demanding complete removal (Cowell and Gibbs, 2007).

Wreck Corrosion

The approximate rate of corrosion in seawater is 0.1 mm/year. However, this rate can more than double due to wave energy at the surface (MacLeod, 2011). Hull plates were approximately 25mm thick on ships from this era (Moore, 2011), yet internal holding tanks and plumbing, ducts and vents are substantially thinner and are often the first areas to collapse (MacLeod, 2010). Leaking pipes and valves on the *Mississinewa* were as small as four inches in diameter, but actual thicknesses for these components were not available.

Example of pitting corrosion

Corrosion rates for individual ships, while an ideal figure is not likely, as precise pH, dissolved oxygen and temperature would be required for each wreck site (MacLeod, 2010). Further, baseline corrosion rates do not account for natural events, such as tectonic activity or cyclones, which ultimately caused the leaks in the Mississinewa (U.S. Navy, 2004). Localized corrosion, from pitting or microbes occurs much faster and is more likely to cause structural failure, yet cannot be predicted (MacLeod, 2011).

Oil Behavior

Marine oil spills can have a devastating effect on the environment, particularly to productive coastal areas. Species that live at the surface, such as seabirds and sea turtles are at particular risk from oil pollution. While millions of gallons of oil are released into the oceans each year, the majority of spills occur offshore and do not approach coastal waters (ITOPF, 1987). While many oil spills cannot be predicted, these wrecks, predominantly found in near-shore waters, offer a rare opportunity to prevent a disaster.

The majority of WWII ships carried heavier oils, such as “bunker C”, while smaller vessels and submarines carried diesel fuel (U.S. Navy, 1946—Technical Mission X38-N6). Bunker C, or Fuel Oil #6, is a residual fuel, left once lighter compounds have been distilled. In order to use this fuel, it must be re-blended with one of these lighter compounds. Japan’s oil came from California crude, stockpiled before the war, eventually transitioning to oils from Borneo and Sumatra (U.S. Navy, 1946—Technical Mission X38-N1).

Working with experts at the Woods Hole Oceanographic Institution, professional divers were trained in collecting oil leaking from WWII ships in Truk Lagoon. Divers were asked to collect visible oil escaping the ship while performing routine dives through their tourism business. This study did not advocate or suggest penetration dives on any wreck.

Once collected and samples arrived at Woods Hole, oil from the *Hoyo Maru* was analyzed using comprehensive two-dimensional gas chromatography (GCxGC). This process determines oil’s chemical signature. The sample from the Hoyo Maru showed a bunker C fuel, with no lighter compounds present. This is logical, as this sample was collected from a pool of oil inside the ship’s engine room, where it was exposed to seawater, and lighter elements already dissipated.

Once released into the marine environment, oil undergoes several physical and chemical processes. Each site's oceanic and coastal conditions will determine the weathering of petroleum products, as well as the oil that is biologically available to organisms (NRC, 2003). Oil's viscosity, density and solubility are the three key factors in marine spills (Fingas, 2001). Ambient temperature of water and air plays a major role in oil's behavior. In the South Western Pacific, mean air and water temperatures are between 25° and 32°C, likely resulting in faster evaporation of lighter compounds (SPREP, 2002).Heavier oils, like bunker C, are likely to lose their lighter compounds quickly in such a warm environment, while heavier residuals will travel with ocean currents and wave energy until making landfall (Reddy, 2011).

Oil from the *Hoyo Maru* coming ashore in mangrove swamp, Micronesia.

Oils like bunker C are known to coat mangroves, blocking highly specialized photosynthesis and gas exchange (MMS, 1997 and NOAA, 2002). Heavier oils such as bunker C restrict gas exchange more than lighter oils (MMS, 1997). When exposed to bunker C fuels, one study cited by the Minerals Management Service found "severe, long-term effects" on intertidal mangroves (1997). In the case of the Bahia las Minas spill in Panama, 82% of mangroves were impacted within two weeks and significant effects were still visible more than five years after the spill (NOAA 2002).

Mangrove ecosystems also undergo "re-oiling" after spills. During the spill, oil is absorbed into the sponge-like sediment of the mangrove swamp. As the mangroves are poisoned through the soil, their roots and trees die and uproot, overturning the soil, releasing the oil again. Oil is also re-released after heavy rains and high tides. High tides also carry the oil further inland to previously unaffected areas

(Keller and Jackson, 1993). After the Bahia las Minas spill, mangrove mortality was found to be above 50% for oiled areas (National Ocean Service, 2010). This re-oiling cycle may also lead to the remaining oil becoming more toxic over time (MMS, 1997). The Bahia las Minas spill in particular offers an appropriate case study of oil spilled within a sheltered marine habitat, similar to many Pacific ecosystems.

Spatial analysts and oils experts have developed programs and models that identify likely areas for spills, as well as trajectory models for how oil may travel within an environment, and how different oils will react in an environment. Future studies and funding provide an excellent opportunity to model specific plume trajectories. However, many examples have shown that due to the delicate nature of mangroves, field remediation creates more environmental damage than taking no action (NOAA 2002), lending further credence to ship remediation before their fuel reserves are released into the environment.

Risk Index

NOAA's Resources and Under Sea Threats database (RUST), established after the *Luckenbach* leaks, was designed to prioritize potentially dangerous wrecks in U.S. waters, based on the following criteria (Symons, 2010):

Ships built after 1910,
Steel hulled,
Greater than 200 feet or 1,000 gross tons.

This algorithm allows the RUST dataset to narrow down the most dangerous shipwrecks with the capacity to inflict serious environmental damage within US coastal waters from more than 100,000 known wrecks.

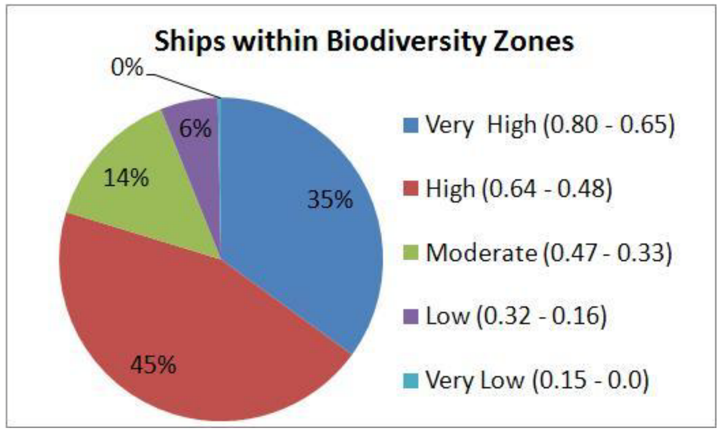
A major flaw appears in NOAA's criteria; failure to account for the surrounding environment. Within RUST, a vessel found in a less productive environment receives equal priority as an oil tanker found within a reef, fishery or marine protected area. As most WWII wrecks meet the RUST criteria, a more robust prioritization is required, accounting for ship size, type and surroundings.

A risk index for American and Japanese WWII shipwrecks was created. Prioritizing sunken vessels could help resource managers and governments use financial resources effectively and assure stakeholders that the problem has been carefully assessed. All analyses were performed using the World Geodetic System of 1984 and the World Winkel Tripel Projection, with a Central Meridian of 160W.

Five factors were chosen to build a matrix of wreck threats, a vessel's tonnage, type, depth, distance from shore and surrounding marine diversity. These components provide a measure of impact that a leaking ship will have on the environment. Each factor is classed between 1 (least dangerous) and 10 (most dangerous), with each of the 3,100 ships scored accordingly. Risk factors were then summed to produce the final risk rating for a maximum score of 50. Large oil tankers found in shallow, near shore waters in areas of high marine biological diversity are ranked highest, while smaller ships in less productive and deeper, oceanic waters are of lowest priority.

Like the RUST criteria, this index accounts for the tonnage of ships, whereas larger vessels may carry larger fuel reserves and ordnance. Tonnage values in the dataset range from 24 to 63,000 tons. Further, oil tankers receive more points within the scoring due to their significant oil capacity. Ships were assigned values for depth according to the ETOPO 1km bathymetric map. Depth classes were determined through discussion with marine salvage professionals in accordance with the industry's best practices and equipment (Grennon, 2011). It should be noted that while shallow wrecks are more likely to corrode faster due to wave action and storm impact, they might also be easier remediation targets. A ship's distance from shore was measured in accordance with traditional maritime boundaries, as some vessels fall within a state's coastal waters, while others sank on the High Seas in international waters.

To account for marine biodiversity, a score was created by intersecting a ship's location within a normalized biodiversity grid, created by Tittensor et al in "Global patterns and predictors of marine biodiversity across taxa" (Nature, 2010). Once mapped, it became clear that a large number of vessels were located within close proximity to sensitive marine habitats. According to the normalized Tittensor et al data (2010), of all the Pacific wrecks, 80% fall in areas of .48 and higher in biodiversity, while no ships are found in areas of the lowest biodiversity. Wreck locations were compared to coral reef and mangrove maps produced by the World Conservation Monitoring Centre and marine protected areas as listed in the World Database on Protected Areas. However, the larger grids created by Tittensor et al proved to be a more appropriate indicator for the scale of this index, since ocean currents were not taken into account.



Risk factors and weight classes

Tonnage

10. 65,000 – 25,000 tons
8. 25,000 – 10,000 tons
6. 10,000 – 5,000 tons
4. 5,000 – 1,000 tons
2. 1,000 – 24 tons

Depth

10. 0 – 200 ft Standard Diving Equipment
5. 200 – 1000 ft Saturation Diving Required
1. 1000 – Plus ft Remotely Operated Vehicles Required

Tankers

5 points added to all Tanker Vessels.

Distance from Shore

Five Zones representing standard international maritime boundaries

10. 0 – 3 Nautical Miles (Coastal Waters)
8. 3 – 12 Nautical Miles (Territorial Sea)
6. 12 – 24 Nautical Miles (Contiguous Zone)
4. 24 – 200 Nautical Miles (Exclusive Economic Zone)
2. 200 – Plus Nautical Miles (High Seas)

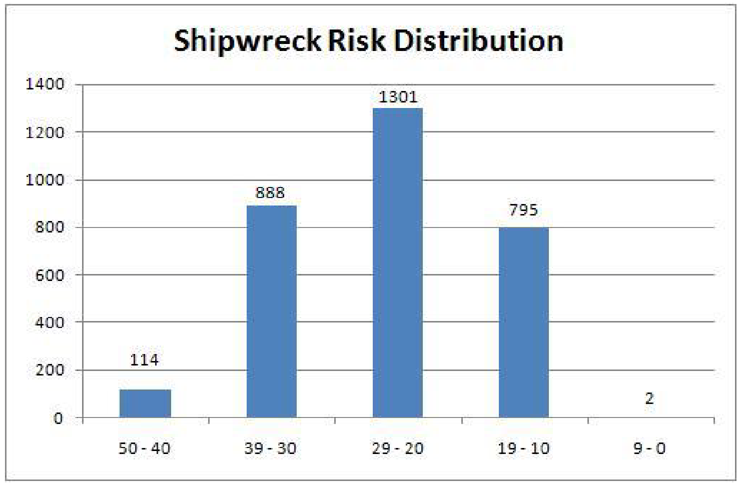
Biodiversity

Five classes based on Tittensor et al's Normalized Marine Biodiversity Index, 0 to 1 scale.

10. 0.80 - 0.65
8. 0.64 - 0.48
6. 0.48 - 0.33
4. 0.32 - 0.16
2. 0.15 - 0.00

Results

The threat assessment follows a near-normal distribution across all ships. The most dangerous category, those ships scoring between 40 and 50 points, account for 3.67% of the total dataset. This small number of wrecks allows governments to assess these ships at finer detail to determine their exact location, cargo and condition. The index showed a minimum score of 9, met by two small and remote wreck sites, and a maximum score of 50, the highest score possible, by a large oil tanker, laying in a shallow, productive, near-shore environment. The average score was 26. From this list, remediation targets can be drawn.



Of special interest is the analysis of a ship's distance to shore. While the close proximity to shore is apparent on a region-wide map, examining the breakdown of maritime boundaries provides another layer of understanding. 40% of all ships are found within three nautical miles of shoreline, in the Coastal Waters of the host state. Additionally, only 1% of mapped wrecks lay in the High Seas, beyond national boundaries. This problem is not "out-of-sight, out-of-mind"; 99% of these wrecks lay within Exclusive Economic Zones.

Resources

In order to begin the dialogue between host and flag states, resource managers in the Pacific must have appropriate knowledge of potentially polluting wrecks within their Exclusive Economic Zones and protected areas. Unfortunately, this data is not easily accessible. Several firms hold proprietary datasets, but many environmental managers in the Pacific do not have the necessary funds to hire these services. In response, I have released my own dataset, including locations, details and risk scores for 3,100 WWII vessels. Resource managers and non-profit organizations will be able to access the data for non-commercial use. The data will be available through the UNEP World Conservation Monitoring Centre, and through a website based on this project, www.potentiallypollutingwrecks.com. This site will serve as a library of information regarding potentially polluting vessels.

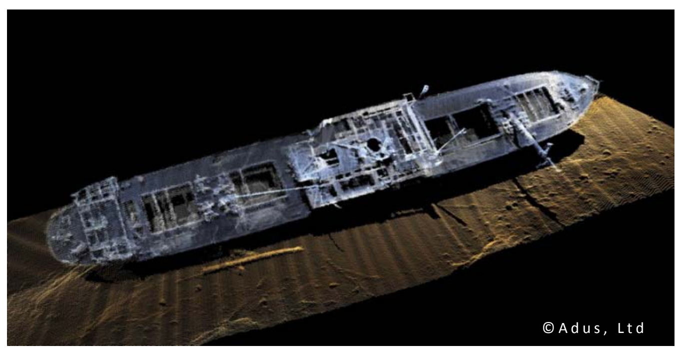
Because ArcGIS software requires significant training, I have also developed a spatial tool to help managers and researchers. This web-based mapping service will be housed on the project website by the summer of 2011. The tool takes a user-defined search radius and scans the area surrounding sunken ships for sensitive ecosystems. Once run, the user receives a map of the World Conservation Monitoring Center's mangroves and reefs that fall within their search distance. Users can then save screen captures of the maps for use in reports and management plans.

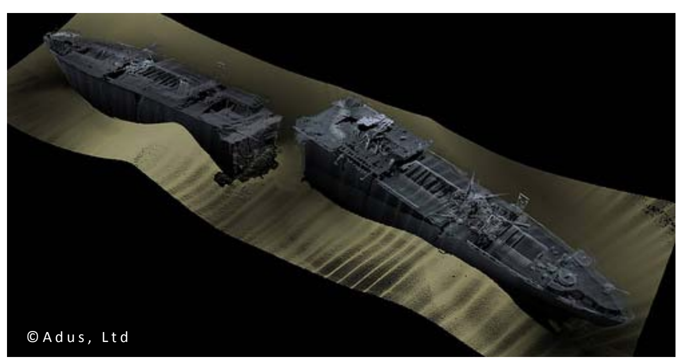
This tool provides a simple overview of a threatened area. Oceanographic conditions such as currents, temperature and depth are not accounted for. Once basic risks to an area are understood, managers may then run or contract for more detailed spill trajectory analyses as necessary using either NOAA's GNOME trajectory model in the United States or several available commercial products, as SPREP has done with the Hoyo Maru (2009).

Recommendations

Due to international law regarding sovereign immunity, flag states are not likely to abandon these wrecks or consent to mandated remediation. However, this does not mean the world will watch thousands of vessels collapse and release their oil. Less formal compacts could be created wherein flag and host states cooperate on systematic remediation. Flag states could, and do, clean up polluting vessels while still asserting their sovereign claims. I believe flag and host states should work together to prioritize and neutralize the most dangerous wrecks within hosting waters.

Once managers have identified wrecks within proximity of important resources, they would be able to approach the United States and Japan for assistance in cleaning out the most dangerous vessels. Economic analysis of remediation is also possible, using a wreck's depth, distance from shore and required equipment, as well as volume and value of onboard oils to create an economic index.





For more in depth understanding of the vessel at hand, new technology, such as high-resolution, multi-beam sonar can provide stunning visuals that allow analysts to see the damage corrosion has done to sunken wrecks. This technology, developed by Dr. Martin Dean of the University of St. Andrews and his team at Adus Ltd, can scan an entire vessel in less than 30 minutes. Once scanned, Adus Ltd provides clients with software where the ship can be visualized in 3D at fine enough resolution to identify corroded areas (Dean, 2010).

The risk index created through this project offers a crude estimate of a sunken ship's potential impact on the environment. Currently, this index does not provide a likelihood of a spill, or a predicted time of structural failure. As these ships become better studied and exact locations determined, the index may be updated and improved. Spill trajectory models will also aid in determining oil plume flow and specific threatened areas.

Ultimately, I believe it will become necessary to perform clean up operations on a number of sunken vessels in the Pacific to protect marine and cultural resources. While the United States and several other states have taken a proactive approach to identifying undersea threats within their own waters, the challenge lay in taking this approach to all state craft, regardless of location. I hope that by providing this data to relevant parties will promote this discussion.

As more ships are cleaned, the remediation technology and planning improves. However, today, ship remediation is a rare event. I hope that the United States and Japan see the need and benefit to mitigate potential disasters before they come to fruition, both at home and abroad.

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GIS DATA

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Data provided by Tittensor and the Marine Geo-Spatial Ecology Lab, Duke University.

IMAGE CITATIONS

All Wreck Maps: Created by Michael Barrett, 2011. Wreck data from Barrett dataset.

Photo: *Hino Maru* Bow Gun, © Florian Brietzke, 2006.

Global Coral, Mangrove and Seagrass Diversity Map: UNEP-WCMC (World Conservation Monitoring Centre) 2001. Created by Philippe Rekacewicz, UNEP/GRID-Arendal http://maps.grida.no/go/graphic/distribution-of-coral-mangrove-and-seagrass-diversity

Photo: *Hoyo Maru* leaking. © Michael Barrett, 2006.

Photo: U.S. Navy divers tapping into *USS Mississinewa*, 2004. © U.S. Navy, photo from “U.S. NAVY SALVAGE REPORT USS *MISSISSINEWA* OIL REMOVAL OPERATIONS”

Photo: Pitting Corrosion from Curtin University, Corrosion Centre for Education, Research & Technology, 2010. http://corrosion.curtin.edu.au/research/mining.cfm

High Resolution Multibeam Sonar, from Adus, Ltd.
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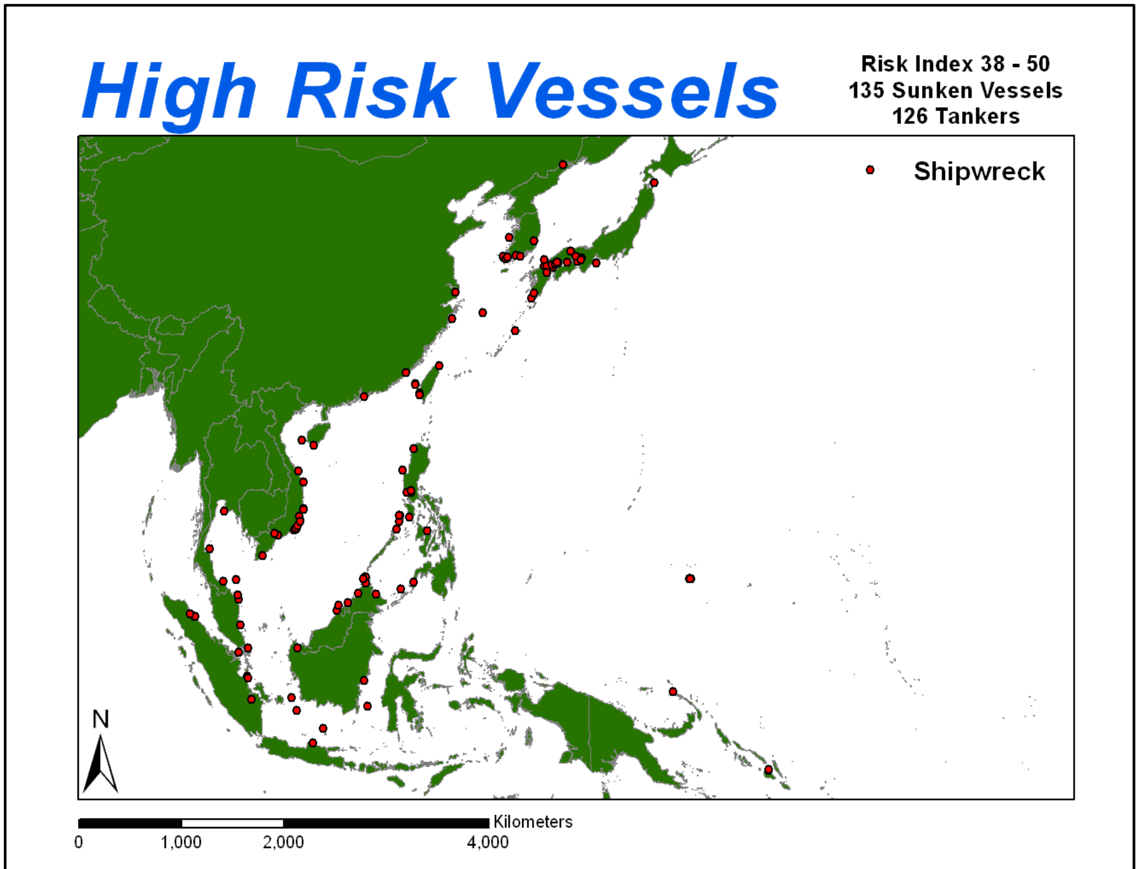
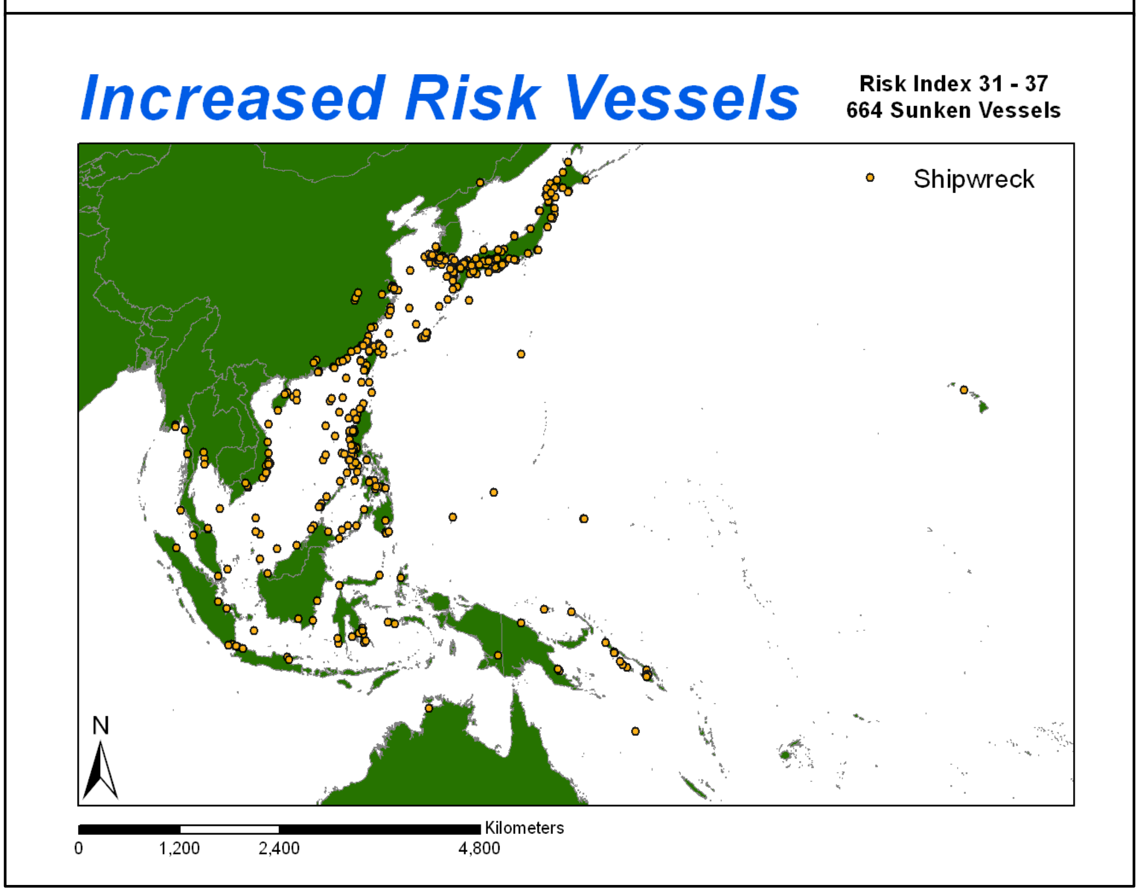
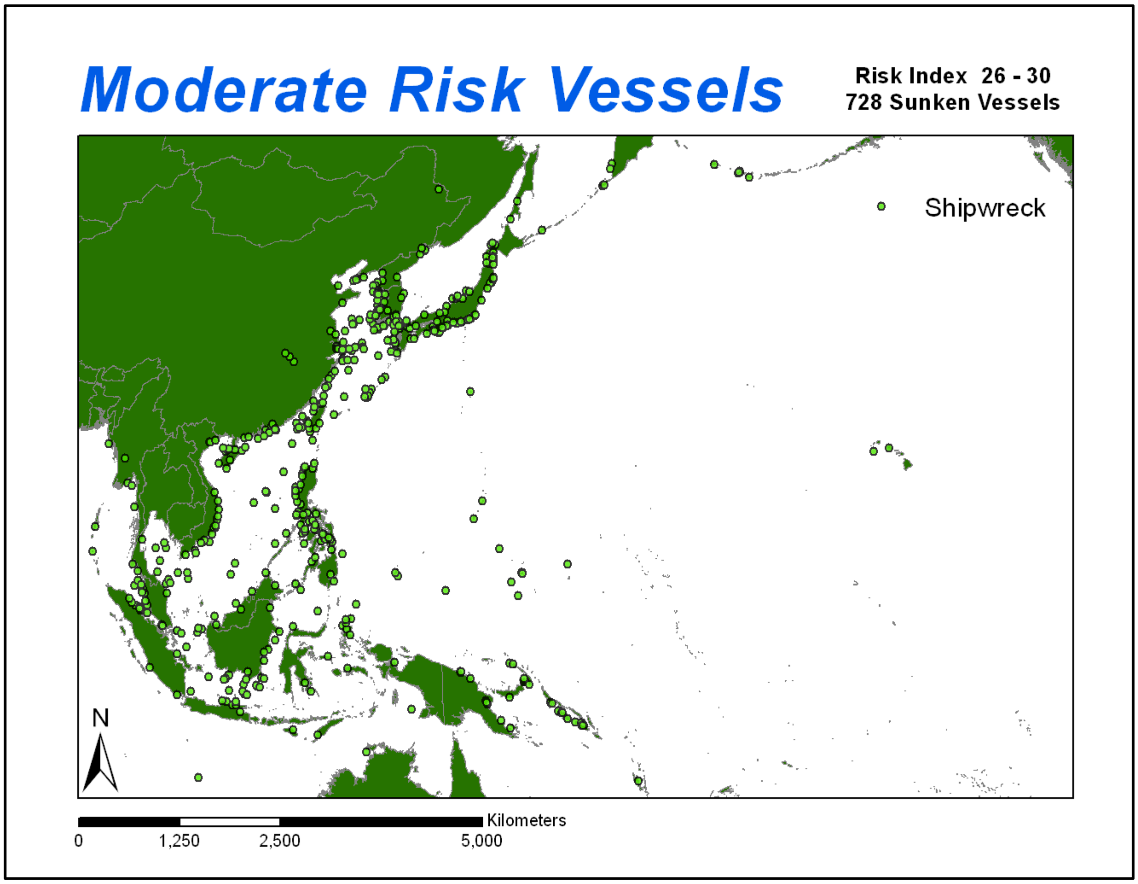
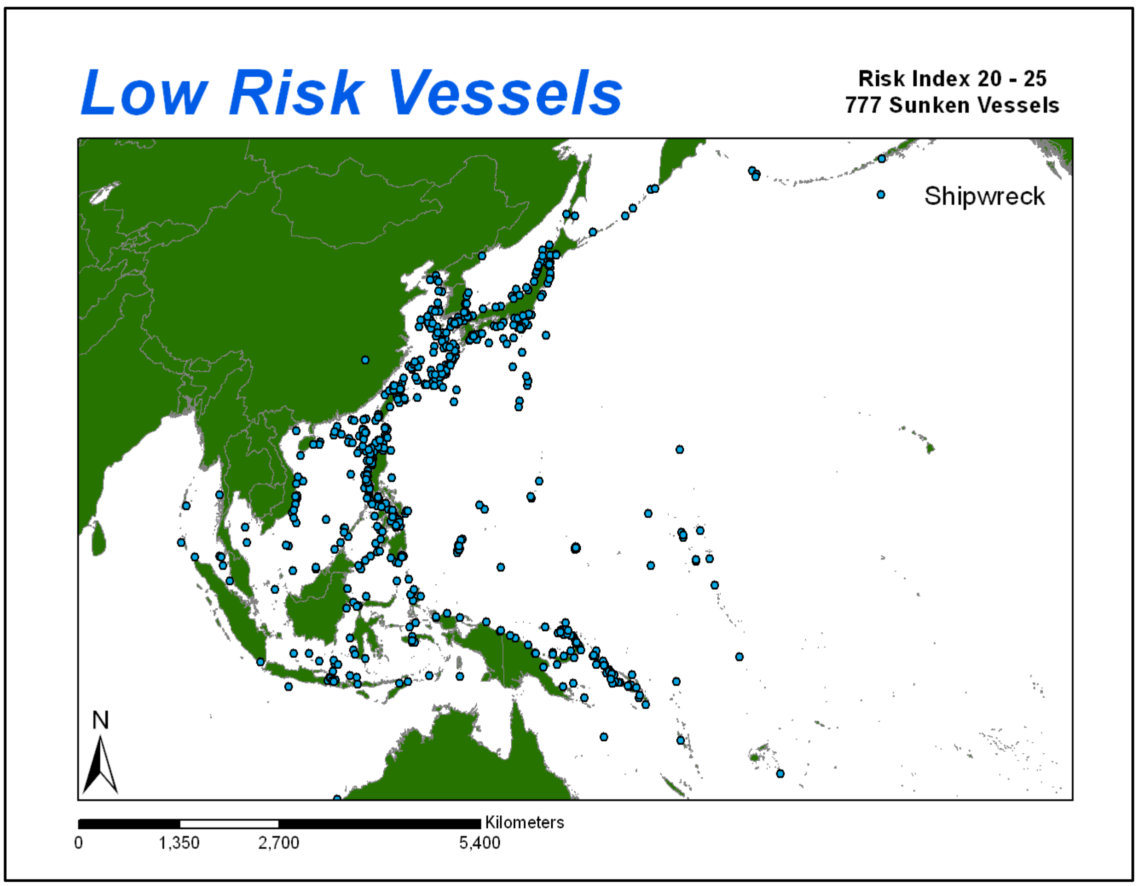
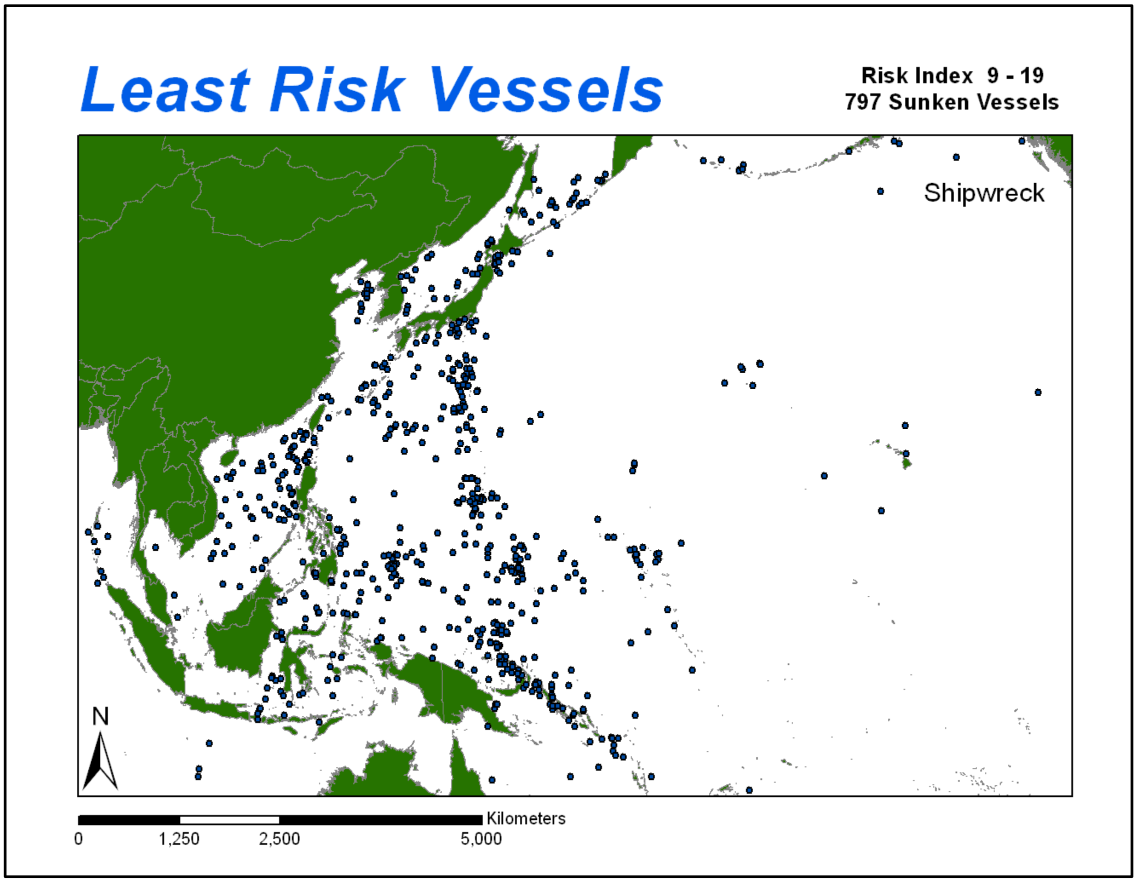
Appendix: Risk Index Maps



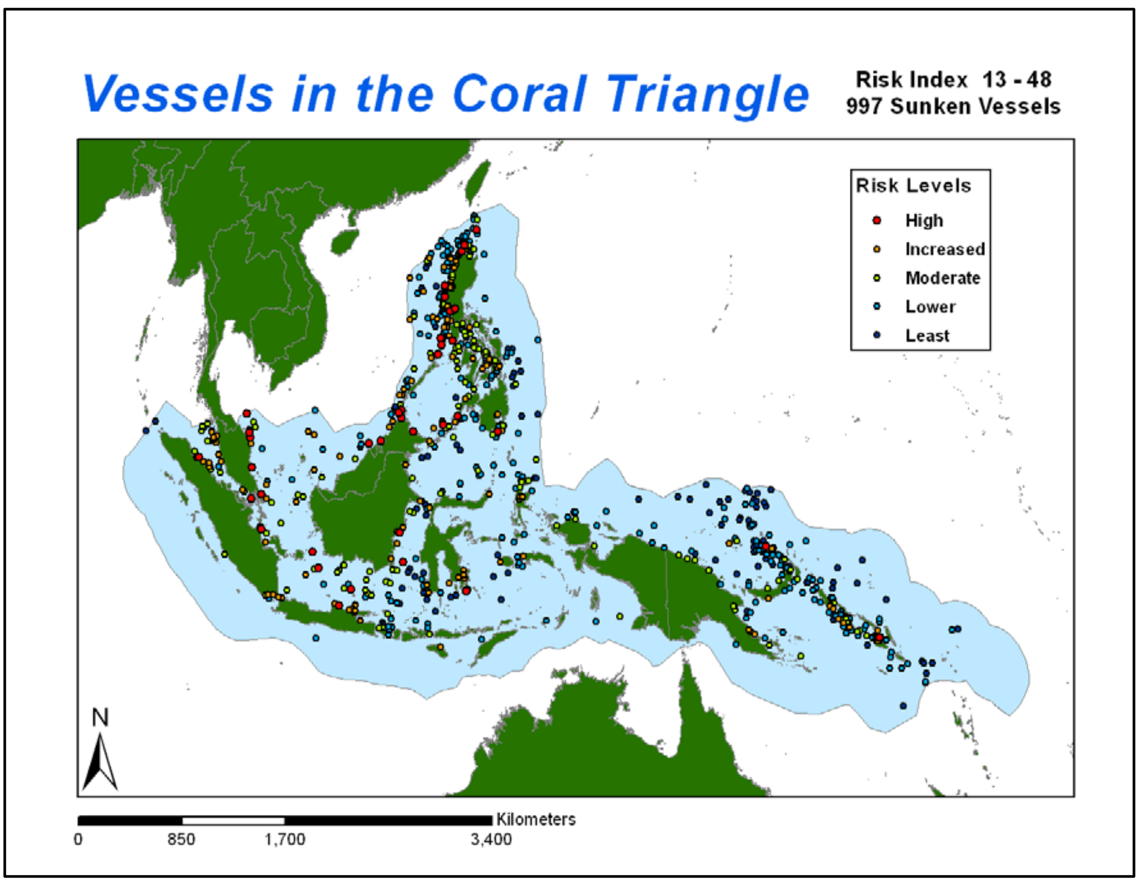



Moderate Risk Vessels
Risk Index 26 - 30
728 Sunken Vessels
Shipwreck
N
Kilometers
0
1,250
2,500
5,000

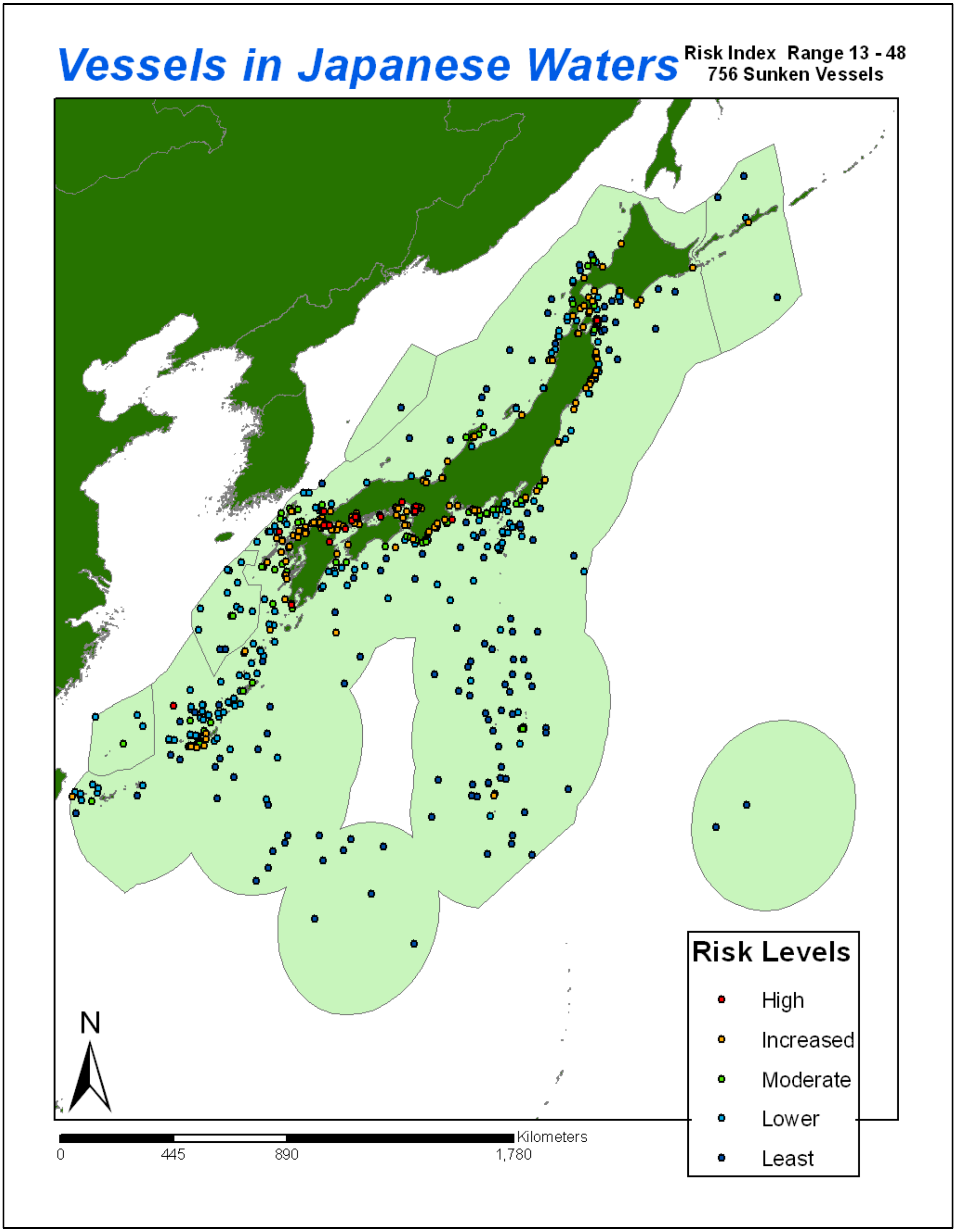

Low Risk Vessels
Risk Index 20 - 25
777 Sunken Vessels
Shipwreck
N
Kilometers
0
1,350
2,700
5,400



Least Risk Vessels
Risk Index 9 - 19
797 Sunken Vessels
Shipwreck
N
Kilometers
0
1,250
2,500
5,000



Vessels in the Coral Triangle
Risk Index 13 - 48
997 Sunken Vessels
Risk Levels
High
Increased
Moderate
Lower
Least
N
Kilometers
0
850
1,700
3,400


Vessels in Japanese Waters
Risk Index Range 13 - 48
756 Sunken Vessels
Risk Levels
High
Increased
Moderate
Lower
Least
N
Kilometers
0
445
890
1,780