Abstract

BLACK GOLD IN THE DEEP BLUE SEA:
AN EXPLORATION OF SHIPWRECK SEARCH MODELING
IN THE SEARCH FOR SS *WILLIAM ROCKEFELLER*

by

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The waters off the North Carolina coast are home to a veritable graveyard of shipwrecks. Many were destroyed by the eternal enemies of all ships--storms, fire, and grounding--but many others have fallen victim to the ravages of war. Between 1941 and 1945, 87 ships were lost off North Carolina; 52 of these were casualties of the Battle of the Atlantic. Many of these wrecks have been found, and their last resting places marked for posterity. Some, however, remain lost.

This thesis will explore the possibility of locating one of these missing wrecks, the oil tanker *William Rockefeller*. *Rockefeller* is historically significant for three reasons. First, from the time of its launch in 1921 to its sinking on 28 June 1942, it was one of the largest oil tankers in the world. Second, it earned the unfortunate distinction of being the largest ship lost off the North Carolina coast during the Battle of the Atlantic of WWII. Third, it is one of the last of these WWII-era wrecks whose location is not known. Ships like HMT *Bedfordshire*, *Bluefields*, *Caribsea*, *Dixie Arrow*, *Papoose*, and *U-576* have all been found, but *Rockefeller* remains elusive, due to the circumstances of its sinking. Because of its cargo of heavy fuel oil, it is also a

potential risk for severe pollution of the Eastern seaboard, so locating it is crucial in order to begin planning potential mitigation strategies. This thesis will seek to establish the most promising areas in which to search for the wreck through a combination of historical research, probability mapping, and computer modeling. If successful, this methodology may be of use in the creation of search models for other lost shipwrecks.

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AN EXPLORATION OF SHIPWRECK SEARCH MODELING IN THE SEARCH FOR SS *WILLIAM ROCKEFELLER*

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BLACK GOLD IN THE DEEP BLUE SEA:
AN EXPLORATION OF SHIPWRECK SEARCH MODELING AND CULTURAL RESOURCE MANAGEMENT IN THE SEARCH FOR SS *WILLIAM ROCKEFELLER*

by

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DEDICATION

This thesis is dedicated to my grandfathers, Technician Fourth Grade Bill Robinson and Chief Warrant Officer Harrold Edwin Detlie, Sr., United States Army, and to the men and women of the United States Merchant Marine who braved all hazards across four oceans to support the Allied war effort from 1940-1945.

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GLOSSARY OF ACRONYMS AND TERMS

ASWORG	Antisubmarine Warfare Operations Research Group
BBL	Barrels of oil
BdU	Befehlshaber der Unterseeboot (Commander of U-boats)
BOEM	Bureau of Ocean Energy Management
CET	Central European Time
CNO	Chief of Naval Operations
CSPM	Classical Search Planning Method
CASP	Computer Assisted Search Planning
ESF	Eastern Sea Frontier
EWT	Eastern War Time
EBK	Empirical Bayesian Kriging
GIS	Geographic Information System
GMT	Greenwich Mean Time
GRT	Gross Register Tons
IDW	Inverse Distance Weighting
JAWS	Joint Automated Worksheets
Kapitänleutnant	Abbr. KptLt., "captain lieutenant"; German naval rank, equivalent to US Navy lieutenant
Korvettenkapitän	Abbr. KKpt., "corvette captain"; German naval rank, equivalent to US Navy lieutenant commander
KTB	Kriegstagebüch ("war diary", log of events kept by German ships and shore commands)
MNMS	*Monitor* National Marine Sanctuary
NARA	National Archives and Records Administration

NMU	National Maritime Union
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NMI	Nautical miles
NODC	Naval Oceanographic Data Center
NNSDD	Newport News Shipbuilding and Dry Dock Company
OCNO	Office of the Chief of Naval Operations
ONI	Office of Naval Intelligence
ONMS	Office of National Marine Sanctuaries
RULE-T	Remediation of Underwater Legacy Environmental Threats
SAR	Search and Rescue
SAROPS	Search and Rescue Optimal Planning System
USCG	United States Coast Guard
USDCEDV	United States District Court Eastern District of Virginia
USN	United States Navy

CHAPTER ONE: INTRODUCTION – THE DRUMBEATS OF WAR

Introduction

"Boats form Group Paukenschlag." With these four words Admiral Karl Dönitz unleashed his beloved sea wolves, the U-boats of the German Kriegsmarine, upon the United States (Kals 1942:8; Zapp 1942:6). They did not take long to begin fulfilling their mandate. On the night of 15 January 1942, the Panamanian-flagged oil tanker *Norness* was sailing from New York to Liverpool with a cargo of Admiralty fuel oil, unaware that it was being stalked by the submarine *U-123*, under the command of veteran U-boat sailor Kapitänleutnant Reinhard Hardegen (Basta et al. 2013a:3-4). At 2:30 AM Eastern War Time (EWT), 60 miles off Montauk Point, Long Island, the hunter struck. A torpedo slammed into the tanker's side, punching a hole through its hull and igniting a colossal fireball. A second torpedo followed fifteen minutes later, with similar results. As burning oil gushed into the Atlantic and the tanker's crew scrambled to escape their mortally wounded ship, *U-123* brazenly surfaced and closed with its victim, leisurely prowling around *Norness* like a big cat circling its kill. As the sailors watched, the submarine began firing more torpedoes at the stricken vessel. One of these "fish" malfunctioned and bounced off *Norness*' side, but the next one broke the tanker's back and sent it to the bottom along with two of its 40 crew (Hardegen 1942:12-13; Basta et al. 2013a:4). The following morning, the American public awoke to headlines proclaiming that the U-boats had come to their shores for the second time in thirty years. *Norness* had earned the dubious distinction of being the first ship to be sunk in American waters by a U-boat during World War II, but it was to be far from the last (*Boston Globe* 1942a-b; *Detroit Free Press* 1942:1; *New York Tribune* 1942:1-2; Stick 1952:229; Hickam 1989:9; Gannon 1990:215-220; Basta et al. 2013a:3-4).

Indeed, by the time American newspapers were proclaiming his first kill, KptLt Hardegen had already scored his second. Early on the morning of 15 January, he torpedoed the fully laden British tanker *Coimbra* within sight of New York City. The ship went up like a firework display, killing most of its crew and producing a column of flame that Hardegen estimated to be 200 meters high. The fireball was clearly visible to people on shore 27 miles away (Hardegen 1942:14-15; Hickam 1989:10; Gannon 1990:233-236).

Three days after Hardegen's attacks, Korvettenkapitän Richard Zapp's *U-66* struck Paukenschlag's first drumbeat in North Carolina waters by firing two torpedoes at the tanker *Allan Jackson* as it steamed past Cape Hatteras. Despite a last-ditch attempt at evasion, both torpedoes found their target. The first hit an empty oil tank on the starboard side, inflicting minimal damage, but the second struck between two full tanks, breaking the ship in half and turning it into a torch. Twenty-two of *Allan Jackson*'s 35 crew perished. It was the first of many ships that would ultimately meet their end in the waters of North Carolina during World War II. Together, these three sinkings heralded the beginning of the U-boat war in American waters and six months of death and destruction, often within sight and sound of coastal cities (Zapp 1942:9-10; Standard Oil 1946:109-110; Stick 1952:229-232; Hickam 1989:11-13; Gannon 1990:228-229, 244-247, 361-363).

While there were many inviting target areas along the American coast, the Outer Banks proved to be an especially rich hunting ground for the U-boats. The waters around Cape Hatteras form a natural bottleneck in the shipping lanes of the East Coast. Ships sailing north cruise with the Gulf Stream, which cuts in close to Hatteras as it passes the Outer Banks, while southbound vessels are obliged to steam near the cape and its many shoals to avoid sailing against the Stream or wandering too far into open ocean and out of the sea lanes. Even better, from the U-boats' perspective, is that the edge of the continental shelf lies close by this bottleneck. This allowed them to hunt in the shallows near the cape, then quickly retreat to deeper waters off the shelf to avoid retribution from American antisubmarine patrols (Hickam 1989:11; Dolan 2016).

Between 1941 and 1945, 87 ships were lost off North Carolina. Fifty-two of these were sunk by torpedoes, mines, and gunfire from U-boats (Stick 1952:239; Dolan 2016). Most of these sinkings occurred during one six-month period in 1942, beginning with the drumbeats of Operation Paukenschlag and ending only when the United States Navy and Coast Guard finally applied hard-learned lessons from the previous war to the problems of the current one. This record of destruction earned the area the nicknames “Torpedo Alley” or “Torpedo Junction” (Stick 1952:233-239; Hickam 1989:23; Gannon 1990:385-390). Many of these wrecks have been found, and their last resting places marked for posterity. Some, however, remain lost.

This thesis will explore the possibility of locating one of these missing wrecks, the oil tanker *William Rockefeller*. On 28 June 1942, *Rockefeller* was sailing past Cape Hatteras *en route* to New York with a cargo of heavy fuel oil when it was ambushed by the German submarine *U-701*. A single torpedo caught *Rockefeller* amidships, breaching one of its storage tanks, spraying oil across the deck, and setting the ship on fire. After its crew abandoned ship, *Rockefeller* was left to drift with the currents and wind before finally sinking sometime later, either on its own or after *U-701* hit it with a second torpedo (Degen 1942c; Standard Oil 1946:321-323).

It is reasonable to ask at this stage: why this ship in particular? *Rockefeller* is significant for several reasons. First is its historical significance. From its first voyage in 1921 until its sinking in June 1942, *Rockefeller* was one of the largest oil tankers in the world, and one of only two ships of its class. It set new records for carrying cargo through the Panama Canal and was directly impacted by the National Maritime Union (NMU) tanker strike of 1939, the outcome of which permanently damaged the NMU's credibility as a labor organization and strengthened Standard Oil's bargaining position in future contract negotiations. Its sibling, *John D. Archbold*, was scrapped in 1963, meaning that *Rockefeller* is now the only extant ship of its class (*Wall Street Journal* 1921; *Baltimore Sun* 1923; Willett 1990; Mariners' Museum 2022).

Second, *Rockefeller* became a participant in the Battle of the Atlantic by dint of its sinking, making it part of one of the longest, largest, and most costly sea battles in human history. It also earned the unfortunate distinction of being the largest ship lost off the North Carolina coast during World War II (Blair 1996:xiii; Hoyt 2008:9). NOAA officials have suggested that *Rockefeller* is a potential candidate for inclusion on the National Register of Historic Places, both for its historical uniqueness and because of its status as a casualty of the battle (Basta et al. 2013b:7).

Third, it is one of the last of the WWII-era wrecks in North Carolina waters whose location is not known. Ships like HMT *Bedfordshire*, *Bluefields, Caribsea, Dixie Arrow, Papoose*, *U-576*, and *U-701* have all been relocated over the past 80 years, but *Rockefeller* remains elusive, due to the circumstances of its loss. It drifted for approximately 12 hours before going down, and there exists no consensus as to its position when it sank. Because of this, it is now one of approximately six wrecks from the Battle of the Atlantic in the waters off the Outer Banks that have yet to be relocated (Dolan 2016).

The fourth factor is a more practical concern. When it was torpedoed, *Rockefeller* was carrying 136,647 barrels (~5,739,174 gallons or ~21,725,136 liters) of heavy fuel oil, excluding its bunkered fuel. Some of this oil was spilled or burned off by *U-701*'s torpedoes, but it is probable that a significant amount remains in the wreck (OCNO 1942b, 1942d; Standard Oil 1946:321; Basta et al. 2013b:13). NOAA has classified *Rockefeller* as a potential risk for severe pollution of the Eastern seaboard, so locating it is crucial in order to determine the wreck's condition, judge whether it is an imminent hazard, and begin planning mitigation or removal strategies if necessary (Basta et al. 2013b:16-22). The ship's present condition is unknown, but studies and analyses conducted on wrecks of similar vintage suggest that it has likely experienced significant corrosion due to 80 years of immersion in saltwater. This being the case, special strategies and techniques may be required to ensure safe removal of the oil without causing further damage to the hull (Robinson 1981; Piero 2004; Russell et al. 2006; Foecke et al. 2010; Rissel 2012:36-38, 43-56; Fox 2015:141-151).

Previous Research

During the Battle of the Atlantic, Axis and Allies alike kept detailed records of their operations off the American coast, based on after-action reports, logs, and statements from participants of the many engagements that took place during the conflict. In turn, naval officers, civilian participants, and historians from both sides wrote their own accounts and analyses of the Battle of the Atlantic, usually from an operational point of view (DIO 1942; OKM 1942; Admiralty 1946; Karig et al. 1946; King 1946; Standard Oil 1946; Morison 1947; Dönitz 1959; Freeman 1987). From this rich wellspring of primary sources has sprung a thriving cottage industry of writing and scholarship. Authors have produced popular histories of the U-boat war in American waters, many of which have focused on specific regions or even individual ships and U-boats (Stick 1952; Balison 1954; Hoyt 1978, 1989; Van der Vat 1988; Hickam 1989; Cheatham 1990; Gannon 1990; Blair 1996; Kurson 2004; Offley 2014). Other sources have focused on the tactics, technologies, and weapons employed during the battle, while still others are meticulously compiled butcher's bills that recount the casualties sustained on both sides of the conflict (OCNO 1963; Rohwer 1983; Hessler 1989; Kemp 1997; Niestlé 1998; White 2006; Brown 2007; Williamson 2010; Browning 2011)

In the academic and governmental sphere, many studies, theses, and reports have been produced, covering a variety of topics and questions. Some of these are concerned with the battle's historical impact and context, while others have sought to adapt terrestrial archaeological techniques and methods to analyze its physical remains. In recent years, another thread has emerged in this sphere. Possibly the most unfortunate legacy of the Battle of the Atlantic is the great number of wrecks lying in coastal waters that still contain oil, unexploded ordnance, and other pollution or safety hazards. The National Oceanic and Atmospheric Administration (NOAA) has developed an ongoing project in which these wrecks are catalogued and assessed for their pollution potential, while strategies have been developed to remove their hazardous cargoes or otherwise mitigate their potential impact on America's maritime resources (Blake 2006; Campbell 2008; Hoyt 2008; Wagner 2010; Bright 2012; Basta et al. 2013 a-b; Symons et al. 2014; Freitas 2017; Hoyt et al. 2021, Michael Brennan 2022, pers. comm.).

In the specific context of *William Rockefeller*, however, there is little extant research. Since *Rockefeller* sank unobserved after drifting for approximately 12 hours, establishing a concrete search area has proven problematic. Because of this, no serious effort to locate the wreck has yet been undertaken. Some estimates have suggested that a search area for the ship would encompass up to 750 square nautical miles (Basta et al. 2013b:6; NOAA 2011). What research has been performed on the subject has been limited to NOAA's evaluation of the wreck's pollution potential, as well as a few books on the history of Standard Oil's tanker fleet and the U-boat war in North Carolina waters (Standard Oil 1946; Balison 1954; Hickam 1989; Blair 1996; Basta et al. 2013b; Offley 2014). None of these sources has offered an in-depth analysis of *Rockefeller*’s last hours afloat or attempted to define a more compact search box. Therefore, this thesis seeks to establish the most promising areas in which to search for the *Rockefeller* wreck through a combination of historical research, probability mapping, and computer modeling. If successful, this methodology may be of use in the creation of search models for other shipwrecks lost under similar circumstances.

Research Questions

While the possibility of solving the mystery of *Rockefeller*’s final location is certainly tantalizing, the wreck also provides an opportunity to answer several important research questions. The wreck’s intrinsic historical value notwithstanding, it is valuable to the archaeologist as a kind of case study for answering these questions.

This study’s primary research question is as follows: *What is the potential of GIS-based mapping software and predictive modeling methods for locating WWII shipwrecks off the coast of North Carolina?*

Over the past 40 years, the rise of GIS-based technologies has made charting drift patterns and predicting the effects of wind, waves, and other natural processes upon a steel hull much easier and more accessible to the archaeologist and the historian. Other studies have been conducted that employ GIS or its derivative systems; their findings will be discussed as part of the theory and methodology chapter.

In turn, this leads to other questions. As any researcher who has spent time trying to reconstruct a narrative from primary sources can attest, human biases and errors often creep into what are supposedly neutral and objective records. This tendency is magnified by the stress inherent to naval combat and sinking events, when there may be only minutes at most to record positional data or send distress signals before a ship has gone down and its crew are at the mercy of the ocean. Thus, the second question follows: *how can researchers account for inaccuracies in historical documents to refine shipwreck search models?* At least three separate sets of coordinates have been recorded for *Rockefeller*'s position when it was attacked. Determining which of these is the most accurate will directly affect the research and modeling that follows.

This leads to the third question: *How can researchers account for the effects of ocean currents and vessel drift as reported in historical documents in order to refine the explanatory/predictive models they use to search for shipwrecks?*

The ocean is not a static entity. Prevailing winds and the Coriolis effect generate currents that can flow for thousands of kilometers, to say nothing of the effect of storms and other weather events. Variations in temperature and salinity affect the ocean's density and shuffle its waters about in a vast and endless cycle often referred to as the "ocean's conveyor belt." The gravitational effects of the moon cause the tides to rise and fall in a regular rhythm. Thus, anything left to sit in the ocean will not long remain at its origin point, even a 14,000-ton tanker. *Rockefeller* remained afloat for approximately 12 hours before it sank; in that time, it would have drifted a noticeable distance from the spot at which it was attacked. Accounting for this dynamism is a critical element of any shipwreck search, and a variety of solutions have been developed.

Objectives

The key objective of this thesis is to establish potential area boundaries for a systematic underwater search, with the aim of eventually locating, surveying, and recording *William Rockefeller*'s wreck. To accomplish this, several tasks had to be completed. The first was identifying and collating historical data from eyewitness accounts of *Rockefeller*'s final voyage, along with related primary and secondary sources on the tanker's history and the Battle of the Atlantic. This research was conducted at archives, libraries, and online repositories.

With this dataset acquired, the next task was to assemble a predictive model and search map using a Geographic Information System (GIS). This GIS enabled the ship's last voyage to be reconstructed via historical coordinate data and will be of use when and if a search expedition is launched, as the findings of any such expedition can be entered into the GIS to help focus future efforts. The compiled historical data was also sent to the United States Coast Guard so that they could create a probability map using their Search and Rescue Optimal Planning System (SAROPS), a bespoke software package based on decades of research and practical experience in SAR work (Roylance 2007; Turner et al. 2008; Kratzke et al. 2010). Modified versions of this program and its predecessor, the Computer Assisted Planning System (CASP), have previously been used for shipwreck searches, which suggested its use for this study (Stone 1992; Ryan 2015).

Structure

This thesis will consist of seven chapters. The first chapter is the introduction, which provides historical context for the present study, outlines previous research conducted on the topic, and enumerates the research questions and objectives of this study.

Chapter Two is a historical account of *William Rockefeller*'s construction and career, leading up to its brief wartime career and sinking on 28 June 1942. Besides providing a biography of the vessel, it provides a wider context for the conditions into which *Rockefeller* was sailing on its last voyage. This chapter uses a combination of primary and secondary source narratives to reconstruct *Rockefeller*'s career and the events on the day of its sinking. As these narratives diverge beyond reconciliation when discussing *Rockefeller*'s last hours afloat, they are reevaluated and analyzed in the following chapters.

Chapter Three reviews the history and theory of maritime search methodologies, including Bayesian search theory, predictive modeling, and drift mapping. These methods were selected for this thesis because they have previously been successfully employed to search for wrecks such as USS *Scorpion*, Air France Flight 447, MV *Derbyshire*, and SS *Central America* (Craven 2001; Stone 1992; Stone et al. 2014).

These methods are applied in Chapter Four, via the development of a GIS-based predictive model and search map and the employment of the United States Coast Guard's Search and Rescue Optimal Planning System (SAROPS). Here the objective is to winnow out unreliable and inaccurate data and construct a predictive model that reduces the potential search area to a more manageable size.

In Chapter Five, the results of this process are discussed, including their potential for narrowing down the potential search area for *Rockefeller*'s wreck. Chapter Six will analyze the results and the datasets used to produce them, discussing the strengths and weaknesses of each dataset in relation to the scenarios that they produced and comparing the points of agreement and disagreement between the GIS model and the SAROPS model. Chapter Seven will review the questions posed in this introduction, discuss whether they have been answered, and consider potential next steps in the process of searching for *Rockefeller*.

A combination of primary and secondary sources will be employed in the pursuit of this thesis, including statements filed by *Rockefeller*'s crew and its Coast Guard escort and interrogation reports from the survivors of the U-boat that sank the ship; deck logs reports produced by the Coast Guard and Office of Naval Intelligence relating to the sinking; popular books written on the subject of the U-boat war off North Carolina; academic and government papers and reports covering the previous research performed on *Rockefeller*; and papers, reports, and books which discuss the maritime search methodologies listed above. These sources and the data and methodologies they contain will be used to establish the most likely location in which to search for *Rockefeller*.

Part of the process of examining these sources will be determining which data is unreliable or inaccurate. For example, there are at least three last recorded positions on file for *William Rockefeller*. This is not an uncommon issue in maritime search. The stress of a sinking event, especially one that occurs unexpectedly and under violent conditions, tends to interfere with decision-making processes and *ex post facto* recall. Even if someone has the presence of mind to record a ship's position while it is burning or being battered by a storm, they will very probably remember it inaccurately later. Anyone who embarks on a search for a lost shipwreck must contend with this problem. The sources must be considered carefully and weighed according to their reliability.

The case of SS *Central America* is a notable example of this issue. Its loss in a hurricane in 1857 was accompanied by a similar level of confusion over its last known position. *Central America*'s captain passed his last position fix to another vessel shortly before the steamer sank, but a survivor of the wreck and two rescue vessels reported different positions, all of which varied widely from each other. However, a careful analysis of the available data and application of Bayesian search theory enabled a team of private contractors to develop a probability map that was successfully used in searching for the wreck (Stone 1992:37-39). Given the available level of data on *William Rockefeller*'s loss, it should be possible to construct a similar map and model.

In order to construct this model, it will be necessary to start from the beginning. Therefore, let us step back to the dawn of the Roaring Twenties.

CHAPTER TWO: ITS BLOOD WAS OIL AND ITS BONES WERE STEEL – THE HISTORY OF SS *WILLIAM ROCKEFELLER*

William Rockefeller*'s construction and early life*

The year was 1920. The so-called Great War was not long ended, and its participants were beginning the long process of recovering from the devastating effects of the first industrialized mass conflict in human history. As part of this recovery effort, shipyards the world over were constructing merchant vessels of all stripes to replace the tonnage lost to German U-boats and commerce raiders throughout the war. Among these yards was the Newport News Shipbuilding and Dry Dock Company, located in its namesake town on the Virginia coast. Then as now, Newport News was a center of seaborne commerce, and the yard was busy turning out new hulls for its clients.

Two of these hulls, numbers 261 and 262, were being built for the Standard Oil Company, replacements for ships that had been torpedoed and sunk during the war. Hull number 261 was to be named *John D. Archbold*, after a past president of Standard Oil. Hull 262 was to be named *William Rockefeller*, after John D. Rockefeller's younger brother and business partner (see FIGURE 2.1).

FIGURE 2.1. William Rockefeller, Jr., namesake of SS *William Rockefeller*. (Encyclopedia Britannica)

These ships would be marvels of their age. In length, breadth, draft, and tonnage, they were equal to or larger than HMS *Dreadnought*, the revolutionary battleship whose construction and launch in 1906 had touched off the naval arms race that led into the World War. *Dreadnought* was 160 meters in length, with a 25-meter beam and 9-meter draft at full load. Its tonnage while empty was 16,300 tonnes, and it displaced 20,730 short tons at full load (Roberts 2001:13-14).

By comparison, *Archbold* and *Rockefeller* were 169 meters in length, with a 23-meter beam, molded depth of 13 meters, and 9.4-meter draft. Their gross registered tonnage (GRT) was 14,054 tons and they displaced 29,000 tons, with a cargo capacity of 22,390 deadweight tons, or approximately 146,745 barrels of oil (Standard Oil 1946:321; Balison 1954:314-315).

The ships were built with Isherwood/Gatewood-style longitudinal framing and had three continuous operational decks--the upper deck, shelter deck, and bridge deck. There was no main deck as such; instead, the peaks were completely plated at the main deck level, with stringers fitted in the machinery spaces and forward of the oil tanks (Newport News Shipbuilding and Dry Dock Company [NNSDD] 1920:9). The holds were divided into eight tanks, four to port and four to starboard, divided by 13 oil-tight centerline bulkheads that extended to the shelter deck. The tanks had a collective capacity of 800,000 cubic feet. In the center of the ships, between the number 4 and 5 tanks, was the pump room, equipped with four steam-powered horizontal duplex oil pumps and two auxiliary vertical duplex pumps. These pumps could offload oil at a rate of 7,000 barrels per hour (NNSDD 1920:15-18, 91).

The ships had also three watertight bulkheads, fitted at their fore and aft peaks and between the collision bulkheads and the oil tanks. The collision bulkheads extended to the ships' shelter decks, and the watertight bulkheads all extended to the upper decks. A screen bulkhead was added to divide the boiler rooms from the engine room. Double bottoms were fitted to the hulls beneath the engine and boiler rooms, subdivided by a transverse partition and meant to carry feed water for the boilers. Six-foot double bottoms were fitted beneath the forward holds between the collision bulkhead and forward fuel tank, equipped with a watertight centerline partition; these were meant to carry either water ballast or fresh water (NNSDD 1929:13-15). The ships had two deckhouses, one located over the forward hold and the other aft. The forward deckhouse contained the bridge, wheelhouse, chart room, and officers' quarters. The after deckhouse contained quarters for the engineers and petty officers. The rest of the ships' complements were quartered on the upper deck in the after portion of the ships (NNSDD 1920:10, 20) (See FIGURES 2.2 and 2.3). Their power plants, designed and built by Newport News Shipbuilding, consisted of two triple-expansion steam engines powered by three oil-burning Scotch boilers. These engines developed a combined 4,100 horsepower, driving twin manganese bronze propellers at a maximum speed of 10.5 knots (NNSDD 1920:111-112, 142-143, Standard Oil 1946:321). They were also equipped with the latest technological innovations, including electric lighting, a refrigeration plant, a state-of-the-art steam firefighting system (crucial for ships whose job was to haul volatile cargo), a wireless radio-direction finder, telephones, and a gyro compass (NNSDD 1920: 100-101, Hoyt et al. 2021:7-275). Creature comforts were not neglected. The officers' quarters had tiled bathrooms, porcelain-lined bathtubs, oak furniture, and plush mohair seating, as did the saloon (NNSDD 1929:49-50, 90). Together, these two ships represented America's burgeoning industrial might as it took its first steps onto the stage of world power.

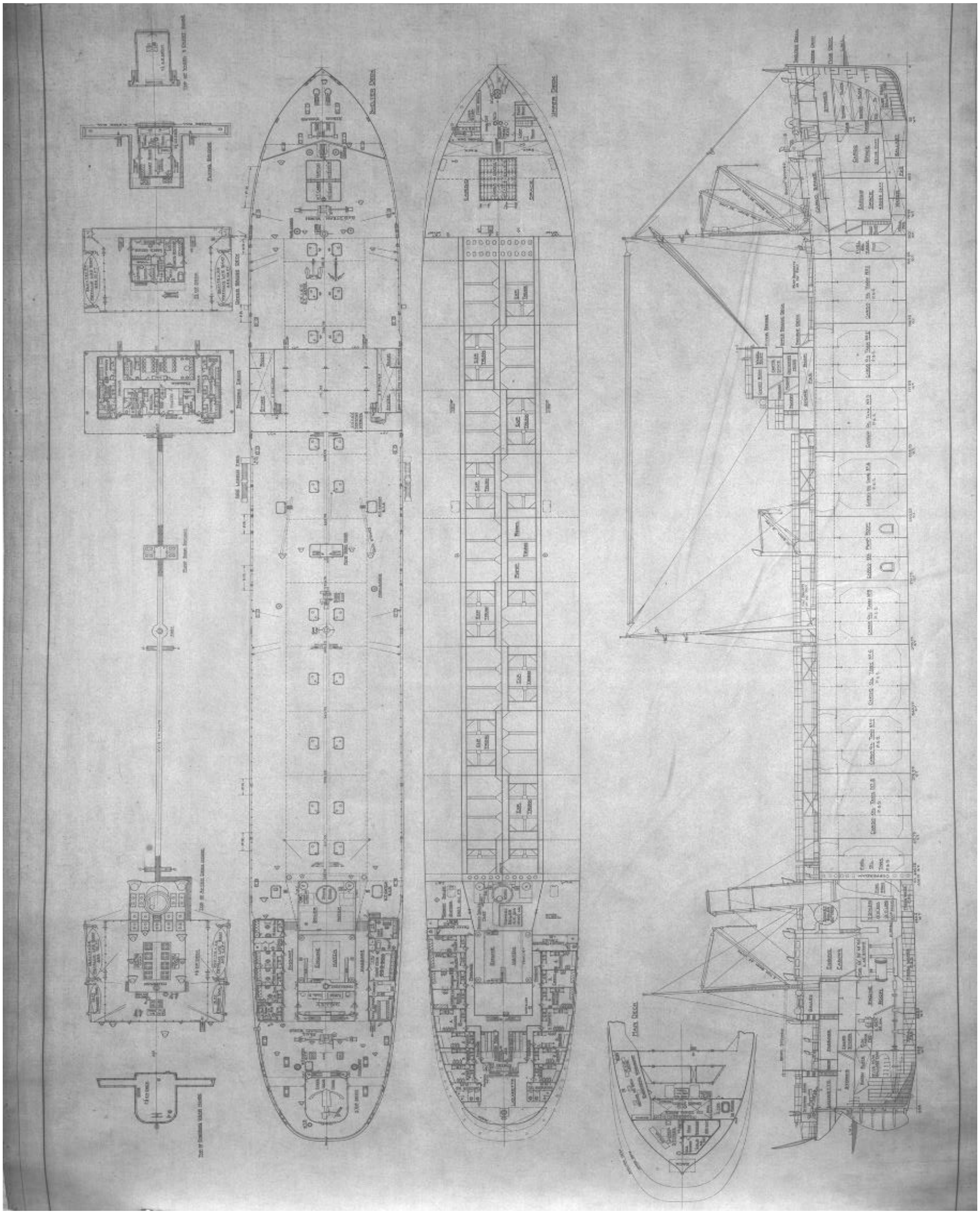


FIGURE 2.2. Black-line drawings for Hulls 261 and 262, *Archbold* and *Rockefeller*. (Mariners' Museum, accession number VM 301.N5 A5 Rare 00)

FIGURE 2.3. *Rockefeller* under construction at Newport News Shipbuilding. (Mariners' Museum, accession number MS0153-01-02.57-0569)

The ships were ordered on 10 February 1920. Construction began shortly thereafter and was completed the following year. *Archbold* was first off the slipway, launching on 10 August 1921 and leaving the yard on 24 September. *Rockefeller* was launched on 5 October and departed the yard on 9 November (see FIGURE 2.4). When launched, they were the largest oil tankers in the world; they were also among the last major ships that Newport News Shipbuilding would produce for two years. A downturn in orders for new merchant hulls coincided with the limits on warship tonnage being set by the Washington Naval Conference to all but sever the yard's pipeline of new construction work (*Wall Street Journal* 1921, Smith 1939:462-464).

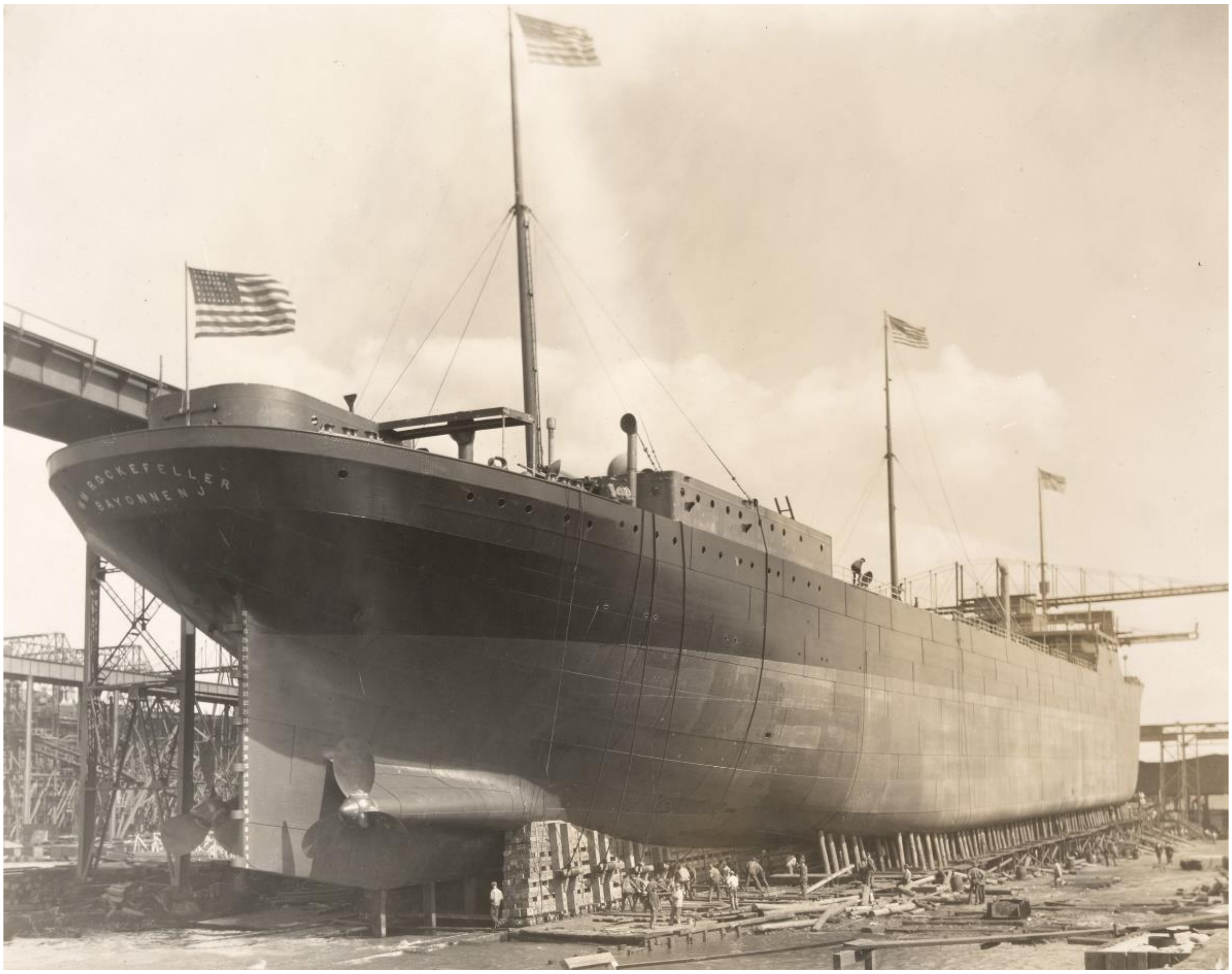


FIGURE 2.4. *Rockefeller* on the slipway at Newport News Shipbuilding, shortly before launch. (Mariner's Museum)

Soon after their launch, *Archbold* and *Rockefeller* became embroiled in a legal dispute regarding their hull construction. Newport News had built the ships with a type of longitudinal framing referred to in their documentation as the Gatewood system, after the yard's chief engineer, William Gatewood (NNSDD 1920:11). However, British naval architect Joseph Isherwood alleged that the so-called Gatewood system was an infringement on his own system of longitudinal framing, which he had patented in Britain in 1906 and subsequently licensed to Newport News Shipbuilding in 1910 at a rate of five shillings per gross ton while he worked to secure an American patent (*Nautical Gazette* 1922:383; *News Leader* 1922:20; United States

District Court Eastern District of Virginia [USDCEDV] 1922:283). Isherwood filed suit against Newport News, which counterclaimed that Gatewood had created a legally distinct improvement on Isherwood's system that allowed for fewer transverse members in a ship's hull by increasing the depth of the individual members, thereby saving weight and increasing cargo capacity (USDCEDV 1922:292-293). The court's conclusion was succinct:

> So far as I am able to determine the differences which exist in the construction of the *Rockefeller,* when compared with the *Asche* [a ship built under the Isherwood system], grow out of an effort to avoid the conditions of the patent, while at the same time employing its basic features. This cannot be done without infringement. The cases so holding are numerous and the principle is really not contested (USDCEDV 1922:294, text in brackets added for clarity).

The court ultimately ruled that Gatewood's system was in no way legally distinct from Isherwood's system, that it was a blatant attempt to avoid paying license fees, and that Newport News was therefore liable for unpaid royalties on *Archbold*, *Rockefeller*, and eight other ships they had built using the "Gatewood system" since 1910. At the five-shilling-per-gross-ton rate set up in their contract with Isherwood, this meant that *Rockefeller* cost the yard £3,515.5 [£136,200.47 or $163,917.13 USD as of 2023] (USDCEDV 1922:293-294).

The Roaring Twenties

Regardless of the legal furor that surrounded their birth, the twin colossi completed their sea trials without incident and joined the Standard Oil fleet, quickly becoming some of its most prized members (Standard Oil 1946:409). The two tankers were designated for the Pacific and Gulf oil trades, transporting "black gold" from ports on the Pacific Coast, the Gulf of Mexico, and the Caribbean to American ports on the East Coast, including New York City, Baltimore, Philadelphia, and Charleston (*The State* 1925). *Rockefeller* quickly made a name for itself as a reliable long-distance hauler. It was a common sight in several California ports, including Los Angeles, San Pedro, and Long Beach, and its name appears regularly in the records of arrivals and departures from those ports (*Daily Pilot* 1923, 1924; *Los Angeles Times* 1925; *Press Telegram* 1926). In October 1922, it set a record for the largest cargo ever carried through the Panama Canal when it brought 6,003,000 gallons (142,928 barrels (bbl) or ~20,892 tons) of crude oil through the canal *en route* to New York from Los Angeles, breaking a previous record of 20,000 tons set earlier that year by the ore carrier *Marore* (in a curious twist, *U-432* sank *Marore* off Cape Hatteras in February 1942, not far from where *Rockefeller* would be attacked four months later) (*San Francisco Chronicle* 1922:14; *Baltimore Sun* 1923:15; Hoyt et al. 2021:7-275).

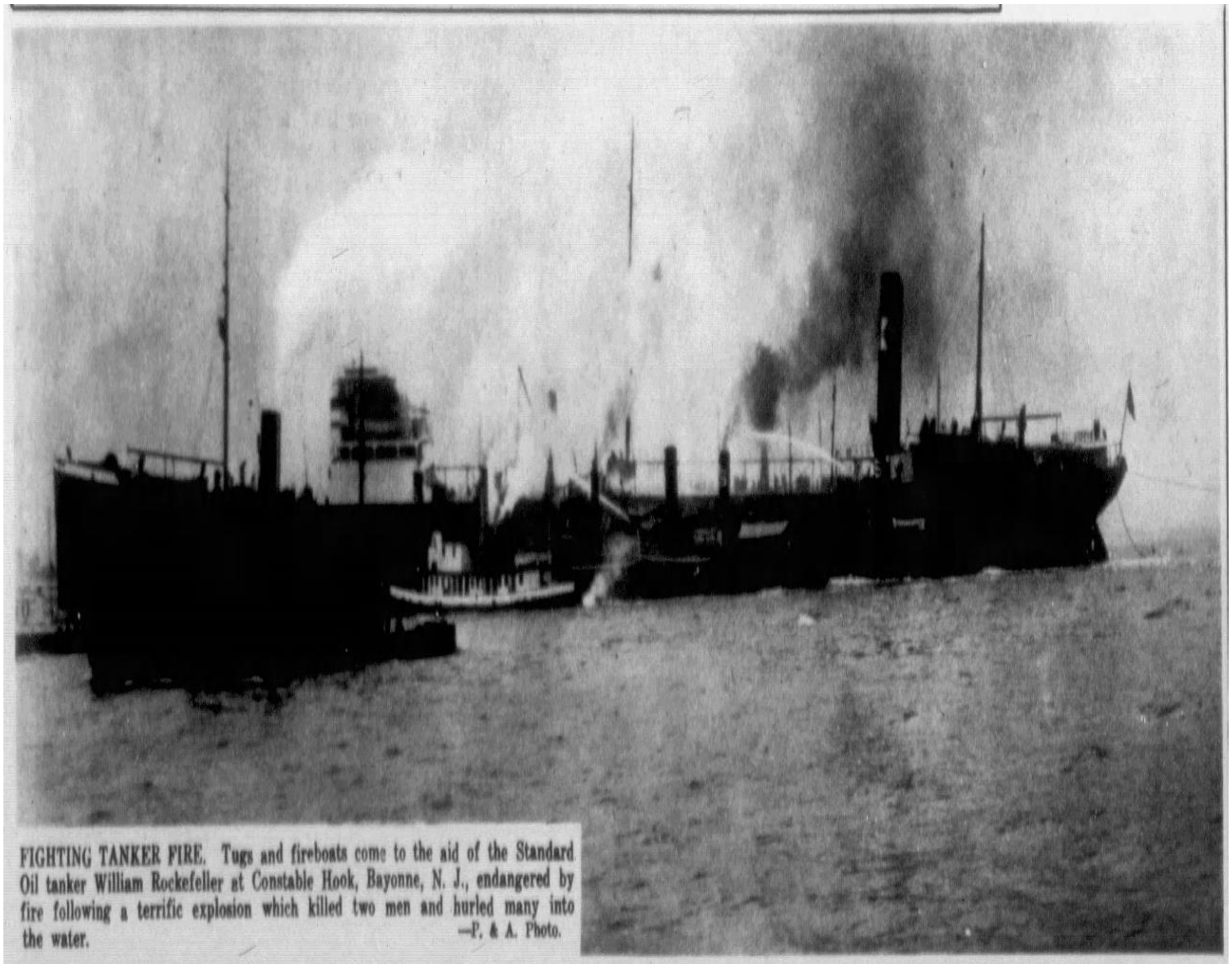
On the morning of 3 January 1925, *Rockefeller* went aground off Jupiter Point, Florida while steaming in heavy fog. Its bow was so deeply embedded in mud that the first steamers to respond to its distress signals were unable to haul the tanker clear. It remained stuck for over 36 hours, until a team of tugs and steamers was able to break the ship loose (*Bradenton Daily Herald* 1925; *Palm Beach Post* 1925). This incident apparently caused no serious damage, as it was back in service by 19 February (*Los Angeles Times* 1925).

Rockefeller's career continued without incident until December 1928, when its rudder was damaged while being towed to a new berth in the yards of Morse Dry Dock Repair Company, which had been contracted to perform general repairs on the vessel. As the tanker was being turned to be placed into the new berth, its stern brushed against a pier, damaging the rudder and twisting the rudder stock. Such incidents were not unusual in the course of a working ship's lifetime, but this particular mishap became the subject of a legal dispute between Morse Dry Dock, Standard Oil, and Olsen Water Towing Company, whose tugs had been engaged to move the tanker. At issue was the damage caused to the ship's rudder stock, and whether this damage had existed prior to the accident in question. Morse had paid for repairs to the stock, and therefore sued to recoup those costs on the grounds that the stock had been damaged prior to the accident and was not their responsibility. The claim against Standard was ultimately dismissed, though Olsen was found liable for negligence (United States District Court E.D. New York 1932).

A much more serious incident occurred the following year. On the morning of 9 August 1929, *Rockefeller* was discharging cargo at a pier in Bayonne, New Jersey. At about 0600, crew member Edward Haley entered the ship's pump room to locate and repair a leak which was generating oil fumes. The concentrated fumes quickly overcame Haley, and he was taken off the ship for medical treatment. About an hour later, between 0710 and 0715, something ignited the accumulated fumes, sparking a fire and series of explosions that breached one of the ship's storage tanks, tore a 50-square-foot hole in the deck, and sprayed thousands of gallons of burning oil across the pier and into the Kill Van Kull strait, threatening to ignite millions of gallons of oil stored in a nearby Standard tank farm (*Boston Globe* 1929; *Corsicana Semi-Weekly Light* 1929; *Decatur Herald and Review* 1929).

The blast was felt in Brooklyn and Lower Manhattan, shattered windows along the Staten Island waterfront, and generated so much smoke that private homes and businesses in the vicinity were obliged to turn on their lights. Two of the crew were killed and 11 injured; many of the survivors were forced to jump overboard to avoid being burned to death. Boatswain's mate Edward Coulson bravely remained aboard to drain the rest of the ship's storage tanks, sustaining a grievous injury to his hand in the process (*Boston Globe* 1929; *Corsicana Semi-Weekly Light* 1929; *Decatur Herald and Review* 1929).

Firefighters were unable to make headway against the inferno, and the burning vessel had to be towed clear of the pier and grounded on mud flats just off the Brooklyn shore, where it was extinguished by tugs and fireboats (see FIGURE 2.5).



FIGHTING TANKER FIRE. Tugs and fireboats come to the aid of the Standard Oil tanker William Rockefeller at Constable Hook, Bayonne, N. J., endangered by fire following a terrific explosion which killed two men and hurled many into the water. —P. & A. Photo.

FIGURE 2.5. *William Rockefeller* on fire after sustaining a catastrophic explosion (*Nashville Banner* 1929).

Fortunately, *Rockefeller* had already discharged approximately half its cargo when the explosion occurred, otherwise the result might have been much more severe. As it was, the ship had sustained heavy damage; aside from the breached tank and damage to the deck mentioned earlier, several deck winches had been destroyed, the mainmast was warped and stripped of its gear, and the ship’s hull and superstructure were weakened by the fire. Repairs cost an estimated $50,000 (~$864,653.18 as of January 2023). The cause of the explosion was never definitely established. Standard Oil officials attributed it to a short circuit somewhere in the pump room, while a member of the crew stated that it was caused by a broken steam pipe (*Boston Globe*

1929; *Brooklyn Standard Union* 1929; *Decatur Herald and Review* 1929; Hoyt et al. 2021:7-275). This incident would prove to be a curious foreshadowing of the tanker's ultimate fate 13 years later.

After being repaired and reentering service, *Rockefeller* resumed its usual working schedule. It again went aground off Port Eads, LA, in January 1930, though this incident was apparently minor (*Daily Telegraph* 1930). 9 years later, *Rockefeller* was briefly embroiled in the 1939 Tanker Strike, called by the leadership of the National Maritime Union (NMU) against four major oil companies that operated tanker fleets, including Standard (*New York Times* 1939[sec. S]:45; *Socialist Appeal* 1939:1-2; Willett 1990).

The NMU had successfully negotiated a contract with Standard in 1938 that contained major concessions on the latter's part in terms of improved shipboard conditions, increased pay, labor grievances, and collective bargaining. When negotiations began in March 1939, however, they quickly stalled over the issue of "closed shop" vs. "open shop"; i.e., whether the tanker operators would be allowed to hire only union members to work on their vessels (closed shop) or simply grant preferential hiring to union members, while still offering jobs to those outside the union (open shop). The NMU representatives naturally wanted a closed shop, whereas Standard preferred an open shop. Though both sides offered some token concessions on the matter, negotiations ultimately broke down and the NMU gave the order for a strike to commence on 17 April (*New York Times* 1939[sec. S]:45; *Socialist Appeal* 1939:1-2; Willett 1990:158-165).

On 19 April, 32 unlicensed members of *Rockefeller*'s crew downed tools as soon as the ship reached port in Aransas Pass, Texas, and began picketing Standard's facilities, joining hundreds of other strikers across the country *(Austin American* 1939:2, *Corpus Christi Times* 1939b:1). The picket proved so ineffective, however, that within two days non-union workers had been found and brought aboard to replace the strikers. *Rockefeller* sailed for New York City on 22 April, leaving its striking crew behind (*Corpus Christi Times* 1939a:1-2; *Corpus Christi Times* 1939b:1; Willett 1990:167). The strike collapsed after two months due to Standard's efficient propaganda machine and expertise in strikebreaking, as well as the NMU's disorganized and ineffective tactics, and the union suffered a loss of prestige from which it never recovered (Willett 1990:167-173). The remainder of *Rockefeller*'s prewar career continued without incident until Japanese bombs fell on Pearl Harbor and America found itself drawn into the cauldron of another world war.

World War II

Upon America's entry into the Second World War at the end of 1941, the eyes of the German Kriegsmarine fell on the country's East Coast and its rich marine merchant trade. Admiral Karl Dönitz, the *Befehlshaber der Unterseeboote* (BdU, "Commander of U-boats"), immediately pushed to expand the submarine war that he had been waging against British shipping since the beginning of hostilities in 1939. Though he had only 12 U-boats capable of reaching the American coast, half of which had been sent to the Mediterranean on Adolf Hitler's orders, Dönitz initiated Operation Paukenschlag ("Drumbeat"), deploying five of these long-range Type IX U-boats to attack and destroy American shipping (Blair 1996:440-441).

Thanks to a combination of inexperience and institutional prejudice, the United States Navy was unprepared for the onslaught of full-scale submarine warfare. The Navy had had little practice at antisubmarine operations during World War I; though it had conducted studies on the topic during the interwar period, it had yet to fully internalize the concepts thereby established, particularly the usefulness of convoys. Chief of Naval Operations (CNO) Admiral Ernest J. King was a constitutional Anglophobe who was deeply suspicious of any advice or offers of help given by his counterparts across the Atlantic. While Admiral King was not opposed to the idea of convoys, he believed that a convoy with inadequate escorts was worse than a convoy with no escorts at all--a belief *not* borne out by British experience--and refused to implement a convoy system until more destroyers and other ships suitable for escort duty could be built, bought, borrowed, or otherwise pressed into service. Thus, in the early months of the war hundreds of merchant vessels carrying critical cargoes of food, oil, metal ores, ammunition, and other war-related materiel sailed unescorted from port to port along the Eastern Seaboard (Van der Vat 1988:239, 241-245; Hickam 1989:5-6, 54-55; Gannon 1990:164-166, 187-188, 385-390).

Moreover, blackout orders were not implemented for several months, due to complaints from city governments who believed that they would have an adverse effect on tourism. America’s coastal cities remained brightly lit, clearly silhouetting passing ships for the U-boats. In return, the German submariners gave the tourists and residents of these cities a show. Over the course of Operation Paukenschlag, five U-boats—*U-66, U-109, U-123, U-125,* and *U-130*—destroyed over 150,000 tons of shipping without any serious opposition and suffering no losses in return. They were hampered only by unreliable torpedoes that ran deep or bounced off their targets almost as often as they detonated, much to the frustration of the U-boat commanders (Bleichrodt 1942:16-18, 37-39; Hardegen 1942:13, 18; Zapp 1942:13-15). Admiral Dönitz was delighted by this success and immediately dispatched more Type IX U-boats and the smaller Type VIIs, supplemented by Type XIV “milk cow” supply submarines, to exploit this new hunting ground (Morison 1947:129-130; Stick 1952:232-233; Van der Vat 1988:245-246; Hickam 1989:5-10; Blair 1996:468-470; Gannon 1990:185-186).

Throughout the first half of 1942, the U-boats went on a rampage along the Eastern Seaboard. During this time, they accounted for no less than 357 vessels of all types and sizes, totaling a staggering 2,000,000 tons of shipping and costing the lives of approximately 5,000 merchant mariners, US and UK naval personnel, and civilian passengers. In exchange, they lost a mere five U-boats and 194 sailors killed in action, with a further 40 taken prisoner. This is a butcher's bill that invites breathless superlatives, and many have been supplied. Historian Michael Gannon referred to it as the "Atlantic Pearl Harbor" and "one of the greatest maritime disasters in history and the American nation's worst-ever defeat at sea" (Gannon 1990:389). Samuel Eliot Morison, the doyen of US naval history in WWII, stated that "The massacre enjoyed by the U-boats along our Atlantic coast in 1942 was as much a national disaster as if saboteurs had destroyed half a dozen of our biggest war plants" (Morison 1947:127). David Stick remarked that the U-boats "had about as hard a time of it as a hunter shooting into a pond of tame ducks" (Stick 1952:229).

Of all these coastal battlegrounds, none was more fiercely contested than that of North Carolina, for the U-boats found rich hunting in the bustling shipping lanes off Cape Hatteras and the Outer Banks. The first kill of the war in Carolinian waters went to *U-66* when it torpedoed *Allan Jackson* on 18 January 1942, but this was only a taste of the devastation to come. Over the course of two nights in March, *U-124* torpedoed and sank five ships one after the other off Cape Hatteras, as if it were knocking down targets in a shooting gallery. On the second night, the crew of the tanker *Papoose*, after abandoning their mortally wounded vessel, found themselves rowing their lifeboats to shore by the light of another burning tanker, *W.E. Hutton* (Stick 1952:233-234; Hickam 1989:76-80, 85-86; Gannon 1990:388-392). The sheer scale of the destruction quickly earned the area the nickname of "Torpedo Junction" or "Torpedo Alley." Flotsam, spilled oil, and drowned sailors washed ashore with depressing regularity. The delighted German submariners referred to this period as the "Second Happy Time," after the first "Happy Time" of

1940, during which they had sunk hundreds of thousands of tons of British shipping in the North Atlantic (Stick 1952:234; Van der Vat 1988:147-149; Hickam 1989:2-3, 23). Such were the conditions into which *William Rockefeller* steamed on its last voyage.

Rockefeller *at War*

From the outbreak of war in September 1939 to its final voyage in June 1942, *Rockefeller* completed 49 trips, in which it transported a combined total of 7,209,524 bbl (302,800,008 gallons) of oil. Until March 1942, all but one of these cargoes were loaded in Corpus Christi, Texas; the sole exception was loaded in Baton Rouge (Standard Oil 1946:321). Upon America's entry into the conflict, *Rockefeller* was stripped of its distinctive Esso livery, armed with a 76.2mm (3-inch) deck gun, and degaussed to make it less vulnerable to magnetic mines and torpedoes (see FIGURE 2.6) (Office of the Chief of Naval Operations [OCNO] 1942a).

WM. ROCKEFELLER
2-17-42
U.S. COAST GUARD
AMER.
IN

FIGURE 2.6. *William Rockefeller* in February 1942. It is in wartime configuration and riding low in the water. Its Esso fleet livery and name have been removed, and the tub for the 76.2mm gun is visible on the after deckhouse (Mariners' Museum, accession number P0001.003-01—PB30237).

In March 1942, *Rockefeller* began taking on cargo from international ports in the Caribbean and South America. On 30 March, it undertook its longest journey of the war. After loading at Curaçao, it departed for Cape Town in South Africa, arriving on April 28. The tanker then retraced its route across the Atlantic and arrived at Guiria, Venezuela, on 2 June, where it bunkered more oil before sailing to Aruba. There, the tanker offloaded that cargo and took on another load of oil before departing for New York City on the 19th, following routing instructions issued by the British naval authorities on the island (OCNO 1942d; Standard Oil 1946:321; Basta et al. 2013b:3; Hoyt et al. 2021 7-275).

By this time, the US Navy had at last begun to take the submarine threat seriously and had instituted more aggressive antisubmarine warfare protocols and patrols off the East Coast. However, their available escorts remained limited to a handful of destroyers and Coast Guard cutters, a group of armed trawlers on loan from the Royal Navy, some hastily retrofitted civilian ships, and a motley collection of aircraft--flying boats, scout planes, airships, fighters, and bombers--some of the latter borrowed from the Army Air Forces, along with private planes manned by volunteers from the Civil Air Patrol (DIO 1942:575; Van der Vat 1988:241-243, 265-267; Hickam 1989:261-262, 276; Gannon 1990:176-178).

Rockefeller was steaming under blackout conditions and carrying its brand-new 76.2mm deck gun, crewed by six sailors of the US Naval Armed Guard (OCNO 1942a; Standard Oil 1946:321-323). When *Rockefeller* arrived off Ocracoke on the afternoon of 27 June, it was met by a US Coast Guard patrol craft which issued new routing instructions before escorting the tanker to an anchorage inside the Cape Hatteras minefield, where it moored for the night. The next morning, 28 June, *Rockefeller* maneuvered clear of the minefield, accompanied by two Coast Guard ships--USCGC *470* and *YP-388*--and an aerial escort, and set course for New York. Early that afternoon, *Rockefeller* was steaming along the Outer Banks, beating past Cape Hatteras at its maximum speed of 9.2 knots. In its eight storage tanks were 136,647 barrels of Bunker "C" heavy fuel oil, a viscous, tarlike byproduct of petroleum cracking prized in the maritime world for its low cost. At 1216 EWT, approximately 16 nautical miles east-northeast of the Diamond Shoals Light, its journey came to an end (OCNO 1942b; OCNO 1942d; Standard Oil 1946:321).

U-701, under the command of Kapitänleutnant Horst Degen, spied *Rockefeller* and maneuvered in for an attack. After evading the Coast Guard escort, Degen fired two torpedoes at *Rockefeller*, what he later referred to as a *Fangschuss*, or "crippling shot" (United States Navy Office of Naval Intelligence [USONI] 1942b:11). One of the torpedoes struck *Rockefeller* squarely amidships on its port side, tearing a 20 by 20-foot hole in the hull (see FIGURE 2.7). The pump room and number five storage tank were flooded almost immediately, and the detonation sprayed oil from number five tank across the after part of the ship, setting it afire (OCNO 1942d:2; Basta et al. 2013b:4; Hoyt et al 2021:7-277). Captain William Stewart reacted promptly:

> Immediately after the explosion I instructed Third Mate Sullivan to sound the general alarm and the engine was stopped by Chief Engineer Snyder; the fuel oil valves were closed and the steam smothering line opened. (OCNO 1942d:2)

The crew soon found that there was little they could do against the inferno that was engulfing their ship. Chief engineer Edward Snyder had to open the steam smothering lines and shut down the tanker's engines from backup controls on the boat deck, as he was unable to reach the engine room due to the fire (Standard Oil 1946:321-322). Captain Stewart did not initially believe the damage to be serious enough to warrant abandoning ship, as *Rockefeller* did not develop a list or even settle significantly after the torpedo strike (OCNO 1942d:2-3). Given their proximity to land, Stewart instead decided to attempt beaching the tanker and was preparing to carry out this plan until he realized that the engines had been shut down and the crew was already launching the lifeboats without orders. He tried to order them to stand by, but they could not hear him, apparently owing to the noise of the fire and escaping steam. He also could not move aft to issue these orders directly, as the fire had spread amidships and was preventing passage from fore to aft. By the time he processed all this, the crew had abandoned ship and were urging him to join them. He reluctantly boarded the number 2 lifeboat after ensuring that *Rockefeller*'s codebooks and confidential papers were secure and that no one else remained on board, though he had yet to give up hope of saving his ship (OCNO 1942d:2-3; Standard Oil 1946:322; Offley 2014:210; Hoyt et al 2021:7-277).

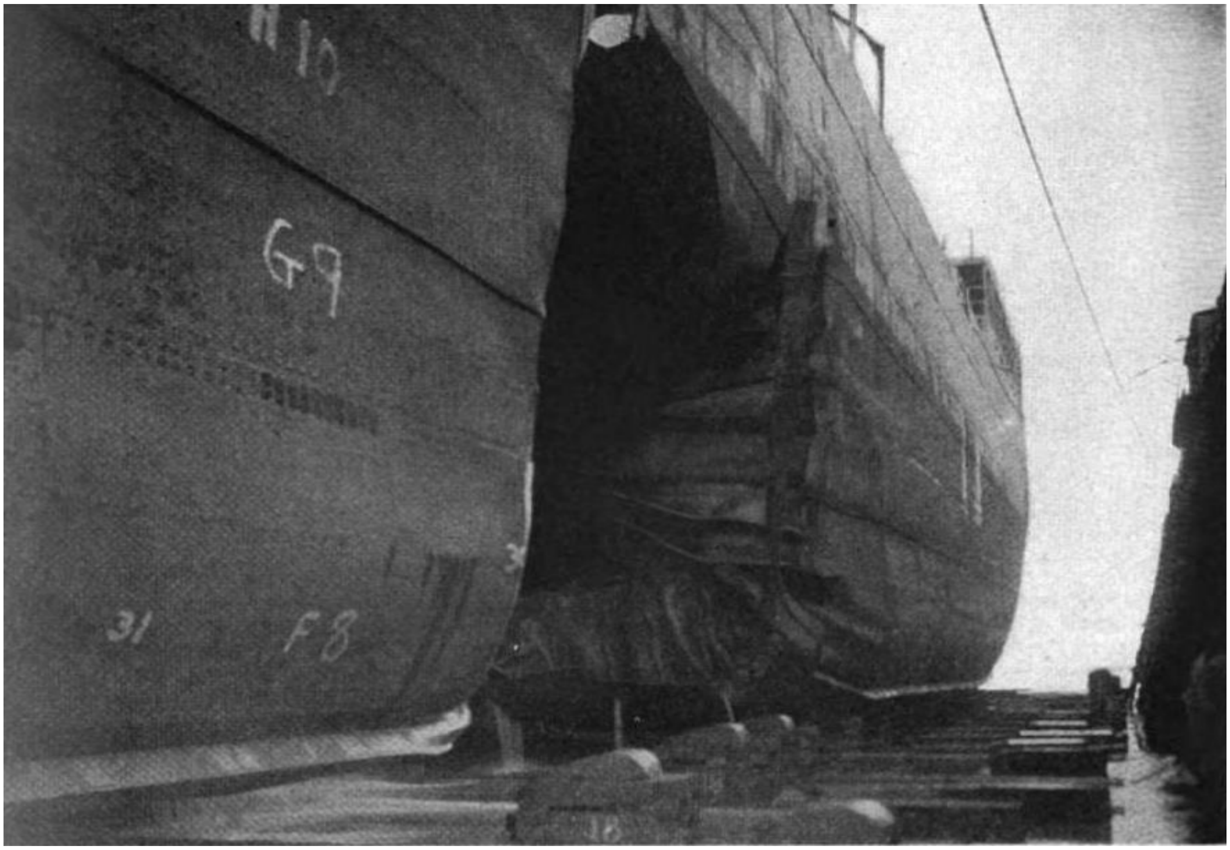


FIGURE 2.7. Hull of the oil tanker *Paul H. Harwood* after being torpedoed by a U-boat on 7 July 1942. The breach measures 20 by 30 feet, approximately the same size as the hole *U-701*'s torpedo made in *Rockefeller* (Standard Oil 1946).

Shortly after the tanker's crew were picked up by the Coast Guard escort, however, Stewart watched as the fire began to spread out of control toward the ship's stern before they lost sight of it entirely (OCNO 1942d:3; Standard Oil 1946:322). Having retrieved the crew, the cutter broke away from the stricken tanker to attack *U-701*, dropping seven depth charges without success (USCG 1942b; Hickam 1989:275). *Rockefeller*'s people were landed at the Ocracoke Coast Guard Station at about 5 PM. Nine members of the crew were slightly injured, but fortunately no lives had been lost. One of the Coast Guard officers stationed at Ocracoke observed that Captain Stewart was greatly saddened by the loss of the ship which he had captained regularly for nine years (OCNO 1942d:3; USCG 1942b; Standard Oil 1946:322-323). Later, interviewing officers would note that Stewart appeared to believe that his crew had abandoned ship prematurely, though he did not express these feelings directly (USONI 1942a).

Despite the Dantesque scene that Captain Stewart and his crew had witnessed, *Rockefeller* was not quite finished. The sturdy tanker had endured a similar cataclysm 13 years previously, and it was apparently prepared for a repeat performance. Still afloat and on an even keel, though burning fiercely and with its engines dead and helm unattended, *Rockefeller* was left to the mercy of the ocean currents. At this point, accounts of *Rockefeller*'s last hours diverge beyond easy reconciliation. The records of the Eastern Sea Frontier indicate that the ship sank on its own at 2338 EWT, almost 12 hours after it was torpedoed. Another account states that the tanker was scuttled by Coast Guard aircraft early in the morning on the following day, 29 June. A third account came from KptLt Degen of *U-701*, who stated during interrogation that he relocated the burning tanker between 12 to 15 hours after his initial attack and sank it with a second torpedo (USONI 1942b:11-12; US Coast Guard 1945:101; Blair 1996:607; Hoyt et al. 2021:7-278). Whatever the circumstances of *Rockefeller*'s last moments, *U-701* did not long survive its victim.

On the afternoon of 7 July, ten days after *Rockefeller*'s loss, *U-701* was cruising on the surface off Cape Hatteras, not far from where it had sent the tanker to the bottom. KptLt Degen and three other sailors, including executive officer Oberleutnant Konrad Junker, were on the bridge keeping watch for Allied aircraft or ships. As two of them were reentering the conning tower, OLt Junker spotted an incoming airplane very close to their position and sounded the alarm. Degen immediately ordered the boat to crash-dive. As they stood beside each other inside the submarine's conning tower, Degen remarked to Junker that the latter had seen the plane too late, to which he agreed (USONI 1942b:13).

The aircraft in question was a Lockheed Hudson bomber of the US Army Air Force

396th Bombardment Squadron, piloted by Lieutenant Harry Kane[i]. Lt. Kane swung his bomber into an attack run and dropped three depth charges on *U-701* as the boat crash-dived in a futile effort to escape (Kane 1981). At least one and possibly two of the charges detonated on or near the U-boat's electric motor room, inflicting catastrophic damage (Degen 1942c:3). The submarine rapidly flooded and sank in 35 meters of water. Of its crew of 43, 28 are known to have reached the surface alive, though one survivor later insisted that almost the entire crew had escaped (USONI 1942b:13).

Still circling over the site of the attack, Lt. Kane saw these survivors popping to the surface amidst the oil slick gushing from the dead U-boat and ordered his crew to throw life vests and rafts into the water. He dropped smoke pots to mark the site, then attempted to signal a passing freighter and a nearby Coast Guard vessel to come and pick up the German sailors. The freighter acknowledged Kane's signals and congratulated him on the kill, but refused to comply with his request; the Coast Guard ship, *CG-472*, was unable to find any of the survivors (First Bomber Command [FBC] 1942:2-3; Hickam 1989:281). Kane's efforts to vector other ships or planes to the area were complicated by radio interference from an unknown station. When Kane went looking for the survivors himself, the smoke pots had disappeared and the seas were worsening, so he was unable to relocate them (FBC 1942:3-4; USONI 1942b:50-51; Kane 1981).

U-701's survivors were slowly carried north and east into the Atlantic by the Gulf Stream. Despite Degen's best efforts to keep up morale, the ordeal proved to be too much for most of his crew. Nearly all the sailors succumbed to delirium or exhaustion and drowned before the survivors were spotted by another reconnaissance flight and picked up by a Coast Guard seaplane approximately 90 nautical miles northeast of the site of the attack, 49 hours after their submarine had been sunk. The seven survivors were taken to the Naval Base Hospital at Norfolk for treatment and preliminary interrogation before being transferred to Fort Devens in Massachusetts and then to the Joint Interrogation Center at Fort Hunt (USONI 1942c:1; Hickam 1989:278-282).

At this time Degen provided a detailed account of his boat's activities during its three war patrols, as well as a great deal of information on the Kriegsmarine's U-boat arm as it was then constituted (USONI 1942b:20-46). His interrogators attributed his volubility to the shock of having his vessel so abruptly shot out from under him and the physical and mental stress of his time in the water, noting that his resistance to questioning increased as he recovered from his ordeal. From this interrogation came Degen's account of his attack on *Rockefeller*, including his claim that he circled back and sank the tanker with a second torpedo after 12 hours (USONI 1942b:4). On 11 July, four days after his U-boat was sunk and two days after he and his six crewmates were recovered, Degen received a visitor at the Naval Base Hospital: Lieutenant Harry Kane. Kane reflected on the unusual meeting many years later:

> They led me into a great big room, and there was this guy sitting in this chair in the middle of the room, and somebody introduced me. I don't remember exactly what they said, 'This is the Captain of the German submarine; this is the pilot that was responsible for sinking you' or whatever. And this is the part I love. He was very badly sunburned. That was the worst thing. See their head and shoulders were out in the sun all the time, but he stood up the best he could and came to attention and threw me a salute and said, 'Congratulations, good attack.' And really, I mean it's just something that you just can't ever forget (Kane 1981).

U-701's wreck was relocated in 1989 by sport diver Uwe Lovas, its hull cracked open by Lt. Kane's depth charges. The submarine is considered a war grave for the German sailors who died in the sinking, and dives to the wreck are rare. However, its largest victim remains missing. As mentioned previously, *Rockefeller* drifted for at least 12 hours before sinking, and now most likely lies in deep water off the edge of the American continental shelf (Hudy 2007; Hoyt et al. 2021:7-278).

Past Searches and Research

After the end of the war *Rockefeller* was largely forgotten, save for *Ships of the Esso Fleet in World War II*, a publication released by the Standard Oil Company in 1946 which celebrated the contributions of its tanker fleet during the conflict. This publication contained a capsule summary of *Rockefeller*'s wartime career and its sinking (Standard Oil 1946). It was also mentioned in a wartime history of Newport News Shipbuilding's vessels produced for the Mariners' Museum (Balison 1954:314-315). Aside from this, the tanker seemed fated to be little more than a footnote in the pages of history, just one more maritime casualty of a global war that had seen thousands of ships sunk across four oceans.

As the 20th century drew on, however, there came a new interest in the historical and environmental legacy of World War II, and *Rockefeller* accordingly began to receive more attention. Accounts of its sinking appeared in books published by Homer Hickam, Edwin Hoyt, Clay Blair, and Ed Offley, among others; the latter was dedicated specifically to *U-701* and its final war patrol, including a chapter on *Rockefeller*'s sinking (Hoyt 1978; Blair 1996; Hickam 1989; Offley 2014).

Alongside this historical resurrection, several organizations have now spearheaded projects that involved research on and potential searches for *Rockefeller*'s wreck. Chief among these are the National Oceanic and Atmospheric Administration (NOAA), the Bureau of Ocean Energy Management (BOEM), and East Carolina University (ECU). Together, these three organizations were collectively responsible for launching the Battle of the Atlantic Project (Hoyt et al. 2021 ii). Supported by other groups, both public and private, this project spanned eight years of research and fieldwork from 2008 to 2016. The project's central aim was to locate, image, and inventory the 87 WWII-era wrecks located off the coast of North Carolina, as well as to consider the potential for these sites to be named to the National Register of Historic Places. Moreover, the project sought to raise the American public's awareness of the hidden trove of history just off its coasts, as shipwrecks by their nature are hidden from public view and are therefore "out of sight, out of mind":

> It is the intent of the authors that this inventory will foster further research, long-term monitoring, public outreach, and educational efforts in support of a holistic historical and archaeological assessment of the Battle of the Atlantic (Hoyt et al. 2021 1-2).

The original impetus for the project came from reports that the wreck of *U-701* was being looted by relic hunters. As mentioned previously, sport diver Uwe Lovas had relocated the U-boat in 1989, after which he had personally contacted the still-living Horst Degen and promised to keep the wreck's exact location a closely held secret out of respect to the sailors who had died when the submarine was sunk. Unfortunately, the wreck was located by divers outside of Lovas' circle in 2004 and promptly became the target of relic hunters, who began removing parts of the boat, including its radio direction-finder (RDF) loop, conning tower hatch, and gunsights. This infuriated Lovas and the others who had kept the submarine's secret in hopes of having it made into an underwater preserve (Hoyt 2008:10; Hoyt et al. 2021:4-1).

In 2008, officials from the Monitor National Marine Sanctuary (MNMS) learned that a group of relic hunters planned to return to *U-701* with the purpose of collecting more artifacts and fittings from the submarine. The German consul-general requested that action be taken to stop these plans, and the MNMS officials concluded that a proper archaeological investigation needed to be performed on *U-701*'s remains to establish a baseline for any future changes wrought on the wreck by nature or humanity (Hoyt et al. 2021 4-1).

To provide a comparative baseline, the project team decided to expand its scope to include other U-boats sunk off the North Carolina coast. In 2008, the first year of the project, the team dived the wrecks of *U-701, U-85,* and *U-352* (Hoyt et al. 2021:4-2-4-3). When this proved to be a success, the MNMS and the Office of National Marine Sanctuaries (ONMS) decided to expand the project into a multiyear study of the Battle of the Atlantic (Hoyt et al. 2021:4-3-4-4). *Rockefeller* was identified as a vessel of interest for the 2011 iteration of the expedition, among other vessels such as *Bluefields*, *Chilore*, and *U-576*. It was not found, though the expedition was otherwise successful (NOAA 2011).

Remediation of Underwater Legacy Threats

In 2010, as a corollary to the then-ongoing Battle of the Atlantic project, Congress appropriated $1,000,000 for NOAA to identify the most ecologically and economically significant potentially polluting wrecks in American waters. Their criteria included the following: vessels sunk after oil came into use as a fuel, metal-hulled vessels, cargo ships over 1,000 GRT, and any type of tank vessel. Working in conjunction with several other organizations, NOAA initially identified approximately 1,000 wrecks fitting these criteria that were potential pollution sources. Of those, 87 were deemed to be special risks, either because of the violent nature of their sinking or because they had been demolished as a hazard to navigation. Given that it was torpedoed and had burned for hours before sinking, *William Rockefeller* was added to this list, which was compiled as the Remediation of Underwater Legacy Threats (RULE-T) Database (Basta et al 2013b:ii).

Based on various spillage scenarios run using the bespoke Spill Impact Model Application Package software, the NOAA risk assessment team ultimately calculated that an oil spill from *Rockefeller* could affect an area of between 1,800 and 64,000 square miles of ocean, the former representing a low-level chronic leak and the latter representing a worst-case scenario in which the entirety of *Rockefeller*'s cargo and bunkered oil is discharged into the Atlantic

(Basta et al. 2013b:14-17).

Fortunately, the latter scenario is considered unlikely, due to the circumstances of the tanker's sinking, and the NOAA team has therefore calculated that the most probable spill would be approximately 15,000 bbl of oil, with a potential slick size of 19,000 square miles (Basta et al. 2013b:15). This model indicates that an area of the U.S. coast from Virginia Beach to Cape Lookout, NC, is potentially at risk of contamination. Associated populations of birds, turtles, fish, marine mammals, and aquatic vegetation are also at risk, along with several national wildlife areas, fishing grounds, and commercial ports (Basta et al 2013b:24, 30-31).

Taking all these factors into consideration, NOAA has tagged the wreck as a medium-level risk for the spillage of pollutants into the Atlantic based on the most probable level of oil discharge, and as a high-level spillage risk based on the worst-case level of discharge (Basta et al. 2013b:39). They have recommended the following courses of action:

- That surveys of opportunity be undertaken in hopes of locating the wreck and determining its condition,
- That the wreck be noted in NOAA's Area Contingency Plans as a possible source of any mystery oil spills in the region,
- That outreach efforts should be made to engage the local diving and fishing communities in order to track any such spills (Basta et al 2013b:38).

All that being said, a preliminary study drafted by NOAA during the Battle of the Atlantic Expedition has suggested that a search for *Rockefeller* could encompass up to 750 nautical miles, based on its various last recorded positions and the ocean currents in the area (Basta et al 2013b:6, see FIGURES 2.8 and 2.9). As Basta et al. note:

> The exact location of this final attack is not known, and the navy could only approximate that the ship had probably drifted 15 miles northeast from the location where the initial attack occurred. (2013b:5-6)

More problematically, it is likely that the ship lies in deep water, beyond the reach of all but a large-scale search expedition with advanced equipment. Due to this large potential search area and the uncertainty of the wreck's last position, no surveys or search expeditions targeted specifically at finding *Rockefeller* have been undertaken as of this writing, though it was listed as a wreck of interest during the 2011 iteration of the Battle of the Atlantic Expedition, as mentioned previously (Basta et al. 2013b:6; NOAA 2011). However, NOAA and the Ocean Foundation are interested in pursuing a survey once a more compact search area has been defined. The United States Coast Guard has also expressed interest in locating the wreck, due to its status as a potential pollution vector (Nathan Richards 2021, pers. comm; Ole Varmer 2022, pers. comm.; Matthew Mitchell 2022, pers. comm.).

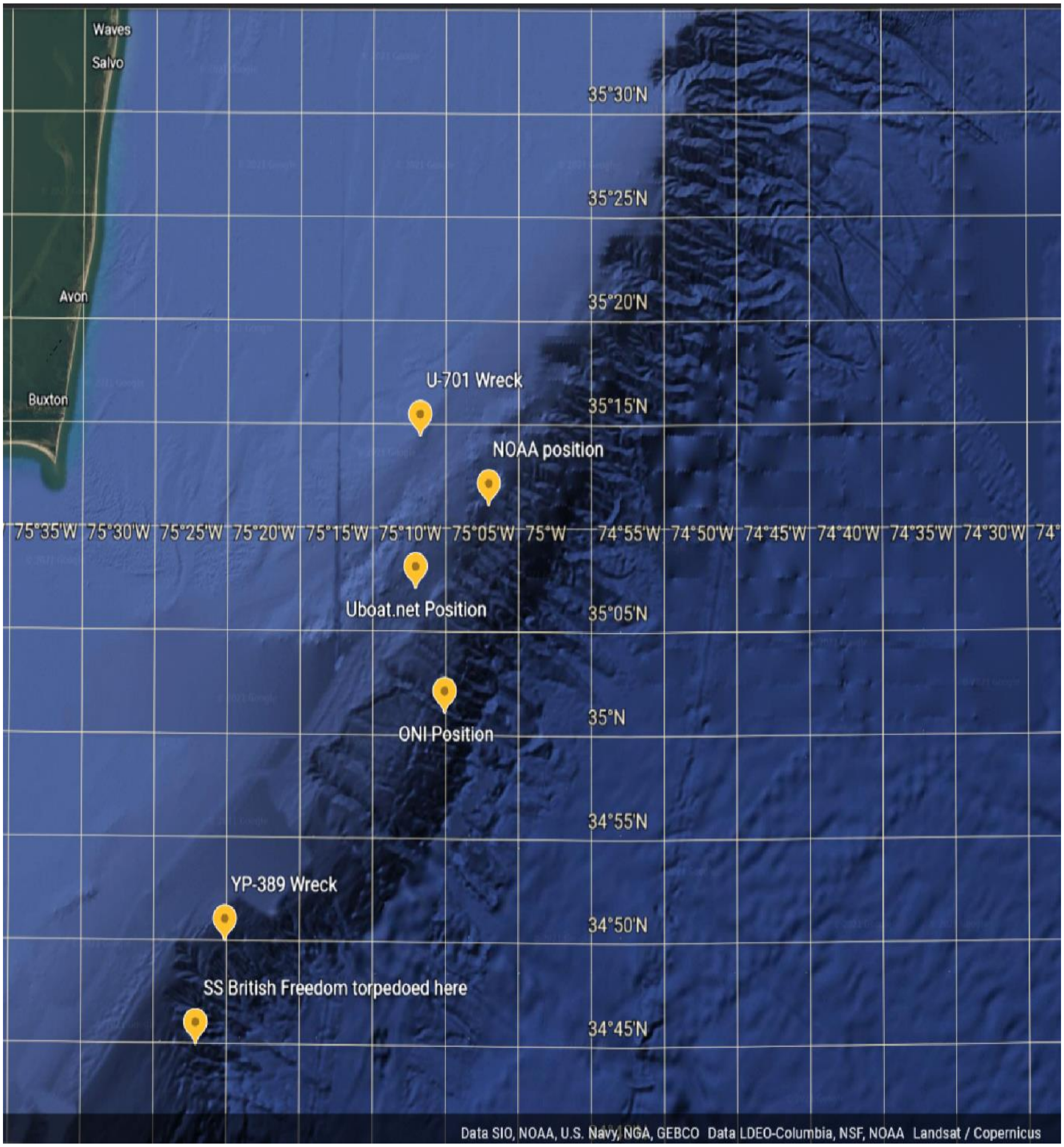


FIGURE 2.8. Reported locations of *William Rockefeller* when torpedoed by *U-701*, with additional points marked for *U-701*'s sinking location and other victims of the submarine. (USONI 1942; Standard Oil 1946; Basta et al. 2013; Hoyt et al. 2021; Uboat.net 2021. Map drawn by the author)

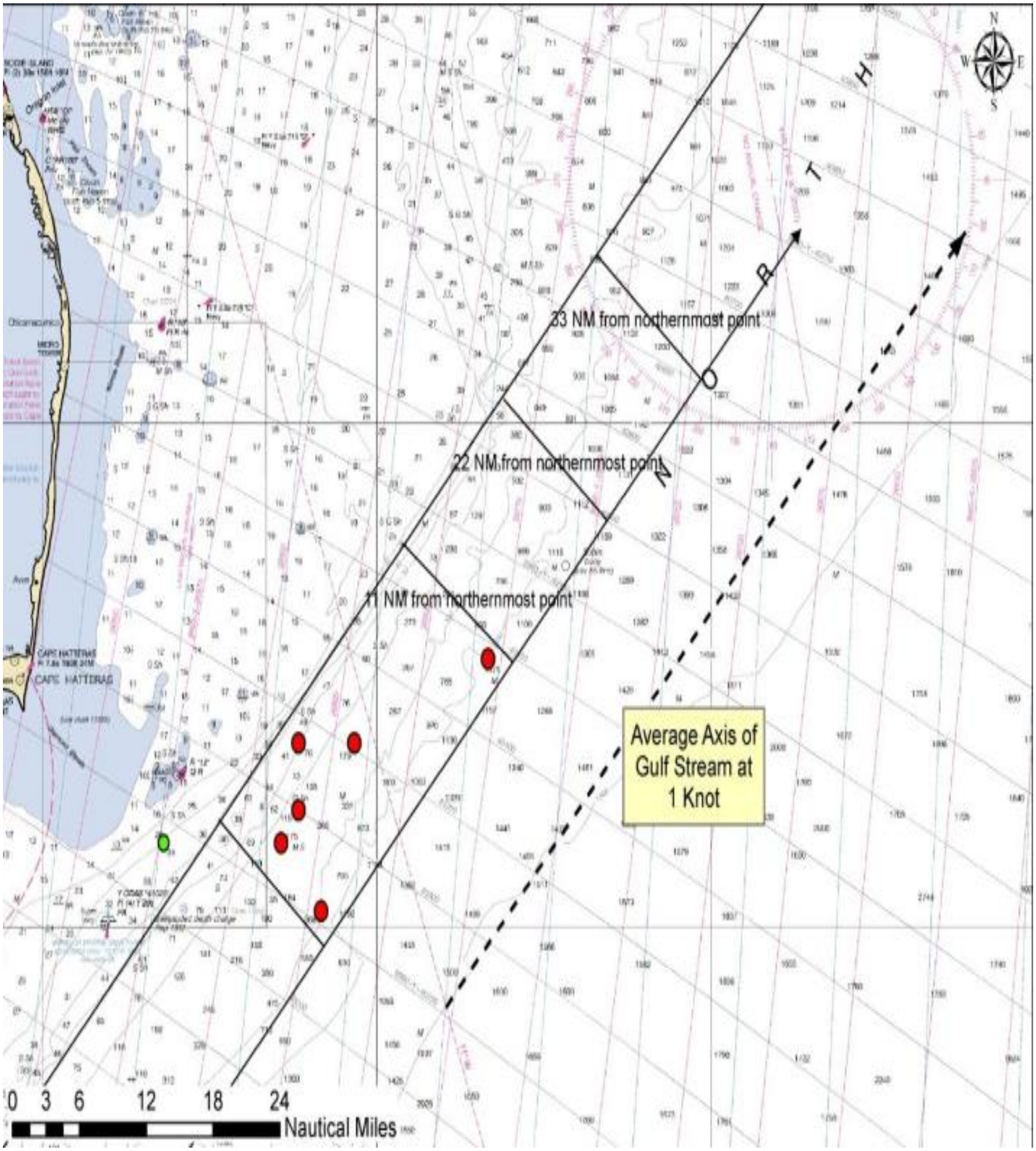


FIGURE 2.9. Potential search area for *William Rockefeller*, based on all available data regarding its last known position (Basta et al. 2013b).

CHAPTER THREE: THEORY – BAYESIAN STATISTICS AND PREDICTIVE MODELING

Introduction

This chapter will cover the basic theories behind maritime search and archaeological predictive modeling. It does not purport to be a complete history thereof, but it will provide a general overview of both. It will begin with a discussion of the problems inherent to maritime search before moving into a discussion of the general history of theory in the field, beginning with its genesis in the 1940s and subsequent development from then to the present day. It will then descend from the general to the particular by covering the major developments in the field: the conception and development of Bayesian search theory and the evolution of search planning from pen-and-paper calculations to advanced software systems, including Esri’s ArcGIS and the United States Coast Guard’s Search and Rescue Optimal Planning System (SAROPS). Case studies will be presented for each methodology, with an analysis of their strengths and weaknesses. Following this will be a discussion of archaeological predictive modeling, its relationship to maritime search, and its typology as defined by archaeologist Jeffrey Altschul. The search methods will then be categorized according to this typology. Archaeological theory as such is not covered in this chapter, as it is difficult to relate the principles thereof to the art of maritime search, which is the primary concern of this study.

The Art of Maritime Search

The title of this section is perhaps a little misleading, for maritime search is in fact equal parts science and art. The scientific principles and hard mathematics of search theory can be successfully applied to the problem of looking for an object lost at sea, but there must also come a certain level of imagination and the occasional bit of educated guesswork, especially when it comes to the matter of choosing data. As mentioned previously, it is often unwise to rely uncritically on primary sources in these cases. A shipwreck is typically a high-stress event involving imminent risk to life and limb, with accompanying repercussions for the thought processes, emotions, and memories of those involved (Gibbs 2002:72-76). Even if someone thinks to record a sinking ship's last coordinates in the heat of the moment, it is very possible that these coordinates will be mistaken, or later misremembered.

One has only to look at the records of past wreck search expeditions to see this problem in action: numbers are transposed, latitudes and longitudes are scrambled, and in some cases the coordinates given are quite simply wrong. Possibly the most notorious example of this phenomenon is that of the RMS *Titanic*. As the famed liner was sinking, wireless operators Harold Bride and Jack Phillips repeatedly transmitted distress signals containing what they believed to be an accurate position for the stricken ship. Subsequent search expeditions took this position data at face value and based their efforts on it, only to come away empty-handed. It was not until Dr. Robert Ballard reevaluated the problem, concluded that the positional data must be in error, and expanded the search area that *Titanic* was relocated in 1985, 13 nautical miles from the position given by Bride and Phillips (Ballard 1987:23, 26, 66, 83).

The problem might seem to be mitigated if multiple sets of positional data exist, either from other survivors of the wrecking event or of eyewitnesses not on the ship. This, unfortunately, is often not the case. Witness, for example, the case of SS *Central America*, wherein four sets of coordinates were given for the ship's sinking location. These coordinates were based on estimates from *Central America*'s captain, one of its passengers, and the estimated positions of the two vessels that responded to the steamer's distress signals, all of which varied widely from each other, as seen in FIGURE 3.1. This problem was compounded by the fact that

Central America sank in a powerful hurricane, which inhibited the ability of the persons involved to take star sights, the most reliable and accurate means of navigation at the time. Ultimately, when an intensive search for the wreck began in the 1980s, this meant that extra work had to be done to account for this varied dataset in the search plan (Stone 1992:37-38, 53).

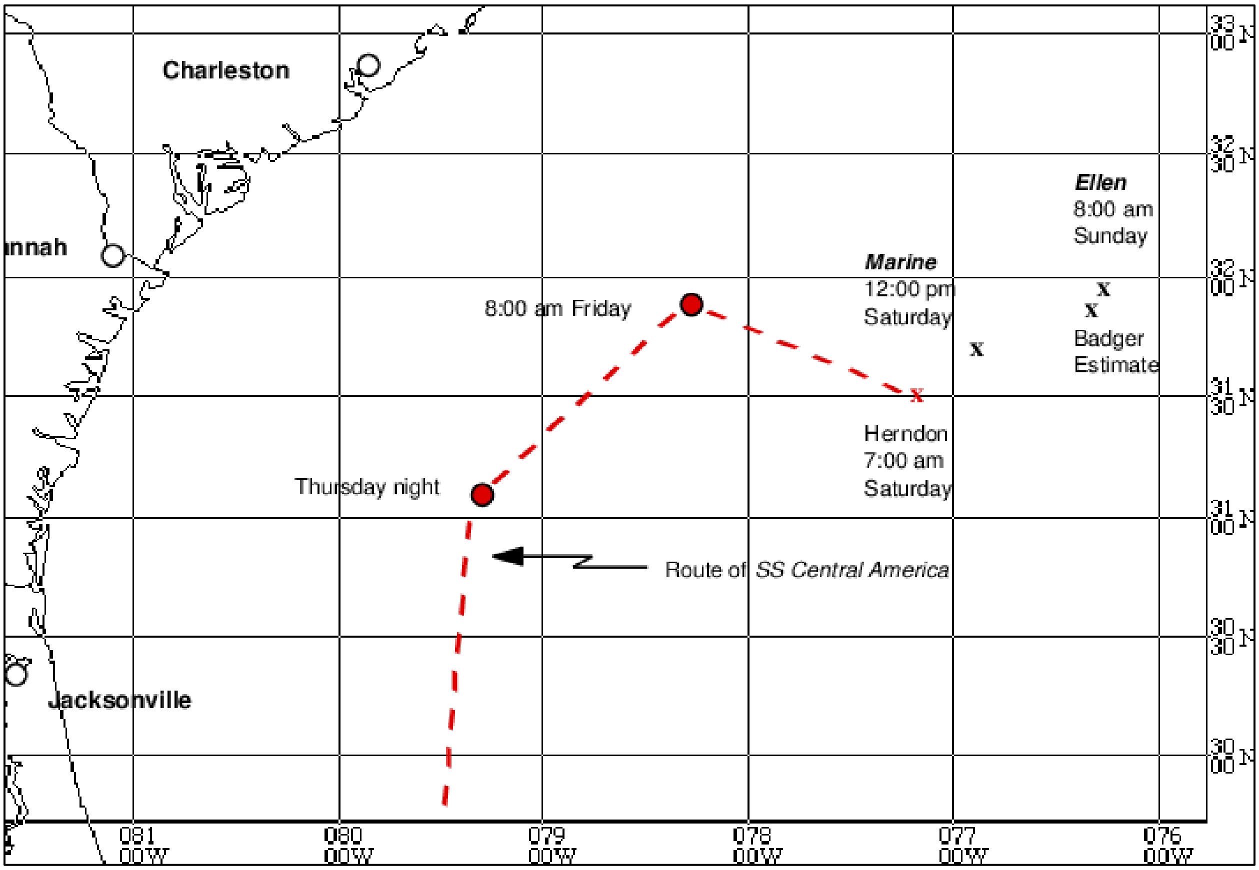


FIGURE 3.1. Route of SS *Central America* on its last voyage, with estimated positions for its loss as given by Captain William Herndon, Captain Badger, and the ships *Marine* and *Ellen* (Lawrence Stone 1992).

Paradoxically, the more data that is available for a given case, the worse the problem may become. When John Bright set out to examine the U-boat attack on Convoy KS-520 as part of his ECU master's thesis, he acquired no fewer than 9 sets of coordinates for the convoy's location at the time of the attack, precisely none of which agreed with each other (see FIGURE 3.2). He noted that, as the convoy was steaming in a formation approximately 5 nautical miles wide, it could reasonably be expected that the sets of data given would be relatively close together. As he found out, this was not the case. The various coordinates were between 4.4 to 29.8 nautical miles apart, distributed over an area of 230 square miles of ocean. What in theory should have been a simple problem was therefore greatly complicated (Bright 2012:56-57).

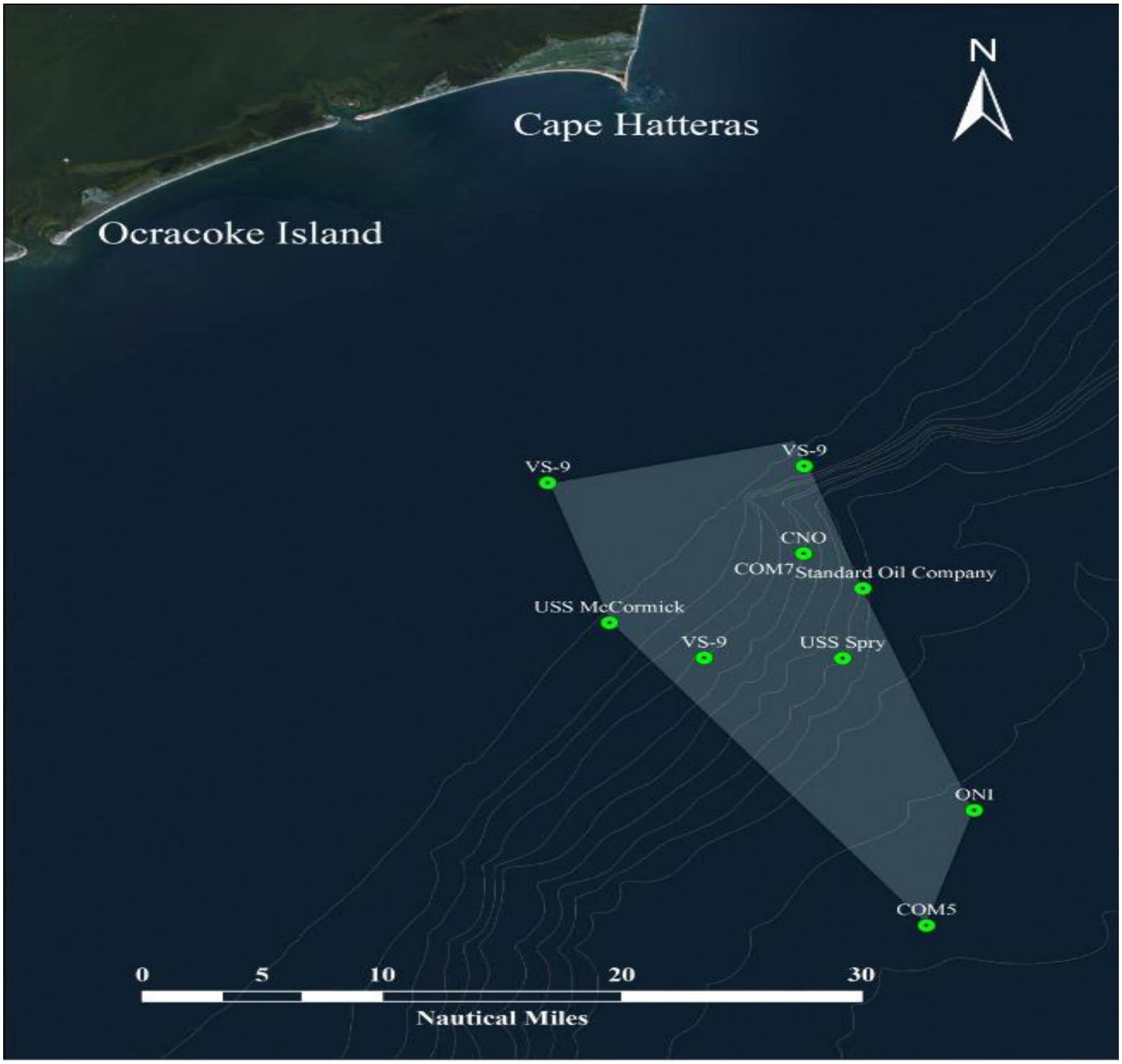


FIGURE 3.2 Distribution of recorded coordinates for U-boat attack on Convoy KS-520. (Bright 2012:57)

The issue is further compounded in cases where no one survived to record the wrecking event. The best illustration of this problem is the curious year of 1968, in which no fewer than four submarines were lost with all hands and no distress calls or other final transmissions: USS

Scorpion, the Israeli submarine *Dakar*, the Soviet submarine *K-129*, and the French submarine *Minerve.* All four wrecks were eventually located, *Scorpion* and *K-129* through a combination of hard investigative work and fortuitous circumstances, and *Dakar* and *Minerve* after new information shed light on their probable locations. None of these searches were easy, however, and in the cases of *Dakar* and *Minerve* the submarines were not found for 31 and 51 years respectively (Craven 2001:212-213; Norman 2009; Willshire 2019).

The problem for the archaeologist or historian, then, is how to utilize these disparate or sparse sets of information in such a way as to maximize their chances of sifting out the best data with which to complete a successful search. Then comes the second issue, which is equally important: selecting a theoretical framework/model into which this data can be fed. All this is done with an eye toward optimizing the search parameters so as to produce the highest chance of success with the least expenditure of money, time, and effort. Dr. Lawrence Stone refers to this as the basic problem of optimal search (Stone 1975:32). There have been a variety of methods proposed for the solution of this basic problem. What follows is a general outline thereof.

The Basics of Bayesian Search

The first type of maritime search theory under discussion is Bayesian search theory, which uses Bayesian statistics as its framework. Bayesian statistics are based on the work of English statistician and philosopher Thomas Bayes, who first formulated the basic principles of his theorem in *An Essay towards Solving a Problem in the Doctrine of Chances*, which was published in 1763, two years after Bayes' death (Bayes and Price 1763). Bayes' ideas were further developed by Pierre-Simon Laplace in a series of papers published throughout the late 18th and early 19th centuries, in which Laplace first applied his theories to solving several statistical problems (Laplace 1902).

Put simply, Bayesian statistics operate on a definition of probability wherein "probability" expresses a degree of belief in the occurrence of a given event. This belief may be based on prior knowledge of the event, whether derived from personal experience or historical records, or it may be based on one's own theories or beliefs about said event. The probabilities are then expressed as part of an equation which is used for a given purpose, in this case searching for a lost shipwreck. Bayesian theory as applied to maritime search is a relatively straightforward concept. The researcher must first form as many reasonable hypotheses as possible about what may have happened to their target object, based either on hard data or their own beliefs as to what may have happened to the target. These hypotheses are then used to generate a probability density function for the object's location, which calculates the probability of a random variable (in this case, the location of a submerged object) falling within a particular range of values (Stone 2011:23).

After this, a second function is constructed which expresses the likelihood that the target object will be found at a given location, *if it is really in that location*. This information is used to generate a probability map, which gives the probability of finding the target object in a given location for all possible locations within the projected search area. After this, a search grid and path is devised that covers the entire area, from highest to lowest areas of probability. During the search, the probabilities must be continually revised according to the findings. For example, if the object is believed to have fragmented before sinking, and fragments are not found in the areas where they are most likely to be according to the map, then the fragmentation hypothesis becomes less probable and should be revised or discarded accordingly (Stone 2011:23-24).

As new data is gathered about the event, it is fed into the model, thus revising and updating the probabilities contained therein. The model, of course, is only as good as the data that is used to make it, so someone who chooses to employ Bayesian theory must be sure that they are collecting and using data that is as accurate as possible. As may be obvious, this is a theoretical model which is quite suited to the problem of maritime search.

Early Developments in Maritime Search

Indeed, this type of search theory, along with the probability maps and predictive models it generates, has an illustrious history in the art of maritime search and recovery operations. The development of modern maritime search theory began in 1942, when the US Navy established an Antisubmarine Warfare Operations Research Group (ASWORG) to confront the ongoing German U-boat threat. Several members of this group were tasked with assembling the existing work on maritime search into a proper theoretical model, including Bernard Koopman and James Dobbie (Koopman 1957, Frost and Stone 2001:2-1). Koopman specifically defined the problems of optimal search as follows:

- A prior probability density distribution on search object location (so the probability of containment (POC) for any subset of the possibility area can be estimated),
- A detection function relating search effort density (or coverage, C) and the probability of detecting (POD) the object if it is in a searched area,
- A constrained amount of search effort, and
- An optimization criterion of maximizing probability of finding the object (probability of success or POS) subject to the constraint on effort (Frost and Stone 2001:2-1).

Though ASWORG's wartime work was classified, Koopman published a series of unclassified articles on his work in 1956 and 1957 (Koopman 1957). From these articles, it seems that the United States Coast Guard (USCG) was inspired to produce its first manual on search and rescue operations, the production of which led to the development of the Classical Search Planning Method (CSPM). There is no definitive evidence that this is the case, but Frost and Stone note that the Coast Guard manual's appearance in 1957 is probably not coincidental (Frost and Stone 2001:4-1). However, the work done to transmute Koopman's theory into practical application appears to have been lost. This prototypical manual was superseded in 1959 by the *National Search and Rescue Manual*, a version of which is still in use today (Frost and Stone 2001:4-1-4-2, USCG 2007).

At this time the calculations involved in the use of the CSPM were limited to whatever could be done with paper, pencil, dividers, parallel rules, and paper charts, since computers were then in a very primitive state of development. While still a potent set of tools in the right hands, it was impossible to produce complex computations with these instruments, which led to the introduction of "gross simplifications and sweeping generalizations" (Frost and Stone 2001:4-1). Frost and Stone further describe the CSPM as being a product of its time; when developed in 1957 it was a method which was eminently suited to the available technology and worked quite well in reducing the complexities of maritime search into a practical tool which was quick, simple, and easy to employ (Frost and Stone 2001:4-20). However, nothing is perfect, and the CSPM relied on a basic set of assumptions that were fundamentally flawed:

1. The classical search planning method (CSPM) assumes that the distribution of search object location probability density is defined by a single mean position (known as datum) that has a circular normal distribution of possible errors characterized by a known or estimated radius of probable error (Frost and Stone 2001:4-6).

2. The classical search planning method (CSPM) assumes that the detection (vs. coverage) function is based upon the inverse cube law of visual detection being applied under uniform search conditions by using search patterns consisting of long, straight, equally spaced, parallel tracks relative to the search object (Frost and Stone 2001:4-11).

3. The classical search planning method (CSPM) assumes that the optimal search area is a square centered on datum that is searched with a uniform density of search effort (uniform coverage) (Frost and Stone 2001:4-13).

4. The classical search planning method (CSPM) assumes that the probability of success (POS) for the first search should be about 50%, and that this value should be attained

with a uniform coverage square search in the most efficient manner possible. These requirements are met very closely by using a “safety factor” of 1.1 to determine the size of the square search area and by covering that area with sufficient effort to attain a coverage of 1.0 (Frost and Stone 2001:4-19),

5. The classical search planning method (CSPM) assumes that for all searches, the track spacing will equal the sweep width, i.e., the coverage will be 1.0 (Frost and Stone 2001:4-20).
6. The classical search planning method (CSPM) assumes that for all searches, the size of the recommended search square will be governed by the prescribed “safety factors,” and the amount of search effort available and expended will equal the amount required to cover the recommended search square at a coverage of 1.0 (Frost and Stone 2001:4-20).

Each of these assumptions is in turn based on other assumptions, which may render them unsuitable for a specific search situation. Moreover, these assumptions were developed based on the technology available in 1957, meaning that they were greatly limited. Some of the underlying weaknesses of the theory could therefore only be remedied by the advent of modern computing technology and new developments in the theoretical field. As noted previously, the CSPM was a tool which simplified the complexities of maritime search, but while this lessened the burden on the search planner, it also introduced several constraints into the theory which presented problems when using the method in an actual search scenario (Frost and Stone 2001:4-20-4-21).

The CSPM was ultimately replaced by two updated SAR planning systems, the Joint Automated Work Sheet (JAWS) and Computer Assisted Search Planning (CASP). JAWS was an updated manual planning method, while CASP was, naturally, a computer system. CASP was first developed in 1980 by Henry Richardson and Joseph Discenza, with contributions from Lawrence Stone and others (Richardson and Discenza 1980, Frost and Stone 2001:3-7) While accurate and reliable within their limits and successfully employed in many operations, each system had a fundamental problem. JAWS used only one value for winds and currents over the duration of an entire SAR operation, meaning that it could not account for dynamic shifts in wind and sea conditions. The CASP system used wind and current data that was updated every

12 hours over a 1-degree latitude/longitude grid. Detailed information on currents was only available for the Gulf Stream and Florida Current; for other areas, the only data available was a monthly average. These systems' inability to adapt to dynamic, spatially variable conditions was a problem that was only resolved with the advent of the Search and Rescue Optimal Planning System, or SAROPS, about which more will be said below (Roylance 2007:4D, Turner et al. 2008:1, Kratzke et al. 2010).

Evolution of Maritime Search Theory

The first application of maritime search theory as it is understood today was during the Second World War, when the initial work done by Koopman and the rest of ASWORG was employed to improve convoy screening techniques and searching for underwater targets, in this case German U-boats (Koopman 1957, Stone 1975:1, Frost and Stone 2001:3-2). After the conclusion of the war and Koopman's publication of his unclassified work, maritime search theory was limited largely to the planning of search and rescue scenarios, as mentioned previously (Frost and Stone 2001:4-1).

All this changed in 1966, with the Palomares H-bomb incident. On 17 January of that year, a B-52 Stratofortress collided with a KC-135 tanker aircraft while undergoing midair refueling off the coast of Spain. Both planes were destroyed, with the loss of 7 out of 11 aircrew. The Stratofortress was carrying four B28FI Mod 2 Y1 hydrogen bombs, each with a yield of 1.1 megatons of TNT. Three of the bombs fell on land outside the fishing village of Palomares and were quickly recovered. The fourth could not be found, and the Air Force ultimately determined that it had been lost at sea. As a sea search was entirely outside their capabilities, they contacted the Navy for help. In turn, the Navy convened a Technical Advisory Group led by Dr. John P. Craven to develop a search plan for the bomb. This group, recognizing that there was no real precedent for what they had been asked to do, came to develop what is now known as Bayesian search (Place et al. 1975:13-17, 24, 81; Craven 2001:162-164, 167-168). The initial incorporation of Bayesian techniques was brought about by Dr. Craven's attendance at a lecture by Harvard professor Howard Raiffa on his experiences at a horse track. Having noticed that bettors at the track were often able to successfully predict the odds of a given horse winning a given race, Dr. Raiffa had developed a probability equation using Bayesian theorems that allowed him to accurately predict wins, places, and shows (i.e., first, second, and third place) in the races. Craven, intrigued by this approach to probability, opted to employ Bayesian theory in the search for the bomb (Craven 2001:167-170).

The search planning team used a multiple-scenario approach to develop hypotheses about the bomb's possible location. After determining which scenario was most likely, based on the eyewitness testimony of a Palomares fisher who had seen the bomb fall into the ocean, the researchers used computer modeling to develop a probability map, which was transmitted to the on-scene searchers and revised continuously based on the daily findings. After a search lasting 80 days, they located the bomb in the Rio Almanzora submarine canyon at a depth of 780 meters. An initial attempt to recover it with the submersible *Alvin* failed, and the bomb was lost again. It was relocated at a new depth of 880 meters and successfully retrieved with CURV I, a prototype remotely operated underwater vehicle (Sontag et al. 1998:58-60; Craven 2001:167-170, 173-174; Frost and Stone 2001:3-4; Stone 2011:21).

Two years later, the nuclear attack submarine USS *Scorpion* was reported overdue on 27 May 1968, after it did not arrive in its homeport of Norfolk at the end of a Mediterranean patrol. The Navy immediately launched a search with aircraft and surface vessels but found nothing. Nine days later, the submarine's status was changed to "presumed lost" and a more comprehensive search effort began with the aim of locating *Scorpion*'s wreck (Sontag et al. 1998:93-97; Craven 2001:202-203).

A team of naval officers, mathematicians, and scientists, once again led by Dr. Craven, used Bayesian theory and computer modeling to aid in their hunt for the submarine. Though *Scorpion* had disappeared without sending any final transmissions, the team was fortunate in that several sets of hydrophones belonging to the US Navy's Naval Research Laboratory and the SOSUS early-warning network had detected several unusual sounds along *Scorpion*'s projected track. After triangulating the origin point of these sounds and verifying that they were in approximately the same position *Scorpion* was expected to be at that time, the team concluded that the sounds had been caused by *Scorpion* imploding as it passed "collapse depth," the point beyond which its hull could no longer resist accumulated water pressure and was crushed almost instantaneously (Sontag et al. 2001:96-98; Craven 2001:202-203).

Assuming that these sounds indeed represented *Scorpion*'s destruction, they set their origin point as the datum and employed much the same process as had been used to search for the Palomares bomb. The team gamed out a series of 9 possible scenarios for the submarine's sinking, took bets on the relative probabilities of each scenario, and developed a probability distribution via Monte Carlo computer simulations. From this, the team devised a search pattern that eventually located *Scorpion*'s wreck in deep water 760 kilometers southwest of the Azores, only 260 yards from the highest probability cell in their distribution map (Richardson and Stone 1971:141-144, Sontag et al. 1998:104-106; Craven 2001:213, Frost and Stone 2001: 3-4).

Several years after the successful conclusion of the *Scorpion* search, Dr. Lawrence Stone, who had participated in the search planning and execution for both the Palomares bomb and *Scorpion*, produced a formal treatise on the theoretical workings of maritime search, aptly titled

Theory of Optimal Search. This book, first published in 1975, is still considered a classic of the field (Stone 1975). Dr. Stone continued to develop his work on Bayesian search and maritime search theory thereafter, and in 1985 he was asked to employ his methods to relocate the wreck of the steamship *Central America.* The steamer had gone down in a hurricane off Cape Hatteras in 1857 while carrying some 13,600 kg of gold coins and bullion, the loss of which contributed to the Panic of 1857 (Frost and Stone 2001:3-6-3-8, Stone 1992:33-35). While this search expedition was staged for pecuniary gain and is therefore suspect from an archaeological standpoint, it nevertheless provides an excellent example of Bayesian search theory in action, including its strengths and its weak points.

Dr. Stone assembled a diverse dataset to solve the problem, including historical, statistical, analytical, and subjective data. Historical data included the last reported positions for *Central America* as given by Captain William Herndon to the steamer *El Dorado*; one Captain Badger, a passenger who survived the sinking; and the rescue ships which responded to *Central America*'s distress signals, *Ellen* and *Marine.* It also included the drift track of the raft carrying the steamer's survivors and contemporary estimates regarding wind speed and direction of the storm. Statistical data included the probability density models created according to the last known positions and the historical data regarding wind and current in the area. Analytical data included estimates *vis-a-vis* the uncertainty of celestial navigation and estimates of the effect of wind on *Central America* and the currents in the area. The subjective data consisted of the weights given to the quality of the information used to estimate the wreck's location (Frost and Stone 2001:3-6-3-7, Stone 1992:37-38).

After collating this data, Dr. Stone used it to establish weighted probabilities for each scenario under consideration, ultimately concluding that the data provided by *Ellen*'s recovery of survivors from *Central America* offered the most probable loss scenario. He fed the scenarios into a modified version of CASP, which used a Monte Carlo simulation to generate probability maps for each scenario. These were then combined into a composite map for the final search, with the probability of locating the ship in each cell of the map expressed as a number x 1000, with higher numbers representing higher probabilities (Stone 1992:42-52).

However, when *Central America* was finally located, it was in a low-probability area according to the composite map. In hindsight, Dr. Stone reflected that the most accurate scenario was that derived from Captain Herndon's last position, noting the remarkable nature of a captain who could take a more accurate navigational fix from a disabled and sinking ship in the middle of a hurricane than another captain taking a position in clear weather on a ship that was no longer in peril (Stone 1992:53). Though this was technically a failure of the Bayesian method in that the ship was found outside the areas of highest probability, Dr. Stone points out that it proved the fundamental soundness of the technique, since it still requires one to account for all possible scenarios regarding a wrecking event and use them to develop the final search plan. In this way, it prevents a searcher from fixating entirely on the most "likely" scenario according to the data; as every plausible scenario is accounted for in the final map, it means that even low-probability areas are still considered for investigation (Stone 1992:52-53).

Several figures (FIGURES 3.3-3.7) are presented below which illustrate the process of creating a composite probability map according to Bayesian techniques. All of these images are taken from Dr. Lawrence Stone's 1992 article on the search for *Central America*.

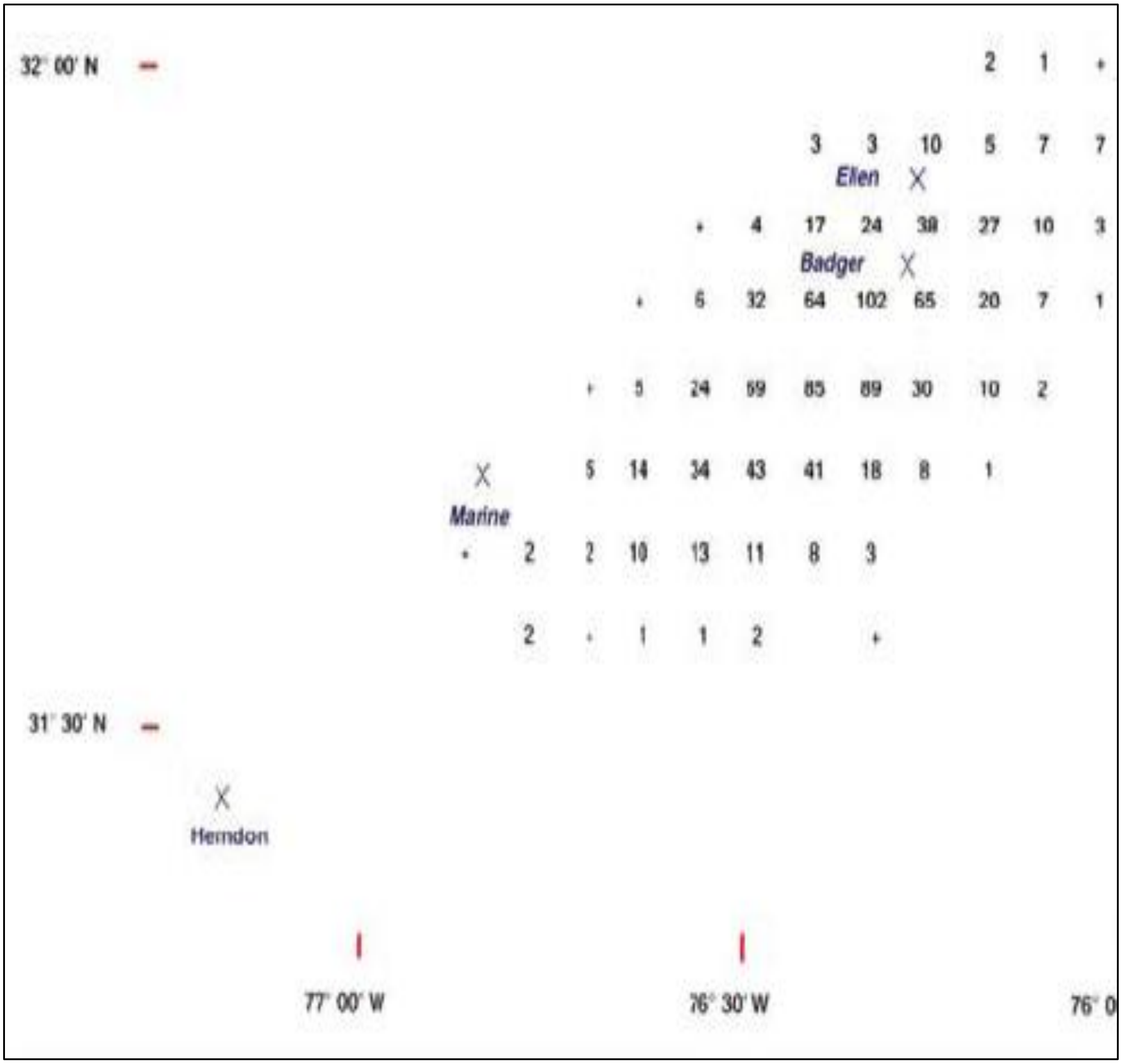


FIGURE 3.3. Probability map based on *Ellen's* recovery of *Central America* survivors. Based on the available data, this was considered the most likely scenario and weighted at 73% (Stone 1992).

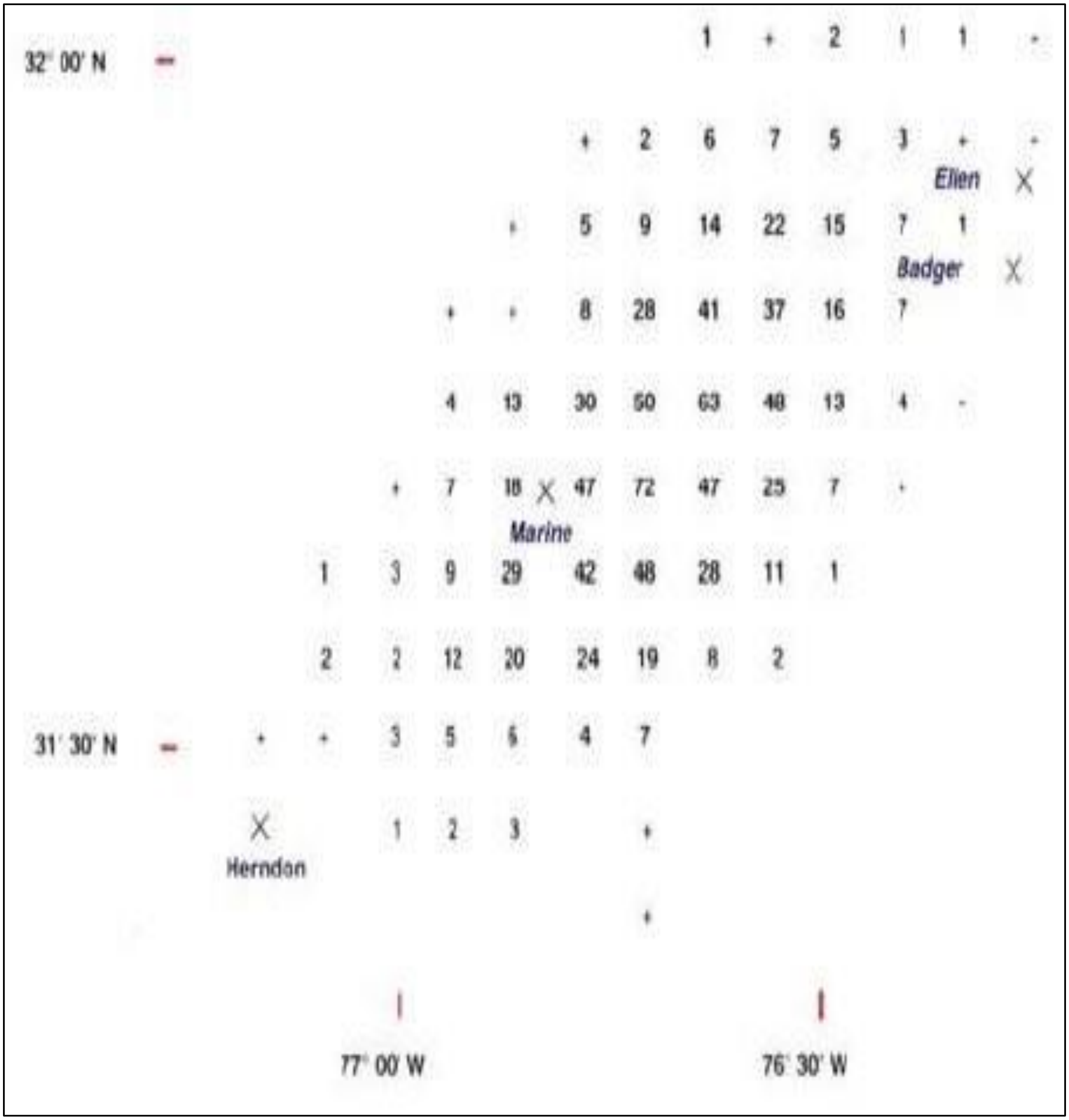


FIGURE 3.4. Probability map based on Captain Herndon's last navigational fix prior to *Central America*'s sinking. Stone gave this scenario a weight of 23% probability (Stone 1992).

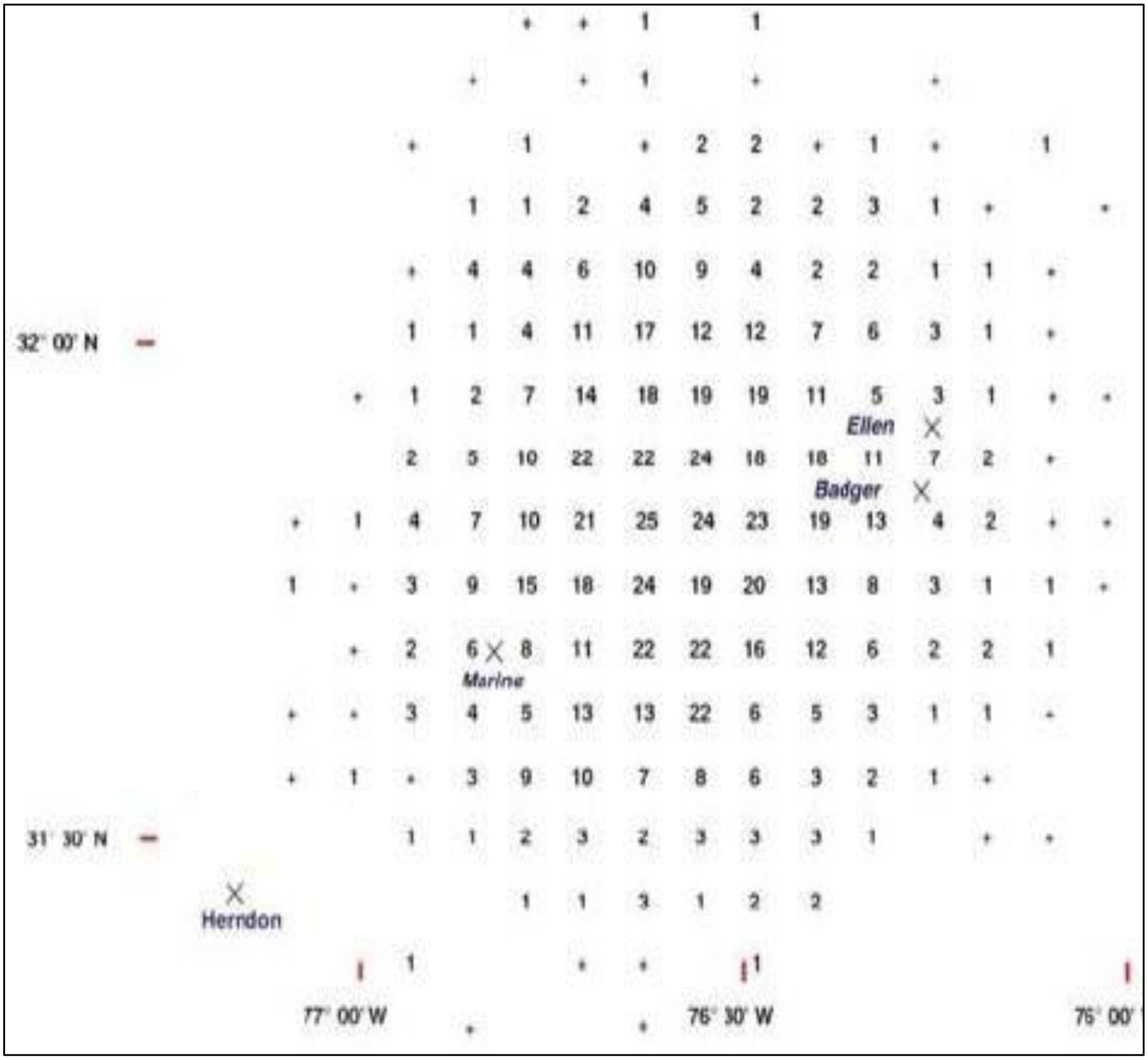


FIGURE 3.5. Probability map based on *Marine*'s sighting of *Central America* prior to its sinking. This scenario was considered the least likely and weighted accordingly (5%) (Stone 1992).

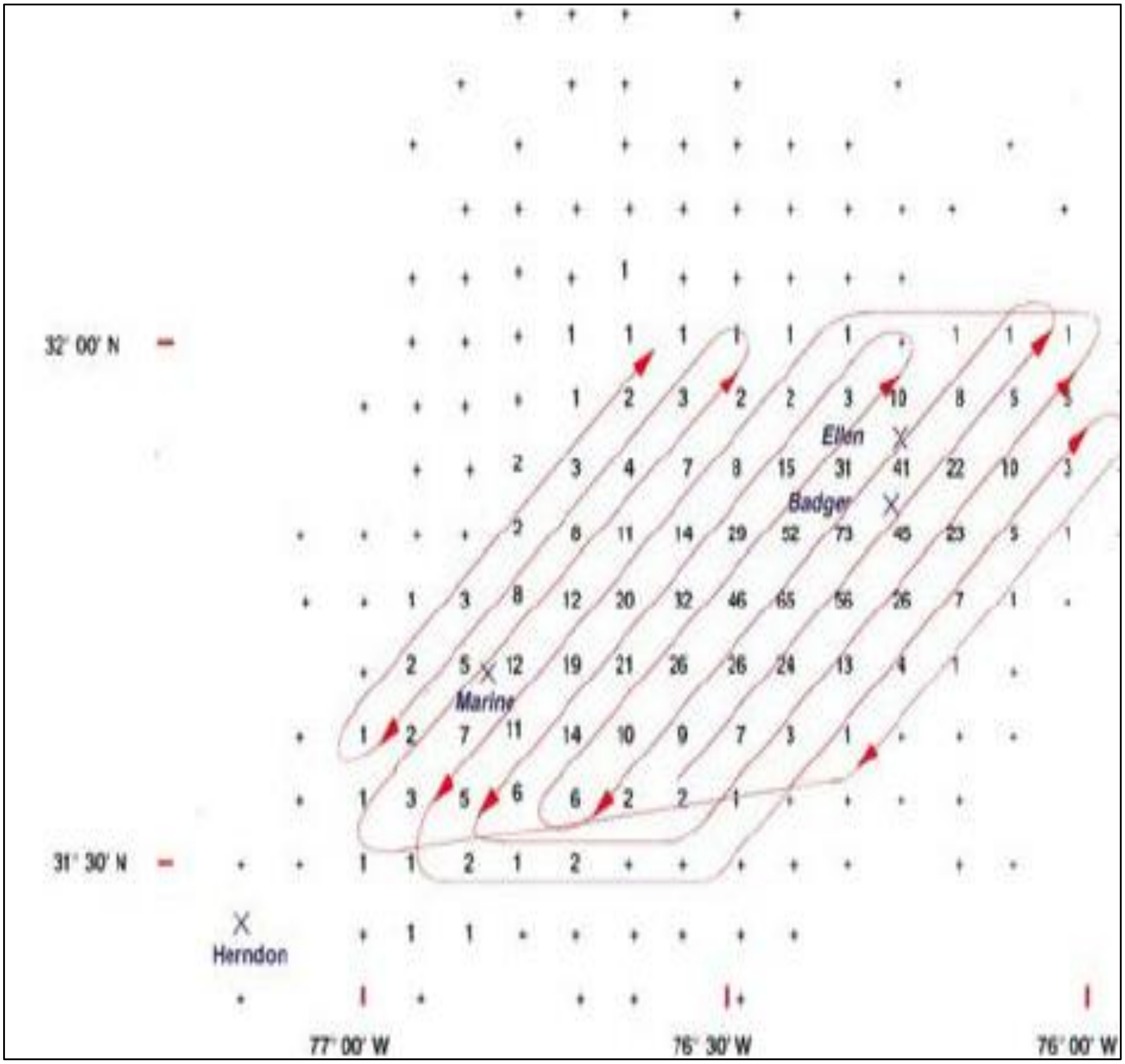


FIGURE 3.6. Composite probability map, with the search pattern overlaid (Stone 1992).

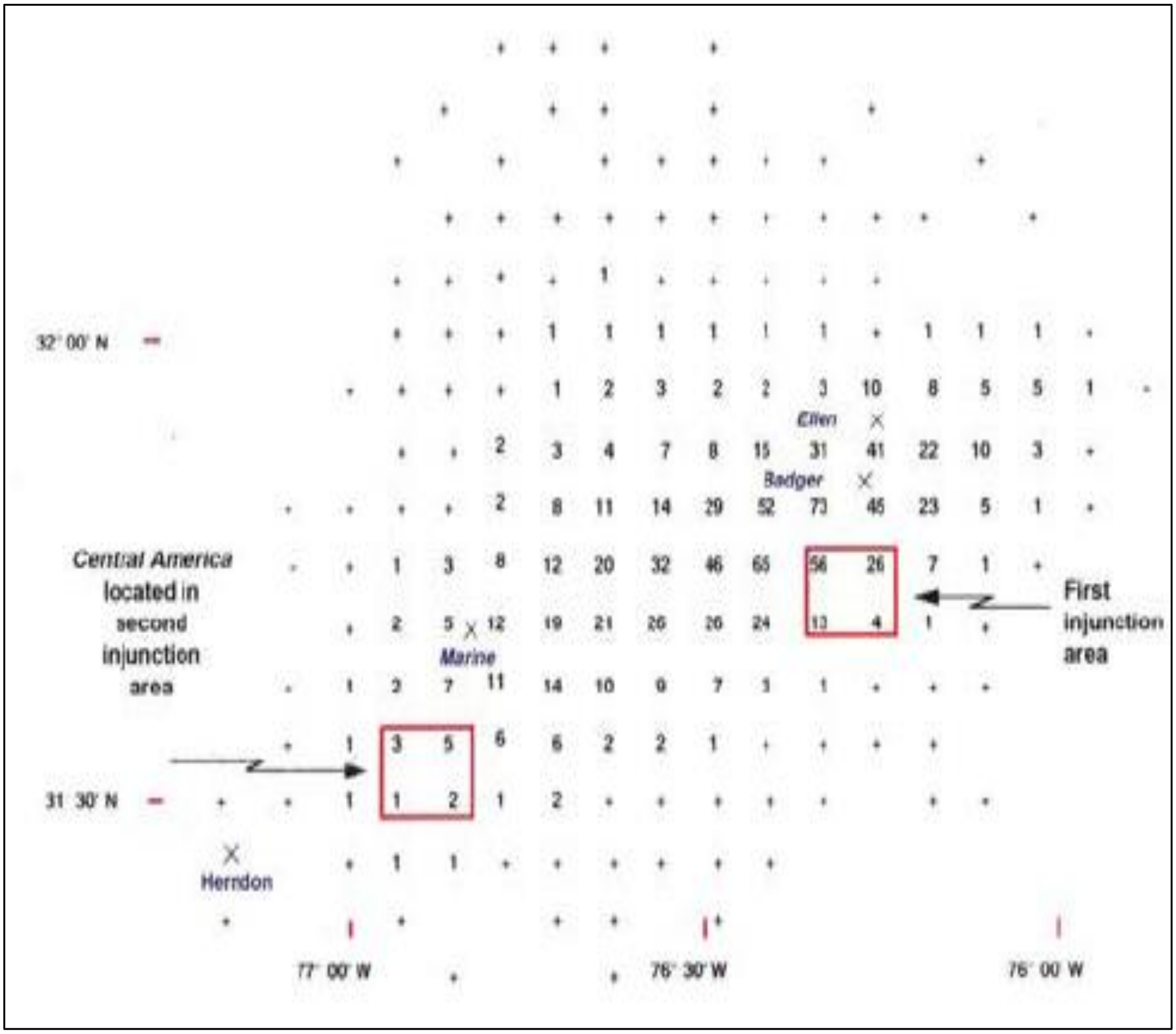


FIGURE 3.7. General location of *Central America* on the composite map, indicating its location in a low-probability cell according to the weighted data (Stone 1992).

More recently, Bayesian search was employed in 2011 to locate the remains of Air France Flight 447, two years after the airliner crashed in the central Atlantic *en route* to Paris from Rio de Janeiro. Using a combination of prior distribution data (the aircraft's last GPS transmission, previous airplane crashes from cruising altitude, and a reverse-drift analysis of recovered cadavers) and posterior distribution (the failure of surface searches to locate bodies or debris for 6 days and the unsuccessful searches for the aircraft wreckage and black box undertaken with acoustic sensors and sonar), Dr. Stone and his team employed Bayesian methods to develop a probability map that ultimately aided in successful location of the wreck and recovery of its black box (Stone 2011:21, 23, Stone et al. 2014:72-80).

An alternative search methodology is that employed by John Bright. In his search for the wrecks of *Bluefields* and *U-576*, he used ArcGIS to recreate the approximate route of Convoy KS-520, based on navigational data obtained from the logs of the convoy's escorts. Here his working assumption was that their navigational coordinates could generally be relied upon to be accurate prior to the U-boat attack; as he had previously established, their data during the attack was confused and unreliable. He used the logs to approximate the convoy's route along the North Carolina coast by inserting their recorded coordinates as X-Y points into ArcGIS and then merging these points into lines. Further, he obtained navigational data from *U-576* as reconstructed from its last Kriegstägebuch (KTB, the war diary kept by U-boats during patrol) and developed a point cloud from the various attack positions as recorded by convoy ships and escorts, along with other map layers containing US and German naval grids and the coast of North Carolina. He used this data to generate a vectorized density cloud over which he laid the attack points recorded by the convoy's destroyers to prioritize search areas for the wrecks, with highest rank given to areas in which recorded attack events coincided with the areas of highest route density (see FIGURES 3.8-3.11). Other factors taken into consideration included the daily search capacity and maximum operating depth of the AUV he proposed to use in the search (Bright 2012:55-61). This methodology was ultimately successful in locating both wrecks.

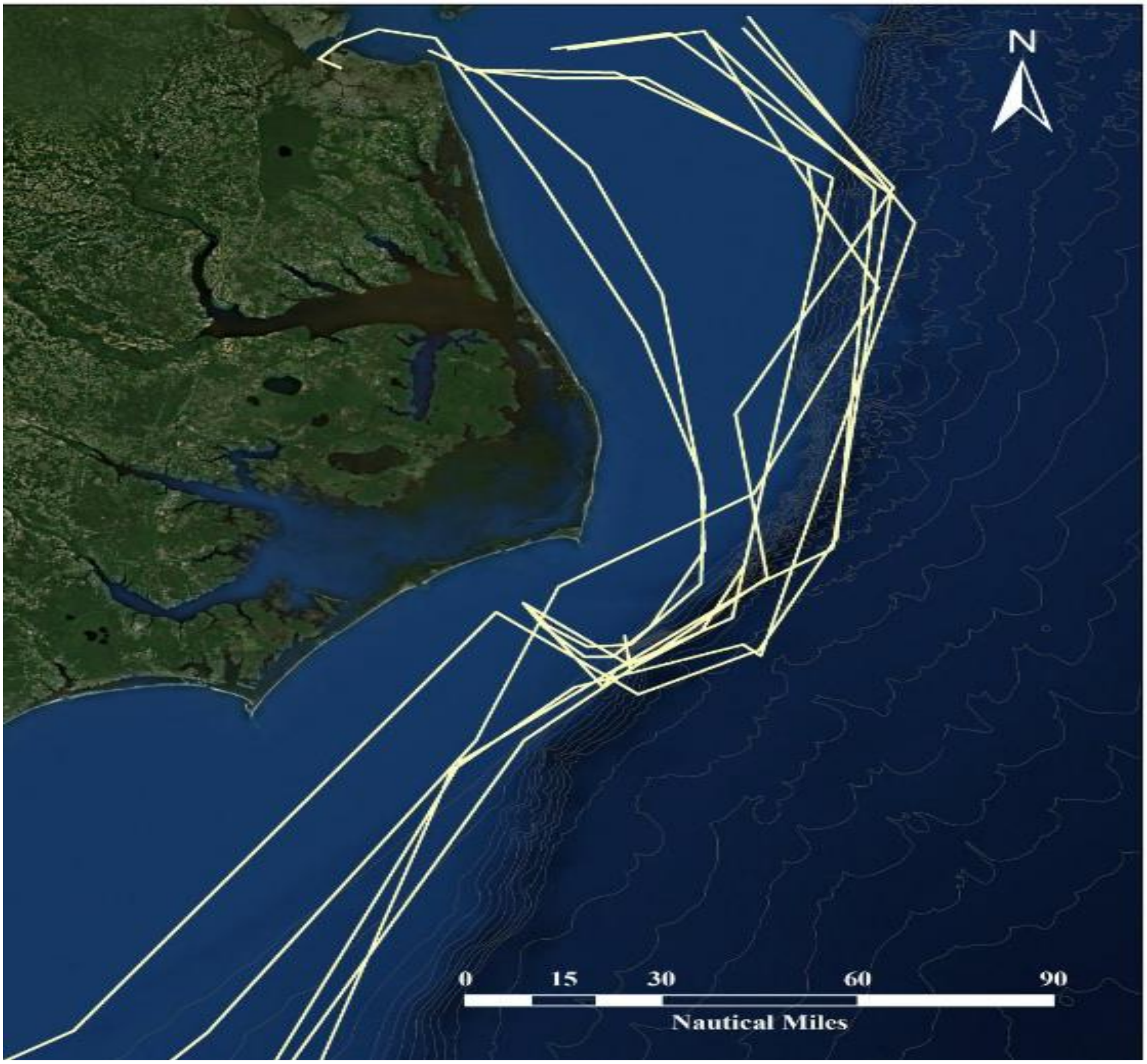


FIGURE 3.8. Merged line point distribution, reconstructing the route of Convoy KS-520 (Bright 2012).

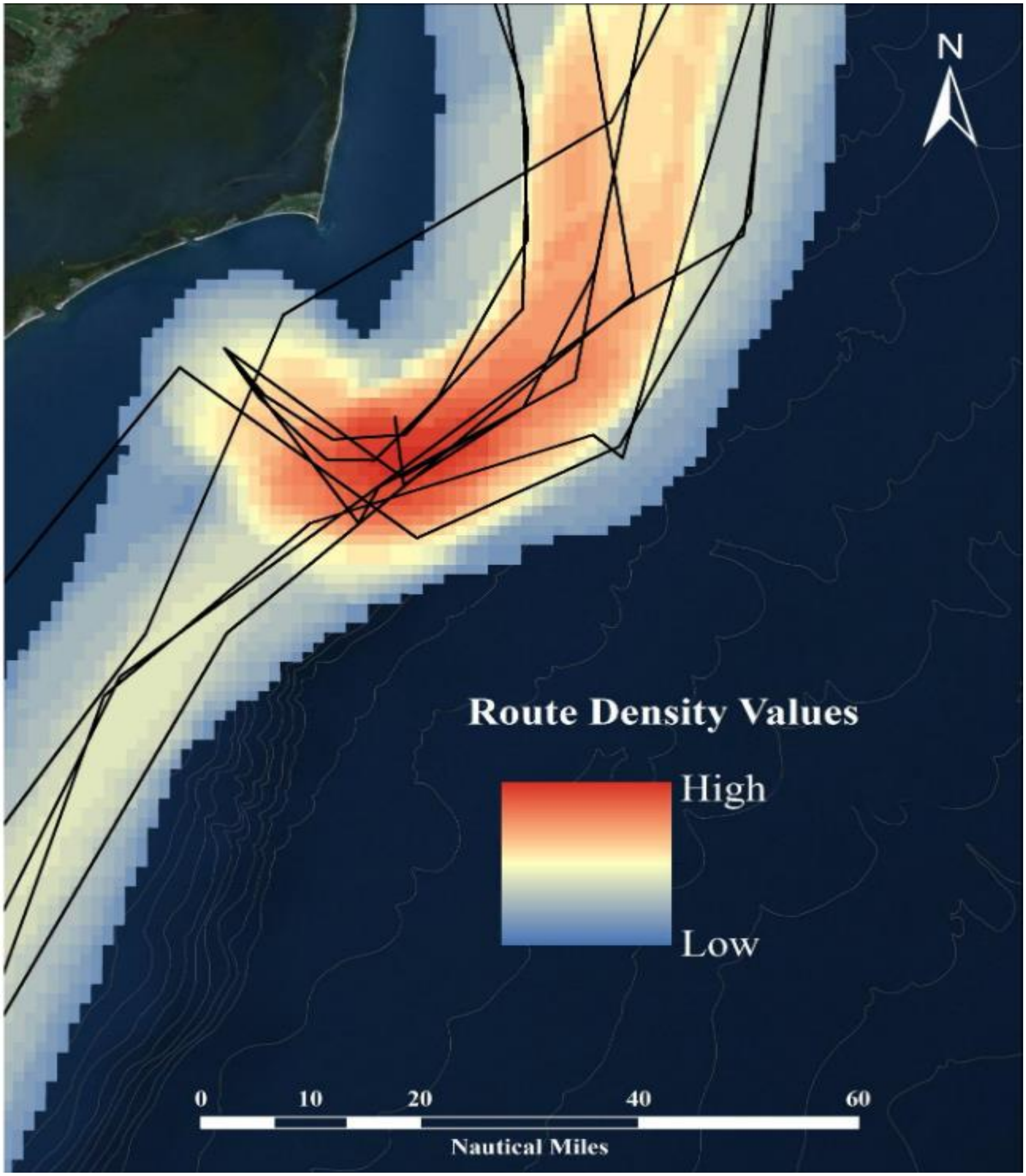


FIGURE 3.9. Rasterized density cloud, with red indicating areas proximate to the hypothetical convoy routes (Bright 2012).

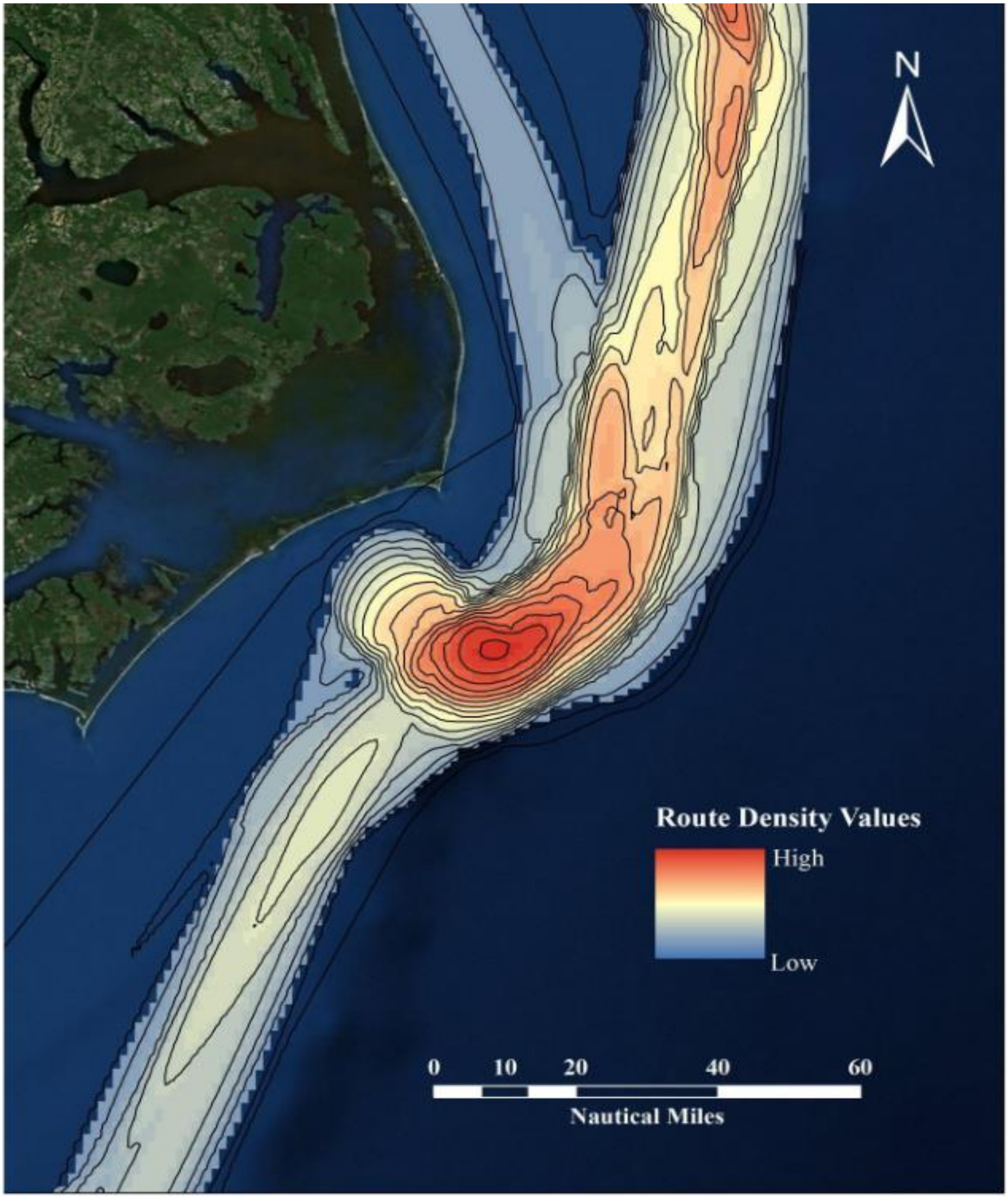


FIGURE 3.10. Vectorized density cloud, with red representing highest density values (Bright 2012).

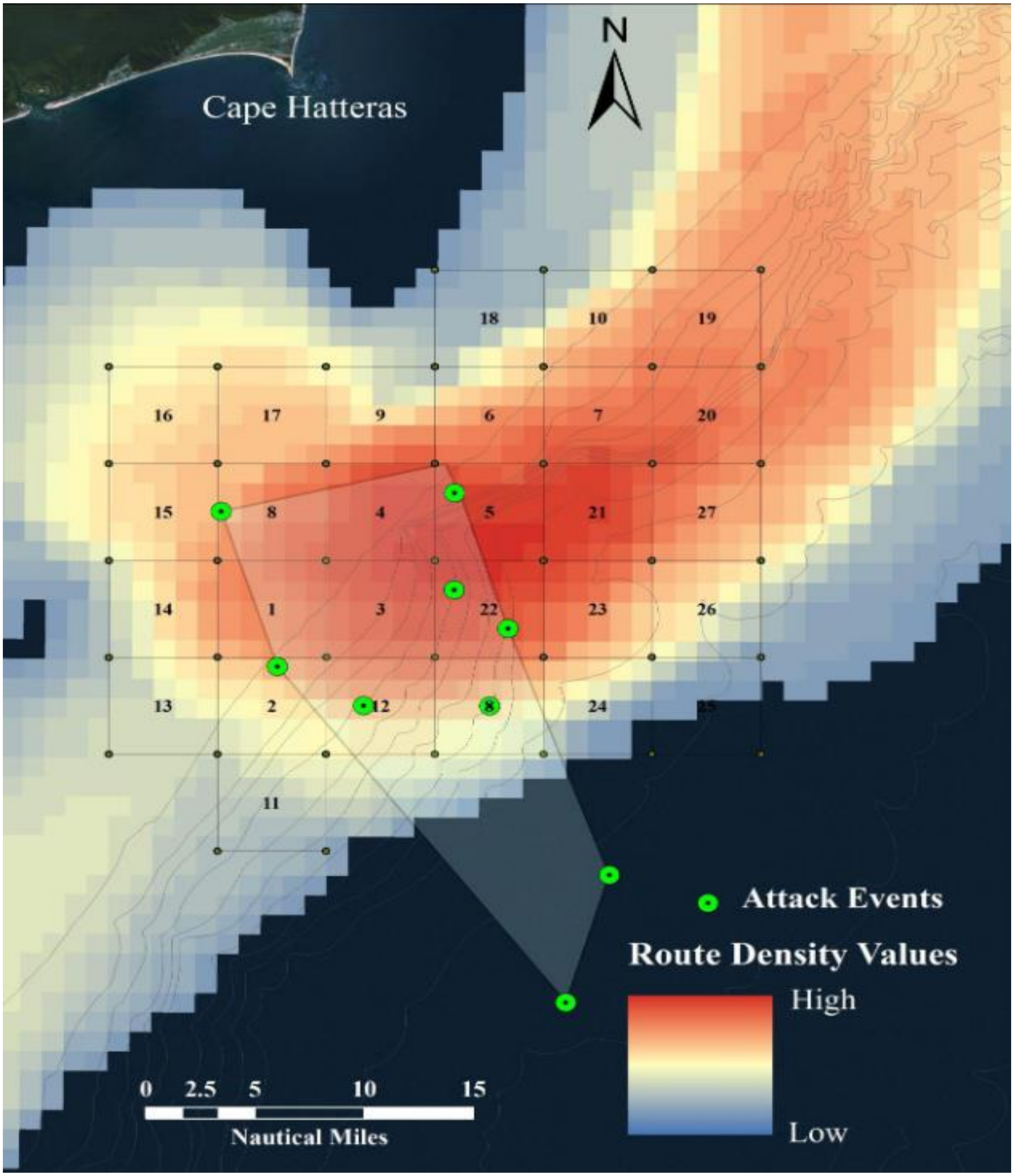


FIGURE 3.11. Bright's final search map, with attack points and search grids based on working capacity of search vehicle overlaid. (Bright 2012).

Software Applications and Their Uses

A key development in modern maritime search theory has been the creation of software packages that automate much of the process of developing probability distributions and generating search patterns and maps. The ArcGIS software developed by the Environmental Systems Research Institute (ESRI) is probably the most well-known of these packages, but other systems have been developed with more specific applications in mind. The United States Coast Guard's Search and Rescue Optimal Planning System (SAROPS) is a package designed specifically for SAR work. The Coast Guard commissioned SAROPS to replace the CASP and JAWS methods it had previously employed; the software was developed over a three-year period by Northrop Grumman, Metron Inc., and Applied Science Associates and first deployed in 2007. SAROPS is a complete set of software tools designed to create accurate and up-to-the-minute search plans for persons and small boats lost at sea (Roylance 2007:4D, Turner et al. 2008:1, Kratzke et al. 2010).

The first part of the system is a graphical user interface (GUI) based on ArcGIS, which adds a set of bespoke plugins to the latter software. These plugins enable the creation of search plans and patterns, environmental datasets, and probability maps within the GIS software. The second part of the system is an Environmental Data Server (EDS), which is maintained at the Coast Guard Operations Systems Center in Martinsburg, West Virginia. The EDS collates and stores environmental data from a variety of sources for distribution to local SAROPS servers around the country. The data it collects includes, but is not limited to, observations on sea surface temperature, sea state, air temperature, visibility, wave height, and tides and currents (Turner et al 2001:1-2). The third part of the system is the SAROPS Simulator, which takes all the data input by the user for a specific scenario and runs it through a Markov chain Monte Carlo simulation to generate an animated probability density map. The simulator can also plot optimal search patterns for available search ships and aircraft based on their distance from the incident, travel time to reach the scene, and current weather and sea conditions, among other factors. As fresh data becomes available, the simulator can update the map every hour to refine its parameters and alter search patterns as needed (Roylance 2007:4D; Kratzke et al. 2010:1-3; Ian Brown 2022, pers. comm.).

While SAROPS is by definition a package tailored for search and rescue, it has obvious applications in the planning of shipwreck searches, since it uses many of the theoretical and methodological approaches enumerated previously. In fact, a customized version of the program has been employed in the ongoing search for the famed American warship *Bonhomme Richard*. Applied Science Associates was contracted by the Ocean Technology Foundation to create a bespoke version of the system so that OTF could produce a GIS database and map for their search. Initial results using this system generated several promising targets, though as of 2022 none of the target wrecks has been positively identified as *Bonhomme Richard* (Roylance 2007:4D, Ryan 2015; National Marine and Underwater Agency [NUMA] 2022).

Though SAROPS is a government-owned program and can only be operated at Coast Guard command stations, discussions with officers from the USCG North Carolina Sector Command have indicated that the program can be made available for use in this project, provided that sufficient spatial and environmental data can be obtained to feed into the SAROPS simulator (Matthew Mitchell 2022, pers. comm). More will be said about this in the methodology chapter. Now that the theories behind the search models available have been outlined, it is time to contextualize them in terms of archaeological predictive modeling.

Predictive Modeling

The use of predictive modeling to locate sites has been a part of terrestrial archaeological work for the last four decades (Altschul 1988:63). In Chapter 2 of *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, Timothy Kohler defines a model as “a simplified set of testable hypotheses” (Kohler 1988:33). In the following chapter, Jeffrey Altschul expands on this idea by offering a typology of archaeological models. Broadly speaking, models can be said to be predictive or explanatory. A predictive model, simply, is one in which an outcome can be predicted based on the alteration of specific components in the model, whereas an explanatory model is one which seeks to determine *why* a particular outcome occurs (Altschul 1988:61). More particularly, there are several categories or subcategories of predictive model which exist. Altschul defines them as follows:

> In general, models can be divided into two groups based on the degree to which they can be operationalized. Those that contain components or relationships between components that cannot be measured in a replicable and reliable manner will be termed *intuitive* models, whereas those with components that can be so measured will be called *objective* models. Objective models are further distinguished on the basis of (a) the spatial referent of the dependent variable (i.e., whether aspects of site location for an area or specific locale are being predicted), (b) the predominant form of procedural logic (inductive or deductive), and (c) the nature of internal relationships among model components (i.e., whether independent variables are given equal weight or relative weights). On the basis of these criteria, three categories of objective models can be defined: *associational*, *areal*, and *point-specific* models… (Altschul 1988:63).

An intuitive model is one that relies on the use of inductive or deductive logic, often with input based on either patterns of human behavior or the archaeological record (Altschul 1988:64). Thus, the statement “Hidden shoals are often the cause of shipwrecks; if we investigate the hidden shoals off Guilliman Point we can expect to find material evidence of the wreck of SS *Horus*, which is known to have sunk in that area” would qualify as an intuitive modeling statement. Altschul notes that the issue with intuitive models is that their components are not necessarily conceptualized. That is, it may be the case that not everyone concerned agrees as to what constitutes a “hidden shoal,” in which case it becomes difficult to use the terms in a way that permits the model to be tested scientifically. That said, an intuitive model should not be immediately discounted, as they have been the basis of much brilliant archaeological work. Objective models, by contrast, utilize measurable components to create their outcomes. Altschul’s typology separates objective models into three categories, as noted above: associational, area, and point-specific (Altschul 1988:63-65).

Associational models operate on a type of pattern recognition that seeks to establish whether certain archaeological sites are more associated with a given locale or combination of environmental variables. Suppose that someone decides to conduct an archaeological investigation of the area around Guilliman Point that encompasses both shoal waters and deep waters in the vicinity, and that this survey locates 12 wrecks in the shoal area and 8 in the deep-water area. This could be the basis for the construction of an associational model that predicts one will find more wrecks in and around shoal areas than in deep-water areas. The issue here is that of generalization; that is, these models are not derived from probabilistic sample work, so taking survey results from one area and applying them to another without any adjustment may amplify any existing biases in the model (Altschul 1988:66-67). It may be the case that the shoals around Guilliman Point did not have a lighted buoy or other navigational aid meant to warn away ships such as the unfortunate SS *Horus*, whereas another shoal area down the coast at Cape Vulkan is equipped with such aids. In this case the results may be skewed in another direction, and the associational model ceases to function properly.

The second type of objective model is *areal*. These models predict the characteristics of archaeological sites or cultural resources based on estimation of unknown characteristics of sites or site distributions on the basis of sampling done in that region. As these models are often derived from probabilistic sampling methods, they are useful for establishing things like site density or number of sites in a given zone. Areal-based pattern-recognition models use data and statistical methods to construct a mathematical function which is then used to predict certain things about site locations in unsurveyed areas, such as site density or the presence/absence thereof (Altschul 1988:69-70). This type of areal model, used in conjunction with standard grid-based survey methods, has proven successful in terrestrial archaeology, though it has two drawbacks: the alteration of grid sizes can throw off the final composition of the model, and the characterization of the environment. This second requires more explanation. The environmental variability of each grid unit is typically characterized based on a few data points taken from within said unit, which are then extrapolated as being representative of the entire unit (Altschul 1988:71-73). As may be obvious, this approach can result in highly skewed data, particularly in a dynamic environment such as the ocean, where environmental characteristics can vary from minute to minute, to say nothing of days, weeks, or months.

The third type of objective model is the *point-specific* model. This model type seeks to predict the likelihood of a specific grid unit or spot containing a site. These models, in the context of archaeology, use numerical classification techniques and binary response variables to develop their conclusions. The latter introduces a flaw into the data framework in that it lumps all sites under consideration into two broad categories (site/nonsite) that offer no flexibility or nuance in differentiating site types. In the context of maritime archaeology, this would mean that the remains of an inundated Bronze Age village off the coast of Denmark would be treated as functionally no different from a modern shipwreck lying in Caribbean waters. It also introduces statistical problems in that heterogenous groups are being fed into a model that assumes them to be internally homogenous, which can produce misleading or completely inaccurate results. Further, this introduces problems of generalization into the model environment, similar to the associational model, which can skew the mathematics and thus the results (Altschul 1988:73-75).

Based on this typology, under what categories can Bayesian search and John Bright's modeling work be catalogued? As it happens, Bayesian search is difficult to quantify using the Altschulian typology, since it fits neatly into no one category. It has some characteristics of several different predictive model types, including intuitive modeling (making deductions based on known or assumed characteristics), areal modeling (use of probabilistic methods to predict possible site locations), and point-specific modeling (predicting the likelihood of a grid unit or particular spot containing a site). It may be best to describe it as an inductive, pattern-recognition-based areal model, with some elements of point-specific modeling included, in that it seeks to use both hard data and educated guesswork to predict the likelihood of a given object being within a given grid unit or cell on a predictive map.

The modeling schema used by John Bright would likely fall into approximately the same category as the Bayesian model. However, Bright put more emphasis on associational modeling than areal modeling, in that he sought to use a type of military battlefield analysis known as KOCOA (**K**ey Terrain, **O**bservation and Fields of Fire, **C**over and Concealment, **O**bstacles, and **A**venues of Approach) to define the boundaries of a nautical battlefield and predict whether it is likely that there are wrecks or other detritus of naval battle in a certain area, given its environmental and geophysical characteristics. Further, his methodology leans toward point-specific modeling, as he used point clouds and the maps generated from this data type to highlight the most likely areas in which to search for the wrecks of Convoy KS-520 (Bright 2012:8-9, 54-62).

Conclusion

This study proposes to adopt the theories of maritime search advanced by Doctors John Craven and Lawrence Stone, among others, to develop a predictive model of *William Rockefeller*'s last hours afloat. Ultimately, these models will then be used to develop a preliminary search plan for the ship. Specifically, this project seeks to use the principles of Bayesian search as developed by Drs. Stone and Craven (1992, 2001, 2011, 2014), as Bayesian search has proven highly effective in previous searches for ships and planes lost at sea (Place et al. 1975; Stone 1992; Craven 2001; Stone 2011; Stone et al. 2014). Therefore, this study will employ the theory with minimal alterations in technique; as the saying goes, "if it ain't broke, don't fix it."

Specifically, this study will use Bayesian methods to compile a series of individual scenario maps based on all known scenarios of *Rockefeller*'s loss, then combine those maps into a composite probability model that will highlight the most likely areas in which to begin a search for the tanker's wreck. This is a method that has been used in similar circumstances to great effect, specifically in the searches for USS *Scorpion* and SS *Central America* (Richardson and Stone 1975; Craven 2001; Stone 1992). In the first case, *Scorpion* went down unobserved and with minimal data regarding its loss. *Central America*'s wrecking event had more data available, but due to the circumstances of its sinking this data was confused and sometimes contradictory. Bayesian search offered a means to maximize the utility of this data in a way that offered the greatest chances of success, and in both cases the wrecks were located with relative ease compared to other maritime searches, such as those conducted for *Titanic* and Flight MH370 (Ballard 1997; Waldron 2017). The process of creating these maps will be delineated in the methodology chapter.

CHAPTER FOUR: METHODOLOGY – MAPS, MODELS, AND PROBABILITIES

Introduction

This chapter will cover the methodologies that were employed in developing a predictive model and search map for the wreck of *William Rockefeller*. These methodologies have similarities and differences to the techniques employed in terrestrial search. An object or person lost on land will often leave physical traces on the landscape, such as footsteps, tire tracks, litter, or damage to the environment. A person or object lost at sea leaves no lasting physical trace on the ocean's surface, and if the event went unobserved or unreported, the problem of locating the person or object in question becomes exponentially more difficult. The case of Malaysian Air Flight 370 illustrates this difficulty quite well. After diverting from its planned course and disappearing from civil and military radar, the plane is presumed to have crashed somewhere in the southern Indian Ocean, but the exact spot where it went down remains unknown (Waldron 2017).

As John Bright notes, in such cases any inferences drawn as to an object's location "must be based upon a composite of historical, geographical, and archaeological information" (Bright 2012:40). Unfortunately, in such cases this information may not be enough to devise a successful search plan. The first search expedition for MH370 was one of the largest, longest, and most expensive sea searches in aviation history, covering ~4,600,000 square kilometers over three years and costing $155,000,000 USD. Despite the recovery of some debris on the western coast of Australia and various islands off the east coast of Africa, the aircraft's wreck has yet to be located as of 2022 (Waldron 2017; Thomas 2022).

Fortunately, this is not the case for *William Rockefeller*, as there exists a great deal of primary source data on *Rockefeller*'s last hours, including statements from the tanker's crew taken after its sinking, logs from the Coast Guard cutter that was escorting it at the time of the attack, and written statements and interrogation reports from KptLt Degen, who was fortunate enough to survive the loss of his U-boat (OCNO 1942b, 1942c, 1942d; USCG 1942b, 1944b, USONI 1942b).

The methodology for this study was relatively straightforward. As in Dr. Lawrence Stone's search for *Central America,* a variety of historical, statistical, analytical, and subjective data was compiled. Bayesian methods were then used to construct a series of predictive models based on the generally accepted scenarios of *Rockefeller*'s sinking. The historical data included the logs and reports of *Rockefeller*'s crew, its Coast Guard escort, and KptLt Degen of *U-701.* It also included data on weather, sea conditions, and ocean currents in the area at the time of the attack event. Statistical data included the probability maps developed for each scenario and the estimates of current strength and wind speed/direction at the time. Analytical data included the uncertainty of *Rockefeller*'s position when it finally sank. Subjective data included the weights given to the quality of the information used to assemble each of the scenarios regarding the tanker's loss. Once the individual models were constructed, they were compiled into a composite map or model which defined a more compact search area for *Rockefeller* and was then further updated with any information acquired during subsequent research or actual search expeditions for the wreck.

First came historical research. Though some initial research had been conducted by others, it proved necessary to reassess all available primary and secondary sources to determine the most likely coordinates for *U-701*'s attacks on *Rockefeller* and the area to which the tanker drifted prior to sinking. This step was crucial, given the lack of solid data on *Rockefeller*'s position when it sank. Further, as there was no possibility of doing fieldwork until a more compact search area had been defined and funding and equipment acquired for a deep-water search, this study was required to extrapolate from historical sources and work from conjecture and hypotheses. Inaccurate interpretation of the available data is a possible issue, given the conflicting statements vis-á-vis *Rockefeller*'s last position. Though the creation of a probability map has great potential for aiding in the location of the wreck, the final map is only as reliable as the data it was given.

Also needed was contemporary information on prevailing currents and general conditions in the Atlantic on the North Carolina coast, as this information was used to model the effects of drift on *Rockefeller*'s final course. Ocean charts and similar materials are obtainable from a variety of sources, but in this case NOAA was the go-to entity for this data, as they are tasked with maintaining nautical charts for the entire American coastline. They also maintain a database of freely accessible legacy charts reaching back to 1807, which were useful for comparative purposes (NOAA 2020). Other materials that were helpful in this case included contemporary government publications on the currents of the East Coast (Haight 1942).

Once all this material was collated and analyzed, and with the variables listed in the research questions section accounted for, it was used to create a predictive model, following the principles of Bayesian search theory (Stone 2011). This model sought to establish potential locations for the wreck within the given search area, running from areas of highest to lowest probability. It may be further refined by field data when and if a search for *Rockefeller*'s wreck is undertaken. The predictive model was realized with the aid of GIS software, which was used to create a map for the *Rockefeller* wreck and highlight likely locations for the wreck site. While there was no way to test the accuracy of the model and map without conducting fieldwork, it was still possible to gain some insight into contemporaneous conditions off the North Carolina coast and begin to answer the questions posed at the beginning of this thesis.

This approach bears some similarities to the methods employed by John Wagner and John Bright in their own studies of the Battle of the Atlantic off North Carolina (Wagner 2010, Bright 2012). Wagner's end goal was more generalist, as he sought to design a GIS model that would accurately represent North Carolina's waters during World War II (Wagner 2010:22). Bright's work is closer to the specific context of the present study, as he sought to examine a single naval battlefield, that of Convoy KS-520, and develop a survey plan to locate the missing wrecks contained therein, namely the Nicaraguan freighter *Bluefields* and the U-boat *U-576* (Bright 2012:42-43). Whereas Bright also conducted an adapted KOCOA and METT-T analysis of the battlefield, this study sought only to establish a more compact search box in which to begin an archaeological survey with the goal of locating *William Rockefeller*'s wreck.

As mentioned previously in the case of Flight MH370, one of the key problems of maritime search is the time and cost it takes to investigate a large search area. The potential search area for *Rockefeller* is only a fraction of the area which was defined for MH370 (750 nautical miles as opposed to 4,600,000 square kilometers), but this still required some narrowing of focus to maximize the chances of success during any potential search operations (Basta et al. 2013b:6, Waldron 2017).

Phase One: Historical Research and Data Collection

The first phase consisted of identifying and collecting historical, geographic, and oceanographic data on *Rockefeller* and contemporaneous conditions off North Carolina's coast. This phase also involved studying the basics of Bayesian search theory, which is a mathematical/statistical model not ordinarily employed by maritime archaeologists.

Primary source information was acquired from several repositories, while secondary source information was acquired from a wide variety of physical and online databases and collections, both public and private. Further sources on the nature and methodology of Bayesian search were acquired in similar fashion, as was information on the geographic and oceanographic characteristics of the North Carolina coast. GIS data on the region was obtained from public GIS clearinghouses. Oceanographic data, including historical data on currents and wind, was obtained from publicly available NOAA databases. All relevant information was collated and used to develop a series of potential sinking scenarios for *Rockefeller*, each covering the various narratives of its loss as given in firsthand statements and military records. This phase of research was conducted in the spring and summer of 2022. Mr. Ole Varmer of the Foundation was especially helpful in this phase of research, as he paid visits to the archive on behalf of the author and conducted preliminary investigations of these sources.

The primary sources were mainly acquired from two repositories: the Mariners' Museum in Newport News, Virginia, and the United States National Archives and Records Administration (NARA), more specifically the NARA facilities in Washington, D.C. and College Park, Maryland. The data was collected via a series of trips to Newport News and Washington, D.C. Other primary source records which were potentially helpful were obtained from the state archives of North Carolina. The following table (TABLE 4.1) delineates the specific records acquired from each repository.

Record	**Subject**	**Location**	**Description**
RG 26	Records of the United States Coast Guard	Archives I Textual Records Washington, D.C.	Deck logs of USS *CG-470* Logs from USCG Coast Guard Lifeboat Stations Coast Guard Casualty Reports Suggestions for Safety of Tanker Crews WWII Merchant Ship Sinking Reports

RG 38	Records of the Office of the Chief of Naval Operations	Archives II Textual Records College Park, MD	Mercantile Atlantic Routing Instructions (MACRI) Affidavit of Capt. William Stewart Summary of Statements from *Rockefeller* Crew Naval Transportation Service Armed Guard Records Report of Interrogation of *U-701* Survivors
Mariners' Museum	Newport News Shipbuilding and Dry Dock Company	Mariners' Museum Archives Newport News, VA	Blueprints of *Rockefeller* and *Archbold* Photographs of *Rockefeller* and *Archbold* Spec books Shipyard logs and histories
North Carolina State Archives	William Chapline Papers	Raleigh, NC	Logs of Ocracoke Coast Guard Station USS *YP-389* sinking report

TABLE 4.1. Listing of primary source materials acquired from archival repositories.

The holdings in the Mariners' Museum included a great deal of information on the construction and early career of *William Rockefeller* as found in the archives of the Newport News Shipbuilding and Dry Dock Company (NNSDD), which had built *Rockefeller*. These materials included builder's plans of the vessel, a specifications book outlining the construction details of *Rockefeller* and its sibling ship as ordered by Standard Oil, photographs of its construction and career, shipyard logs, and a narrative of the yard's history during the relevant period written by NNSDD employee Edward O. Smith. The material was scanned by archivists at the museum and provided as digital copies, some of which were later printed out as hard copies. This material provided information on *Rockefeller*'s general dimensions, construction, and design specifics. The photographs did not offer any especially relevant archaeological information, but they were useful for visualizing the scale of the tanker and for preparing presentations; when and if a search is launched, these photos will also be useful for comparative purposes should any targets be located.

The NARA sources in Records Group 26 contained the deck logs of USS *CG-470*, one of the vessels assigned to escort *Rockefeller* on the day it was sunk; this log included information on weather conditions and narratives of the watch schedule maintained on the cutter during its journey. Other information held in this record group included the Coast Guard's official narrative of *Rockefeller*'s loss, suggested safety measures for tanker crews, and the collected reports of merchant vessel losses during WWII. These sources provided useful data on position, weather, and the Coast Guard's actions during and after the sinking. Records Group 38 contained statements collected from the captain and crew of *Rockefeller*, the reports from KptLt Degen's interrogation, miscellaneous information on *Rockefeller*'s wartime career, and routing instructions for merchant vessels traveling along the Eastern Seaboard during the war. The material from both archives was photographed and stored in the cloud and on hard drives, with some of the records also photocopied for easier reference.

The North Carolina state archives have the William Chapline Papers, which are the collected records of the Ocracoke Coast Guard Station from 1935 to 1944. These papers, which have been digitized and made available online, provided contextual information from the station on *U-701*'s activities prior to its attack on *Rockefeller.*

Other sources consulted included secondary sources on the Battle of the Atlantic generally and *Rockefeller*'s sinking in particular, including but not limited to Homer Hickam's *Torpedo Junction*, Ed Offley's *The Burning Shore*, David Stick's *Graveyard of the Atlantic*, Michael Gannon's *Operation Drumbeat*, Standard Oil's *Ships of the Esso Fleet in World War II,* and a study on the Battle of the Atlantic produced by a team of researchers from NOAA and East

Carolina University, led by Joseph Hoyt (Standard Oil 1946; Morison 1947; Stick 1952; Balison 1954; Hoyt 1978; Van der Vat 1988; Hessler 1989; Hickam 1989; Hoyt 1989; Gannon 1990; Blair 1996; Niestlé 1998; Hudy 2007; Campbell 2008; Hoyt 2008; Offley 2014; Hoyt et al. 2021). These sources, acquired from public and personal libraries, provided wider historical context for the circumstances of *Rockefeller*'s loss. Lastly, a thorough search of the Newspapers.com database produced many articles on *Rockefeller*'s career between its launching and sinking, including a pair of grounding incidents and the accidental explosion and fire in 1929 that severely damaged but did not sink the tanker. Articles on the latter incident were particularly useful, as they illustrated the fundamental soundness of *Rockefeller*'s construction and provided context as to how it survived so long after being torpedoed and set afire by *U-701* (*Wall Street Journal* 1921; *Baltimore Sun* 1923; *Bradenton Herald* 1925; *Los Angeles Times* 1925; *Palm Beach Post* 1925; *The State* 1925; *Boston Globe* 1929; *Brooklyn Standard Union* 1929; *Brooklyn Times Union* 1929; *Corsicana Semi-Weekly Light* 1929; *The Daily Telegraph* 1930; *The Austin American* 1939; *Corpus Christi Times* 1939 a-b).

For information on *U-701*'s activities during its patrol, Axis sources were consulted, including the U-boat's Kriegstagebüchen (KTB; translation: "war diaries") and the compiled war diaries of the German submarine command. These sources provided more information on KptLt Degen's claim to have sunk *Rockefeller* with a second torpedo (Degen 1942a-c; Dönitz 1945).

The Scenarios

All this data was used to construct a series of scenarios for *Rockefeller*'s loss, with the aim of covering all the possibilities as to the tanker's fate. They may be summarized as follows:

- Scenario 1: *Rockefeller* sinking on its own after drifting and burning for just over 11 hours

- Scenario 2: *Rockefeller* being sunk by a second torpedo from *U-701*, after ~12 hours adrift
- Scenario 3: *Rockefeller* being scuttled by Coast Guard aircraft on the morning of 29 June

Detailed versions of these scenarios will be given in the next chapter. For now, we may turn to examining the relative probability of each scenario. As is obvious, the scenarios cannot all be correct, so what weight is to be given to each of them? This is a task requiring subjective probability analysis; in plain language, this analysis involves a person looking at all the information they have gathered and deciding what they believe is most reliable, then weighting their subsequent work accordingly. This is a part of the Bayesian method that is meant to quantify the otherwise unquantifiable human factors of intuition, gut feelings, and hunches as part of the search process. This is not to say that the process is unscientific, for it requires the person or persons conducting the analysis to carefully study the available data and evidence when making their decisions, but it contains an element of uncertainty since it remains based on subjective opinions (Stone 1992:45-46; Sontag et al. 1998:59, 104-105; Craven 2001: 167-168).

Phase Two: Mapping and Modeling

The second phase involves developing and creating the predictive map and model. This will be done with ESRI's ArcGIS software and the USCG's SAROPS package. The scenarios enumerated above will be translated into a data format suitable for use with both sets of software, including latitude and longitude expressed as decimals, contemporaneous data on currents and wind, and any other data needed to complete the model. This data will be input into ArcGIS to create a search map and fed into SAROPS to generate probability distributions for each scenario. The probability of each scenario will be weighted according to the strength of the data used to create them, and then combined to create a final composite probability map that can be employed in a search for *Rockefeller*'s wreck.

Discussions with the Coast Guard's North Carolina Sector office confirmed that their SAROPS software package is available for use in this study, contingent on the acquisition of sufficient environmental data to feed into the SAROPS simulator (Matthew Mitchell 2022, pers. comm.). If so, the software will be used to generate a probability density map highlighting the most likely search areas for *Rockefeller*'s wreck. As the software is government property and cannot be shared with East Carolina University, the Coast Guard has agreed to generate the maps on the author's behalf and provide all necessary data and support. Consultations with Joshua Marano of the National Parks Service allowed for the acquired historical data to be refined with terminology and information that would increase its utility for the Coast Guard. The final package sent to the Coast Guard included the following data points: events, time, *Rockefeller*'s speed (known or estimated), *Rockefeller*'s position (given in degrees-minutes-seconds [DMS] and decimal degrees) wind speed and direction, approximate current speed and direction, general weather, compass bearings, and sources for the data. (See TABLE 4.2).

Event	**Last Known Position**	**Course Bearing (to true north)**	**Speed (Knots)**	**Wind Variables (approx.)**	**Current Variables (approx.)**	**Time**	**General Weather**
Rockefeller leaves Hatteras minefield	35°01'12", 75°59'06" (35.02, -75.985)	045	9.2 kt, not zigzagging	Force 1 (1-3 mph/kt), bearing ~45	0.66 kt, bearing ~45	Early morning (approx. 0600-0700)	Calm seas, mostly clear skies, winds Force 1 (1-3 mph/kt) from the

							SW (225deg; i.e. to NE = 45deg)
CG-470 takes noon weather readings; assumed that Captain Stewart takes noon position fix also	35° 11’, 75° 2’ (35.18333, -75.03333)	045	9.2 kt, not zigzagging	Force 1, bearing ~45	0.66 kt, bearing ~45	1200 EWT	Calm seas, mostly clear skies, winds Force 1 from the SW according to *470*; northerly wind, same force, according to Capt. Stewart. Scattered showers (one occurs ½ hour prior to attack)
Rockefeller is torpedoed	35° 11’, 75° 2’ (35.18333, -75.03333)	045	9.2 kt, not zigzagging	Force 1, bearing ~45	0.66 kt, bearing ~45	1216 EWT	Calm seas, mostly clear skies, winds Force 1 from the SW according to *470*; northerly wind, same force, according

							to Capt. Stewart.
Rockefeller is abandoned	35° 11’, 75° 2’ (35.18333, -75.03333)	~045	1.5 kt, engines stopped	Force 1, bearing ~45	0.66 kt, bearing ~45	1230 EWT	Calm seas, mostly clear skies, winds Force 1 from the SW according to *470*; northerly wind, same force, according to Capt. Stewart.
CG-470 breaks off to attack *U-701*			1.5 kt, engines stopped	Force 1, bearing ~45	0.66 kt, bearing ~45	1115 according to *CG-470*’s log, probably ~1215-1220	
CG-470 leaves scene to transport crew to Ocracoke			1.5 kt, engines stopped	Force 1, bearing ~45	0.66 kt, bearing ~45	1145 according to *CG-470*’s log, probably 1245	

Rockefeller sinks	35°1’, 75°5’30” (35.016667, -75.091667)		1.5 kt, engines stopped	Force 1, bearing ~45	0.66 kt, bearing ~45	2336-2338 EWT	Calm seas, mostly clear skies, winds Force 1 from the SW

TABLE 4.2. Data sent to the USCG for use with SAROPS (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946).

As concrete data could not be obtained for all these points, some assumptions and estimates had to be made. The two largest variables are the currents and wind speed prevailing during the attack; a combination of interpretations and contemporary data had to be employed to reconstruct them.

The attack occurred within the Gulf Stream, meaning that *Rockefeller*’s drift after being abandoned would have been influenced by this relatively strong and predictable current. The precise speed of the Gulf Stream on 28 June 1942 is not known, but the Coast Guard casualty report for *Rockefeller* indicates the ship was drifting at 1.5 knots when abandoned (USCG 1944b). Data obtained from a 1942 Coast and Geodetic Survey publication on coastal currents of the Atlantic seaboard indicates that the Gulf Stream was then known to flow strongly northeastward during the summer months, peaking in strength during July. The monthly average of the Gulf Stream in June as measured by the Diamond Shoals lightship from 1919 to 1928 was 0.66 knots (Haight 1942:24-25, 52). Given this data, it is probable that the Stream was pushing *Rockefeller* northeast at low speed. Similar examples of Gulf-influenced drift can be seen in the cases of the merchant ship *Papoose* and *U-701*. Both vessels were sunk in the same general area as *Rockefeller*. *Papoose* was torpedoed approximately 15 miles southwest of Cape Lookout and drifted with the Stream for two days before sinking off Oregon Inlet, and the survivors of *U-701* were carried northeast with the current for 49 hours before being recovered by the Coast Guard (USCG 1944a; USONI 1942c:1; Hickam 1989:278-282; NOAA 2022).

Wind speed is another variable for which assumptions and estimates had to be made, though in this case more solid data was available. *CG-470*, the cutter escorting *Rockefeller*, logged weather data at four-hour intervals during the voyage, noting general conditions, barometric pressure, cloud cover, visibility, and wind speed. Wind speed was recorded according to the Beaufort scale, as prescribed by the cutter's logbook. At noon, 16 minutes before *Rockefeller* was attacked, the cutter logged the following weather data: barometric pressure 3001, winds from the southwest at Beaufort Force 1 (1-3 mph/1-3 kt), blue skies with scattered cumulonimbus clouds, visibility 7 miles (USCG 1942b:2). Given that *Rockefeller* was drifting at about 1.5 kt when it was abandoned, it may be presumed that the wind was very light at this time, possibly not more than 1 knot per hour, given that both wind and current would have been exerting force against the tanker's hull.

As an alternative method to the SAROPS program and its Bayesian modeling, this study has also employed ArcGIS to construct a density analysis map. The methodology approximates that used by John Bright in his KOCOA analysis of the U-boat attack on Convoy KS-526, with a few technical differences.

Several sources of data were tapped in order to develop the GIS. Two raster navigational charts of the relevant area off Cape Hatteras were downloaded from NOAA's online database and imported into ArcMap. Also included was data obtained from the master's theses of ECU alumni John Bright and John Wagner, both of whom generously agreed to share their data for this study. The material obtained from Bright included images of the Cape Hatteras minefield which were georectified and added to the GIS to better determine the nature of *Rockefeller*'s movements on its last day. The data obtained from Wagner included reconstructed wartime convoy routes and bathymetry charts of the East Coast, which were added to contextualize *Rockefeller*'s movements and determine likely depths in the search area.

Once these preliminaries were completed, the various latitudes and longitudes obtained from primary and secondary sources on *Rockefeller*'s sinking and subsequent calculations of its potential drift speed and direction were converted from degrees-minutes-seconds to decimal degrees and logged as XY coordinate data in an Excel spreadsheet. Coordinates were logged for each of the attack and sinking positions found in the primary and secondary source data, along with calculated coordinates for the ship's drift based on the posited scenarios. The coordinates were also saved in a series of spreadsheets based on source data and scenario (i.e., Captain Stewart's position data for Scenario 1 and 2). The drift calculations were done in Google Earth and ArcGIS, using their distance measuring tools.

The spreadsheets were saved in the comma delimited (CSV) file format and added to ArcMap with the Add XY Data option (see FIGURE 4.1). Once this was completed, the Points-to-Line tool from the Data Management toolbox was used to turn each of the scenarios into reconstructed tracklines (see FIGURE 4.2). The tracklines were later converted into a single polyline layer with the Points to Line tool for ease of reference.

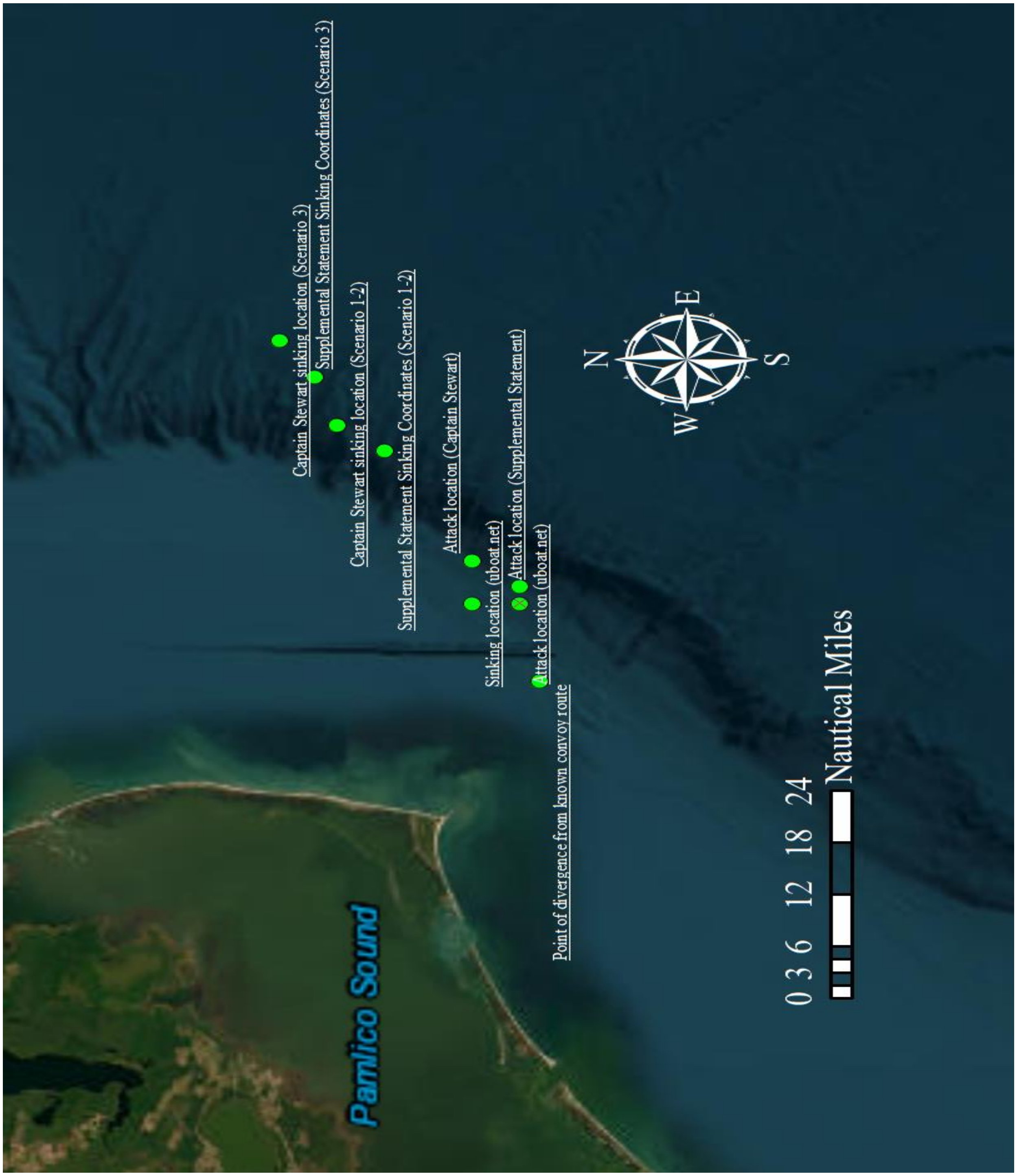


FIGURE 4.1. Position data as derived from various sources on *Rockefeller*'s loss (OCNO 1942b; OCNO 1942c; uboat.net 2021; map drawn by the author).

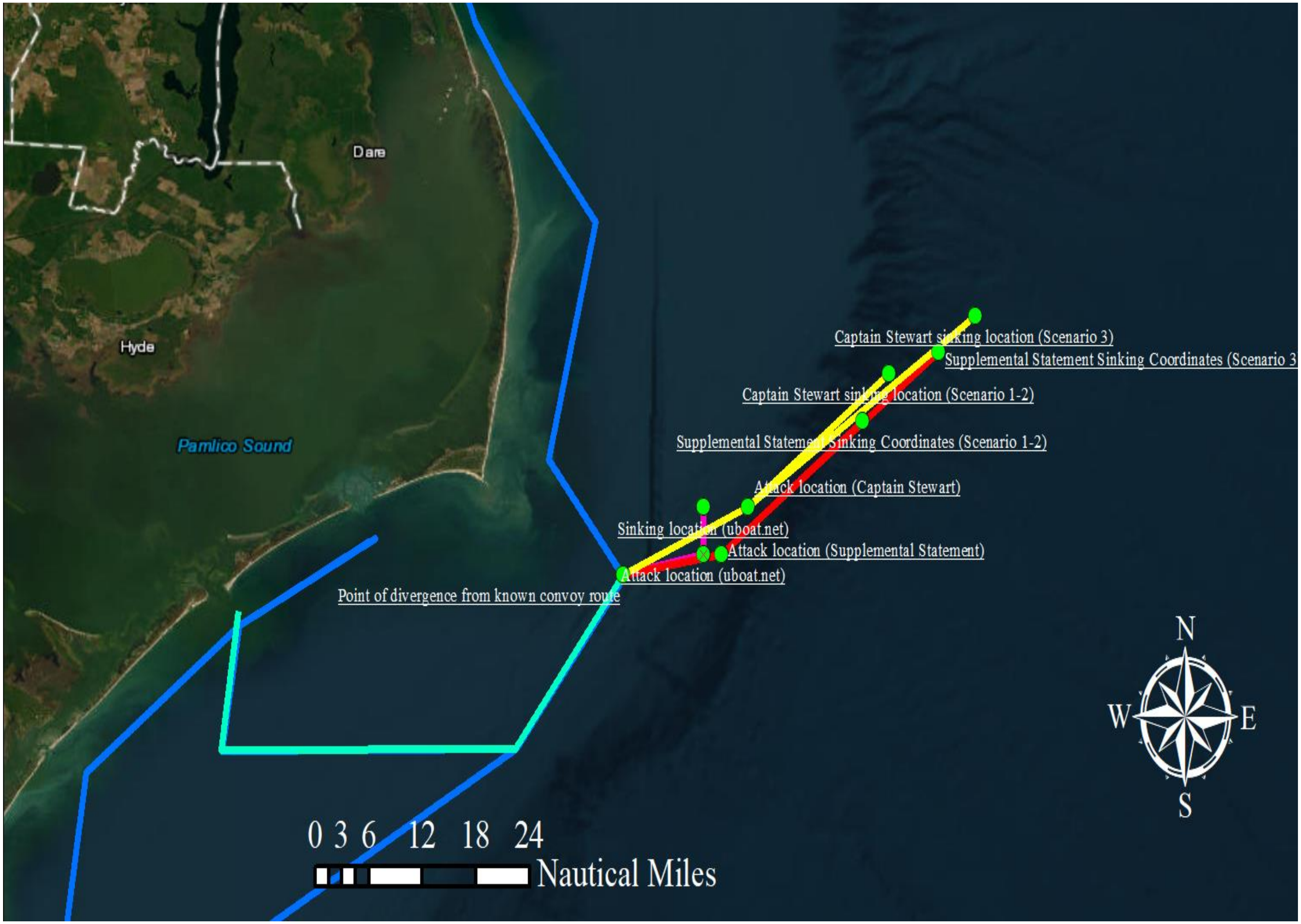

Dare
Hyde
Pamlico Sound
Captain Stewart sinking location (Scenario 3)
Supplemental Statement Sinking Coordinates (Scenario 3
Captain Stewart sinking location (Scenario 1-2)
Supplemental Statement Sinking Coordinates (Scenario 1-2)
Attack location (Captain Stewart)
Sinking location (uboat.net)
Attack location (Supplemental Statement)
Attack location (uboat.net)
Point of divergence from known convoy route
N
W
E
S
0 3 6 12 18 24
Nautical Miles

FIGURE 4.2. Reconstructed tracklines based on the point data. The teal line represents *Rockefeller*'s approximate route based on convoy routing data from February 1943 (the blue line). The yellow lines represent the tracklines reconstructed from Captain Stewart's information, the red lines represent the tracklines reconstructed from the Navy's information, and the pink line represents the trackline reconstructed from the coordinates given by uboat.net. The origin point is the lightship stationed at the entrance to the Hatteras minefield (OCNO 1942b-c; Wagner 2010; uboat.net 2021; map drawn by the author)

Here, some parts of Bright's methodology had to be changed. In his analysis of the Convoy KS-520 battle, he had encountered a similar issue to the one facing this study. The available coordinate data from the convoy was scattered across a wide area of ocean, though in his case the scatter was much wider than that recorded for *Rockefeller*'s last known position (LKP). To solve the issue, he reconstructed the tracks of the convoy's escorts using their logged positions and used those tracklines and the convoy tracks obtained from Wagner to plot a series of hypothetical routes for the convoy (Bright 2012:58-59).

He then conducted a line density analysis to generate a density cloud "representing the space most proximate to all the hypothetical routes" (Bright 2012:58). Over this, he plotted the attack data collected from the convoy's escorts and assigned rankings based on the coincidence of attack data with areas of high route density (Bright 2012:59).

As the problem confronting this study was slightly different from Bright's, a different methodology had to be employed. The Hawth's Tools extension that he used for his modeling was discontinued after the release of ArcGIS 10, and its successor, Geospatial Modeling Environment, is also unavailable, as the website on which it was maintained has been shut down. However, Esri has integrated some of the toolsets from these extensions into ArcGIS 10, meaning that outside tools were not necessarily required.

Correspondence with Bright indicated that he used a kernel density analysis tool to examine his point data, along with the line density analysis tool he used to create the density cloud. Bright further recommended running multiple analyses with a variety of parameters, including altered search radii (John Bright 2022, pers. comm.). The Spatial Analyst toolbox for ArcGIS 10 includes a kernel density analysis tool, along with tools for point and line density analysis. Line density was of little use in this study, and point density analysis also proved unsatisfactory. Other alternatives were tested, including inverse distance weighting (IDW) and Empirical Bayesian Kriging (EBK) interpolation. Also tested was the Integrated Geospatial Tools for Search and Rescue (IGT4SAR), a map template and toolset developed for ArcGIS to aid in land-based SAR operations (Johnson 2016:17-22). Ultimately, however, kernel density analysis proved to be the best option. It is a commonly used spatial analysis tool that provides a means of estimating and predicting event patterns, which matches the methodology used by Bright and is also useful for the purposes of this study as it attempts to predict the pattern of events surrounding *Rockefeller*'s demise (Bright 2012; Kalinic and Krisp 2018).

Some difficulty was encountered in employing the KDE tool, since it refused to work when used off ECU's campus. The reason for this is unclear, but was possibly due to issues with the university's licensing procedure for ArcGIS software downloaded to students' personal computers. On campus, the tool worked as intended and a series of density analyses were produced in accordance with Bright's suggestions. Planar and geodesic methods yielded similar results, while an altered search radius from the default yielded data that was not usable.

Over the density cloud was superimposed a manually drawn grid of cells that were four by four nautical miles. This is the same cell size used in the planning phase of the *Central America* search and slightly smaller than those used by Bright in his thesis. This size was chosen for ease of reference, rather than detailed search planning; the grid can easily be broken into smaller cells when and if a search is launched (Stone 1992; Bright 2012). Drawing the grid was an involved process. First, a measured grid was superimposed over the map in layout view, using the grids and graticules wizard under the Grids tab in Data Frame Properties. The unit of measurement was set to nautical miles, and the grid cell size was set at 4 by 4 nautical miles, as mentioned. The author then traced the grid cells using the rectangle tool in the drawing toolbar, manually adjusting each tracing to ensure proper overlap and coverage inside the grid. The tracings were colored red to ensure that they could be seen underneath the white cells of the measured grid. The completed drawing was then converted into a map layer with the Convert Graphics to Features tool so that it could be more easily moved and manipulated.

This grid was used to highlight priority areas in which to search for *Rockefeller*, with greater priority given to the areas surrounding the position data from Scenarios 1 and 2. As it is currently unknown what search equipment is needed or available to look for *Rockefeller*’s wreck, the remainder of data processing was relatively simple.

Also included were potential sinking locations as mapped in NOAA’s 2013 risk assessment summary for *Rockefeller*, as these provided a useful point of comparison (refer to FIGURE 2.9). The image was added to the GIS and geo-rectified, and the potential locations were checked for coordinate data with ArcMap’s Identify tool. These coordinates were then logged in the spreadsheet and added to the GIS. The other major features of the image were drawn in a shapefile that was also added to the GIS to be used as points of reference later. When importing the image, it was found that the scale bar at the bottom measured only 19 nmi in GIS, though it was labeled as 24 nmi. This did not affect final calculations, though it was a curious anomaly.

The Coast Guard confirmed via email that the data sent to them was sufficient to run a SAROPS simulation (Matthew Mitchell 2022, pers. comm.). The simulation was created by

Senior Chief Petty Officer Ian Brown of the USCG and forwarded to the author for analysis. The process of generating simulations in SAROPS was briefly discussed in the previous chapter, but will be recapitulated here in detail.

The SAROPS program relies on several factors to generate its probability maps. The key data is that directly relating to the lost person or vessel, including physical descriptions, last known position (LKP), and the weather and sea conditions prevailing in the area. LKP data may be obtained from eyewitnesses or distress calls, while weather and sea conditions are acquired from the Environmental Data System (EDS), which is housed at a Coast Guard station in West Virginia. The EDS collects and collates information on sea states and weather conditions from US Navy and NOAA sources, then relays this information to Coast Guard command stations around the country for use with SAROPS. With this system, the search maps that SAROPS generates can be manually updated with up-to-the-minute information from on-scene SAR assets, or automatically updated with EDS data every hour. This represents a major improvement over SAROPS' predecessor systems, the Computer Assisted Search Program (CASP) and Joint Automated Worksheets (JAWS). The CASP could only be updated with new weather information every twelve hours, the JAWS could not be updated at all, and both required a great deal of manual input (Richardson and Discenza 1980:667; Roylance 2007:4D; Turner et al. 2008:1; Ian Brown 2022, pers. comm.).

This accumulated data is fed into the SAROPS simulator program, which is a software add-on for Esri's ArcGIS. This software then creates a Markov chain Monte Carlo simulation to generate a probability density map for a given search-and-rescue incident. This is a system which relies on two separate methods of calculating probability: the Monte Carlo method and the Markov chain (USCG 2008; Kratzke et al. 2010:1-2).

The Monte Carlo method is a computational method used to solve for unknown or uncertain variables in a given scenario. It was first developed by Stanislaw Ulam and John von Neumann, two physicists who were working on nuclear weapons projects at the Los Alamos National Laboratory. While considering how to solve the problem of calculating neutron diffusion, Ulam fell sick and passed his downtime by playing solitaire. He wondered how one might compute the odds of successfully completing a game and concluded that the best way to do so would be to play one hundred games and count the number of successes. He and von Neumann developed the basic idea further, ultimately creating a computer program that successfully calculated neutron diffusion rates for fission weapons and was later used to build the first hydrogen bomb (Eckhardt 1987:131-133). From these belligerent beginnings, Monte Carlo simulations have become a common tool for a wide variety of industries and businesses, including risk analysis, financial analysis, medical physics, clearance of unexploded munitions, industrial engineering, and search and rescue (Frost and Stone 2001:3-5-3-7; Kroese et al. 2014:387-389).

Monte Carlo simulations are used to calculate the probable results of a scenario with a variety of variables. For each of these variables, the user must assemble a range of possible values and feed them into the simulator. The simulator then repeatedly calculates possible results of the scenario using randomly selected variables from the range of values in order to determine the probable outcomes. These outcomes are expressed as probability distributions, showing the range of possible outcomes according to the likelihood of their occurrence. As an example, one could use a Monte Carlo simulation to calculate the probability of a player winning a certain number of rounds in blackjack or craps by simulating the likely outcomes of the card draws and dice rolls (Brownlee 2019).

However, Monte Carlo simulations are not suitable for more complex problems, since large parameter sets (i.e., attempting to determine the outcome of rolling 100,000 six-sided dice as opposed to 100) create an unfeasibly large set of potential results. Likewise, a standard Monte Carlo simulation relies on the assumption that each of the random values for which it calculates results are independent of each other and may be drawn independently. This assumption skews the results in an undesirable fashion when one is working with interrelated variables. The solution to this problem is to use a Markov chain (Brownlee 2019).

A Markov chain computes a series of variables by starting at a given point and calculating each successive variable based on the value of the last variable generated, creating a stochastic chain that allows for greater flexibility in generating the final probability density. The following example may help to explain the process. Imagine a board game that involves rolling dice to move, such as Monopoly or Chutes and Ladders. Each time a player rolls the die, they create a uniform probability distribution with six possible variables (the face values of the die). As the player moves around the board, each position that their piece lands on is determined from this range of probabilities, as well as their previous position and the rolls of the die. These positions form a Markov chain (Brownlee 2019).

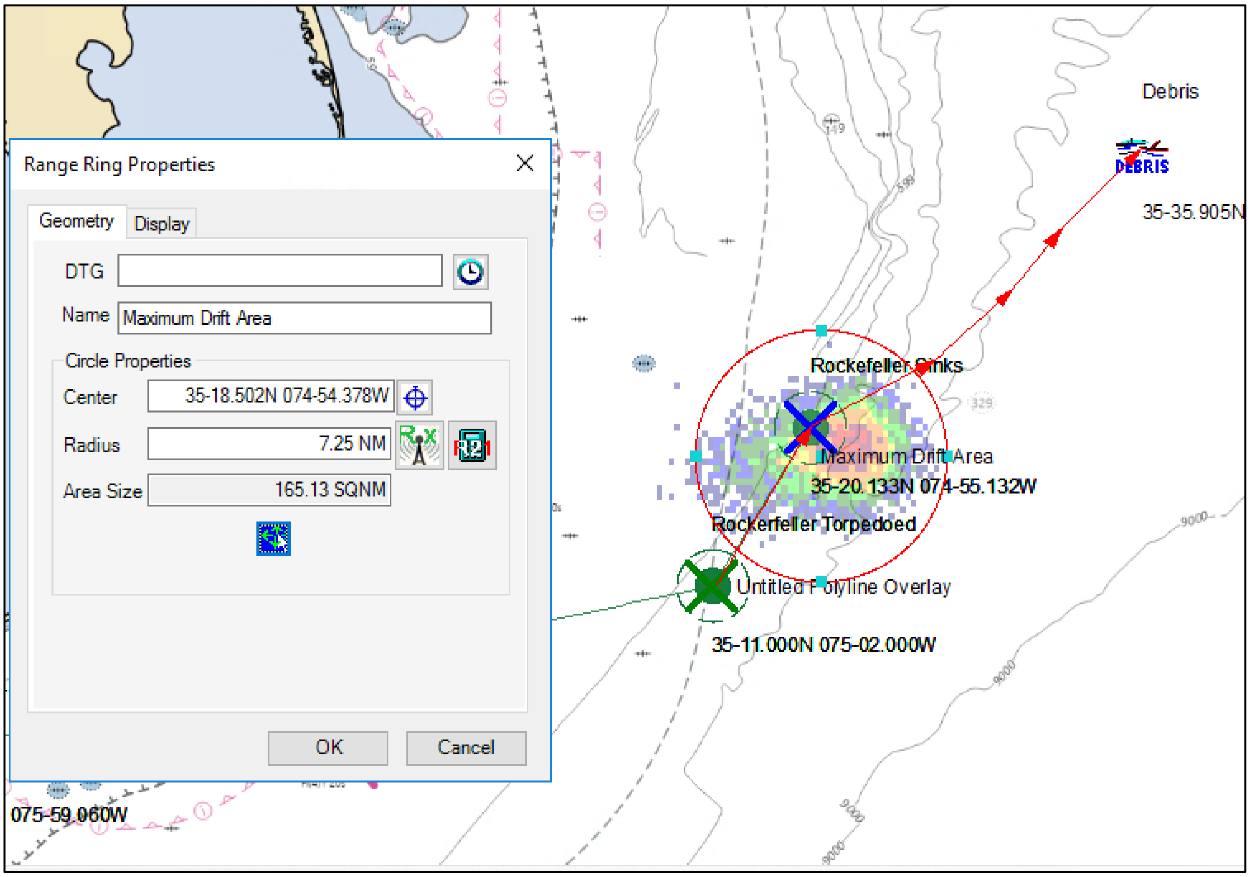
SAROPS functions on the combined principles of Monte Carlo and the Markov chain, creating a probability density function by sequentially generating random variables based on the data that is fed into the program. The resulting simulation is, however, only as good as the data on which it is based. As mentioned previously, this data is normally acquired from eyewitnesses, on-the-spot rescue teams, and the EDS in West Virginia, which enables the production of highly accurate maps (Roylance 2007:4D). In this case the simulation had to rely on the historical data outlined in Table 4.2, which added a greater degree of uncertainty to the simulation’s outcome.

Chief Brown noted the inherent challenges of developing this simulation when explaining the process to the author (Ian Brown 2022, pers. comm.).

To create the simulation for *Rockefeller*, Chief Brown began with the data package that the author sent to the Coast Guard. He consulted with Dr. Cristina Forbes, a Coast Guard oceanographer, who helped him format the data for SAROPS, calculated possible wind and current speeds, and proposed that he create three different scenarios based on possible weather conditions at the time. After this consultation, Chief Brown fed the resulting data into the SAROPS simulator. He explained that the maximum vessel length that could be input into the program was 300 feet, since the program is tailored toward searching for lost individuals and small craft, not large vessels. As *Rockefeller* was 554 ft in length, this meant that he had to split the simulated vessel into two parts and recombine the results later. He also input the estimated current, wind, and drift speeds from the historical data and his consultations with the oceanographer. All times in the program were recorded in Greenwich Mean Time (GMT). He ran three different scenarios based on the data, which form the basis of Scenarios 1 and 2 (a.k.a. the "Long Goodbye" and the Degen Scenario) as previously outlined in this chapter (Ian Brown 2022, pers. comm.).

For the first iteration of the scenario, Chief Brown used a wind speed of 0.87 kt and a current speed of 0.66 kt until time index 1700 GMT (1300 EWT), representing the likely point at which *Rockefeller* would have been in the middle of the Gulf Stream and experiencing its full strength, which he calculated at 1.5 kt. For the second iteration of the scenario, he used a wind speed of 1.74 kt and the same current estimates as in the first iteration, with *Rockefeller* entering the middle of the Gulf Stream at time index 1700 GMT. For the third iteration, he again used the same current estimates and a wind speed of 2.6 kt. Each of these iterations produced a probability density cloud illustrating the potential sinking locations for *Rockefeller* as based on the estimates fed into the program. For each stage of the scenarios, he placed a ring around the density cloud to indicate the general size of the area of potential drift, given in square nautical miles (Ian Brown 2022, pers. comm.). The results of this process are shown below (see FIGURES 4.3-4.14).

Chief Brown sent the probability maps to the author as a series of screenshots in PNG format. These screenshots were cropped to remove extraneous details, then added to the GIS and georectified so that the density clouds could be compared to the GIS work done previously. These results will be discussed in the next chapter.



Range Ring Properties

DTG:

Name: Maximum Drift Area

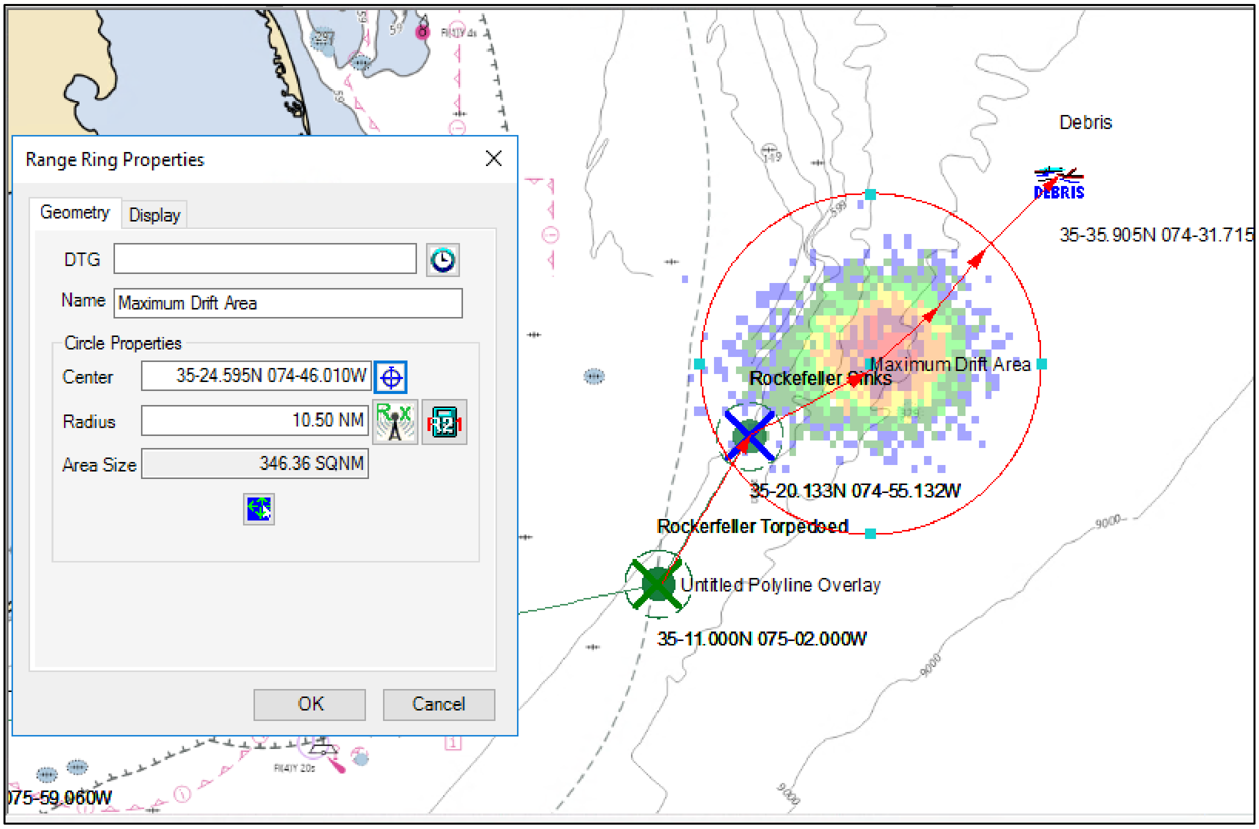
Circle Properties

Center: 35-18.502N 074-54.378W

Radius: 7.25 NM

Area Size: 165.13 SQNM

FIGURE 4.3. Probability density map for SAROPS scenario 1 at time index 1900 EWT 28 June (0000 GMT 29 June). Drift range ring (red circle) is 165 square nautical miles. (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).



Range Ring Properties

DTG

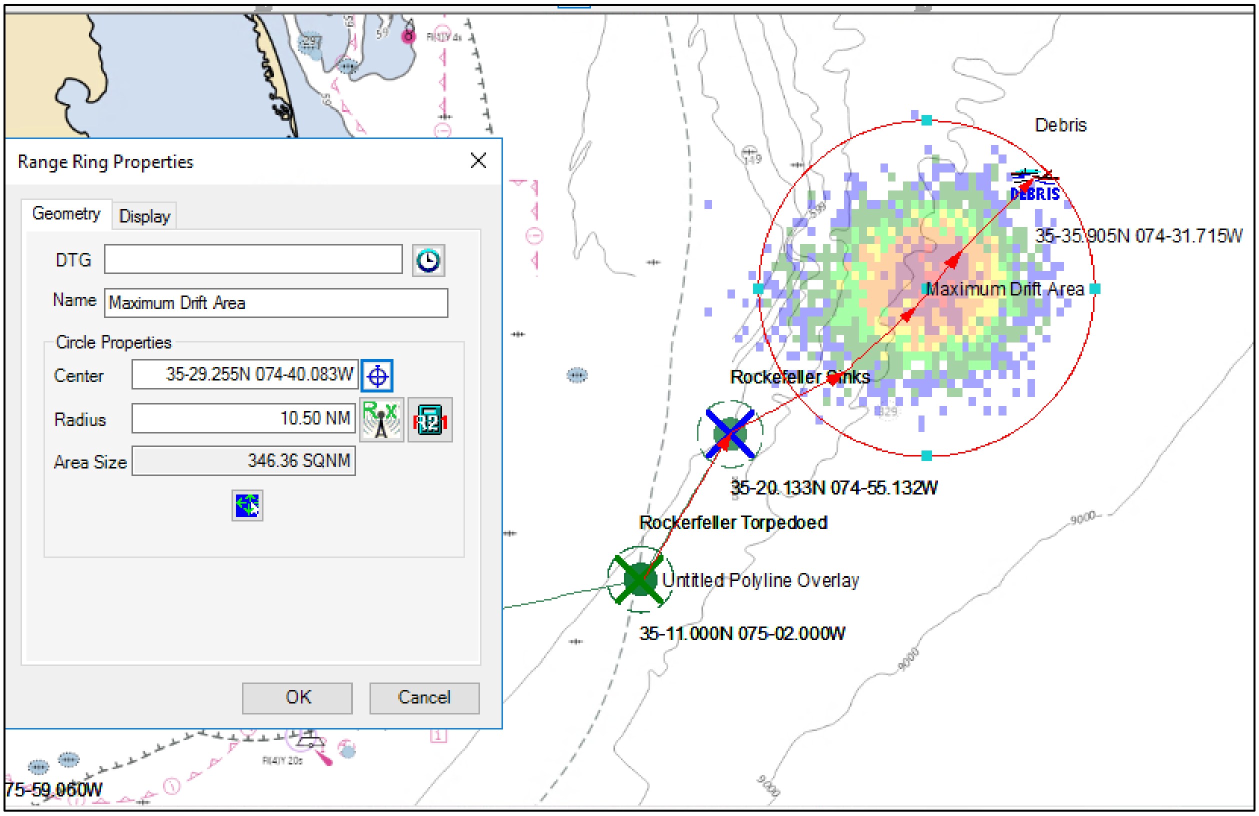
Name: Maximum Drift Area

Center: 35-24.595N 074-46.010W

Radius: 10.50 NM

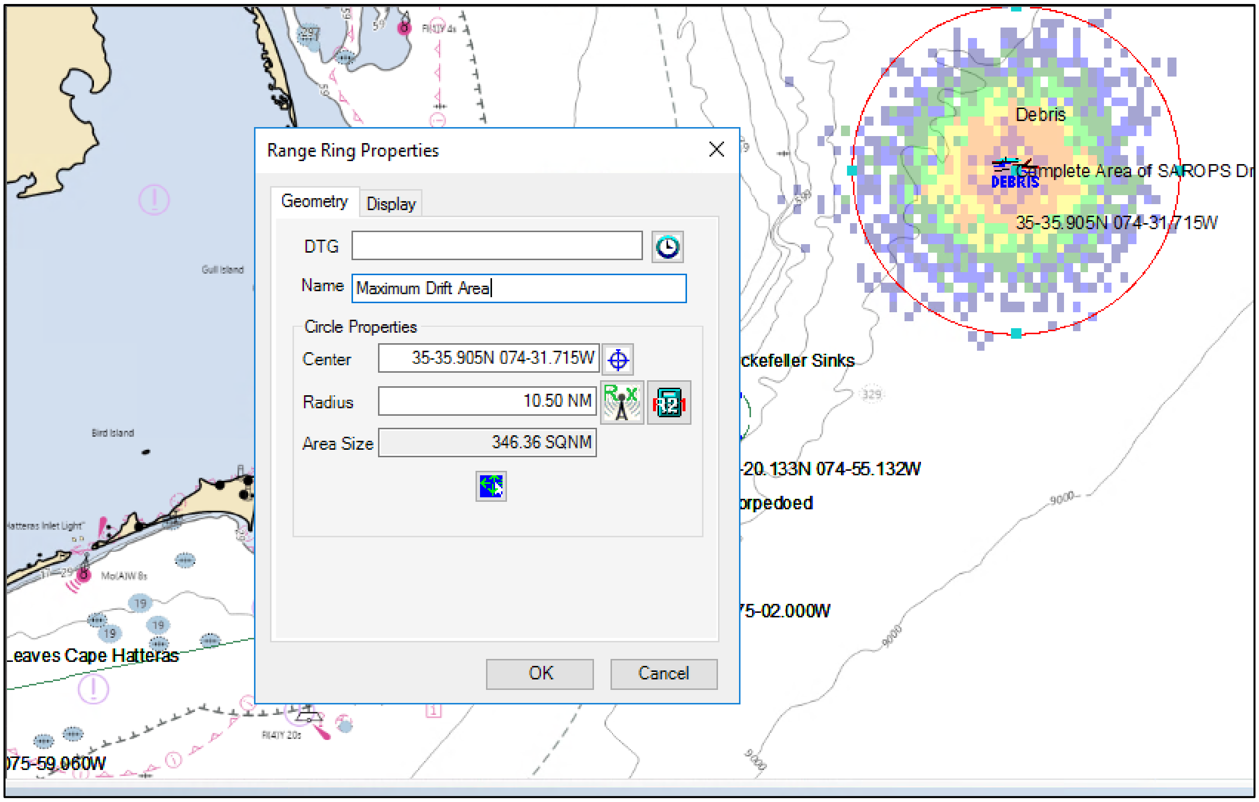
Area Size: 346.36 SQNM

FIGURE 4.4. Probability density map for SAROPS scenario 1 at time index 0100 EWT 29 June (0600 GMT 29 June). Drift range ring is 346 square nautical miles. (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).



DTG:
Name: Maximum Drift Area
Center: 35-29.255N 074-40.083W
Radius: 10.50 NM
Area Size: 346.36 SQNM

FIGURE 4.5. Probability density map for SAROPS scenario 1 at time index 0500 EWT 29 June (1000 GMT 29 June). Drift range ring is 346 square nautical miles. (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).



Range Ring Properties

Geometry | Display

DTG:

Name: Maximum Drift Area

Circle Properties

Center: 35-35.905N 074-31.715W

Radius: 10.50 NM

Area Size: 346.36 SQNM

FIGURE 4.6. Probability density map for SAROPS scenario 1 at time index 1100 EWT 29 June (1600 GMT 29 June). Drift range ring is 346 square nautical miles. (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

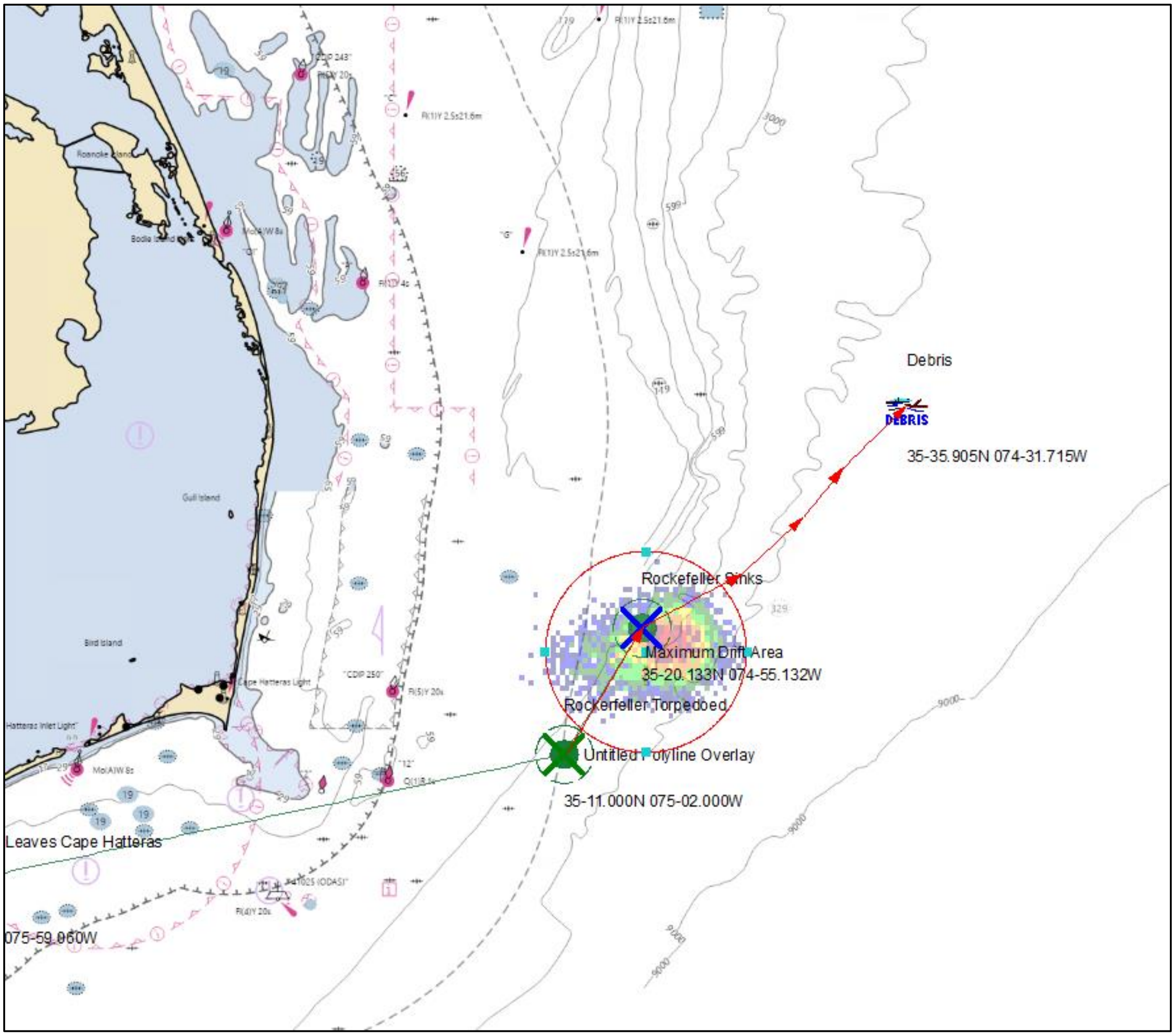


FIGURE 4.7. Probability density map for SAROPS scenario 2 at time index 1900 EWT 28 June (0000 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

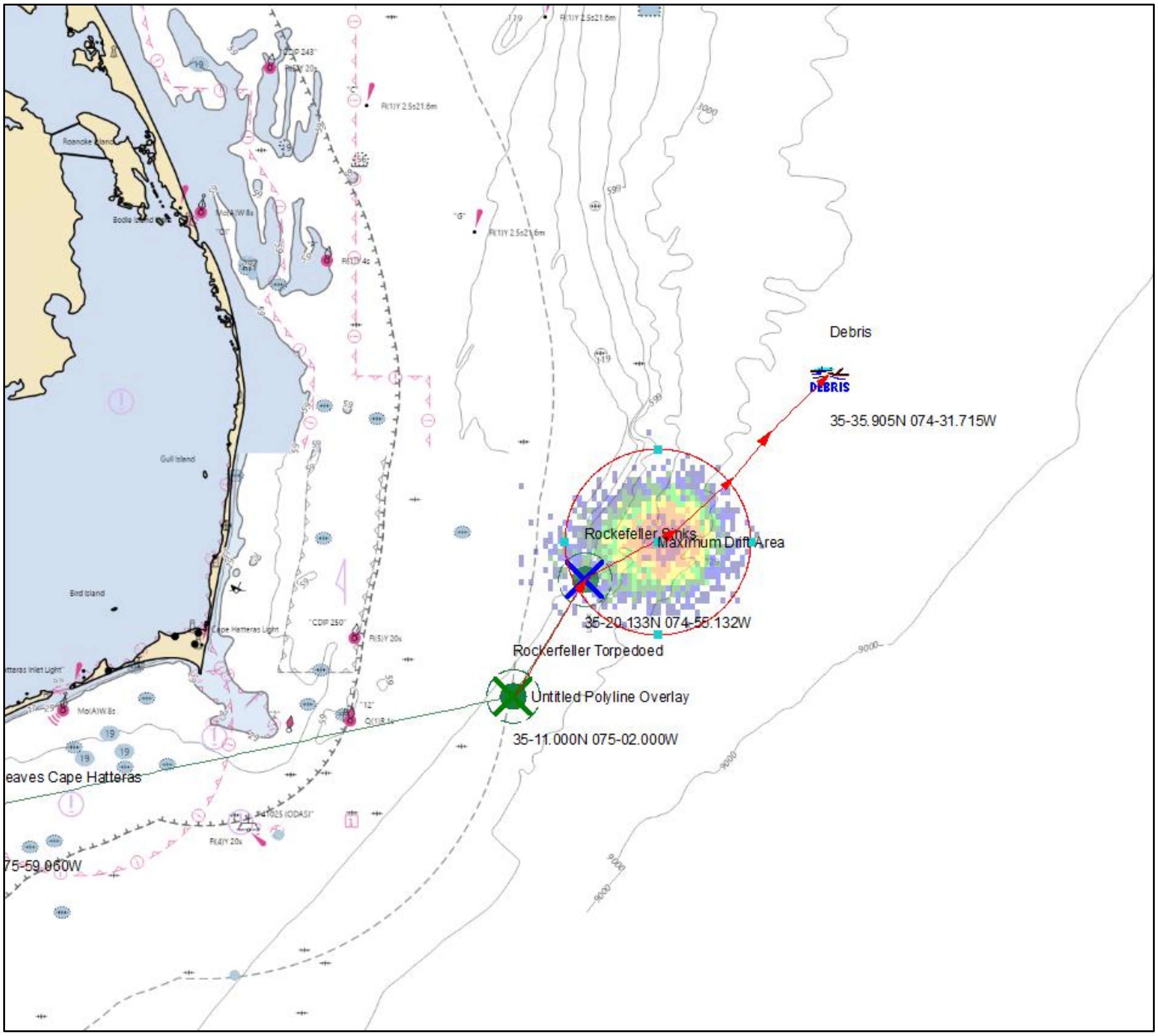


FIGURE 4.8. Probability density map for SAROPS scenario 2 at time index 2300 EWT 29 June (0400 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

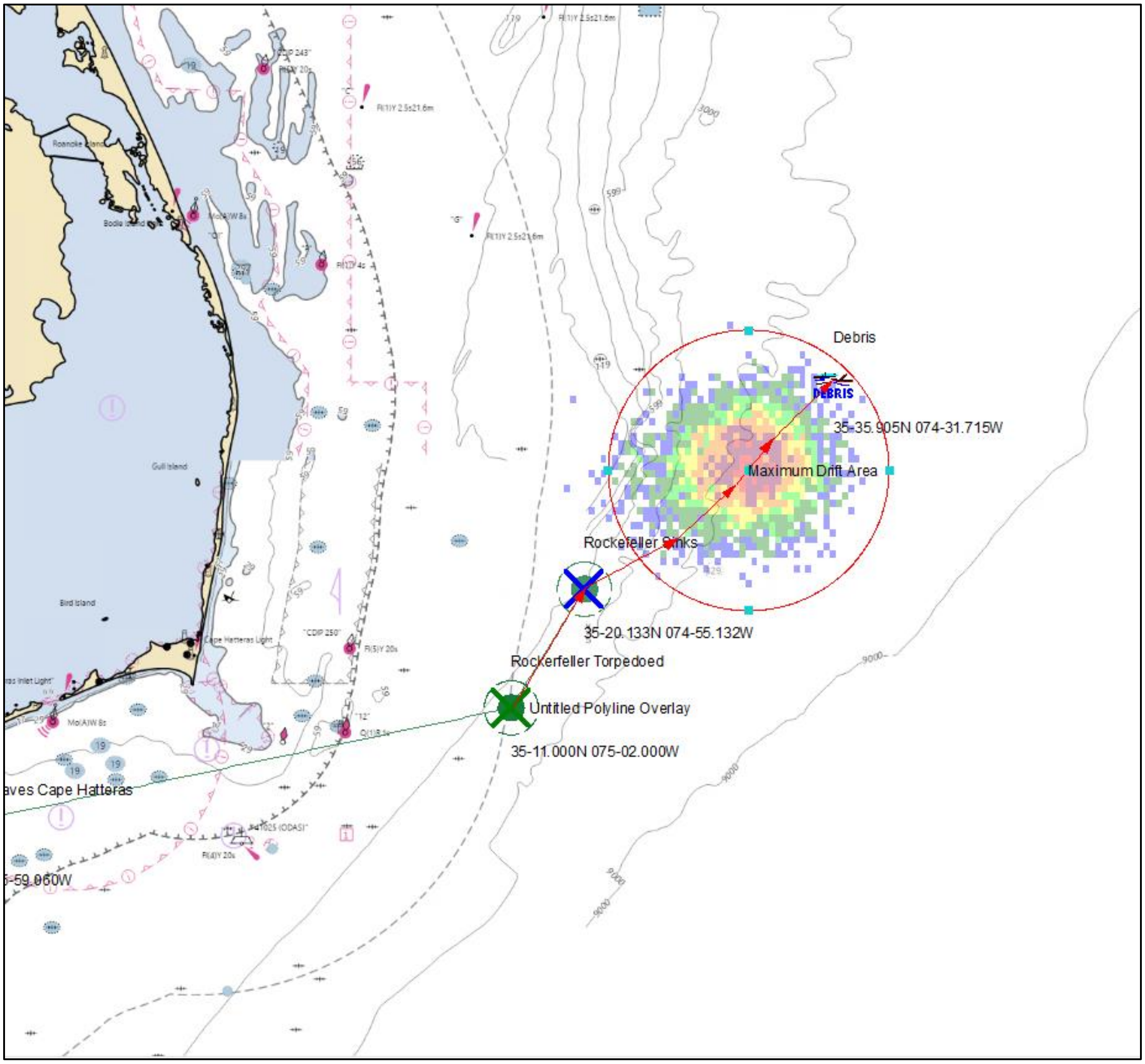


FIGURE 4.9. Probability density map for SAROPS scenario 2 at time index 0500 EWT 29 June (1000 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

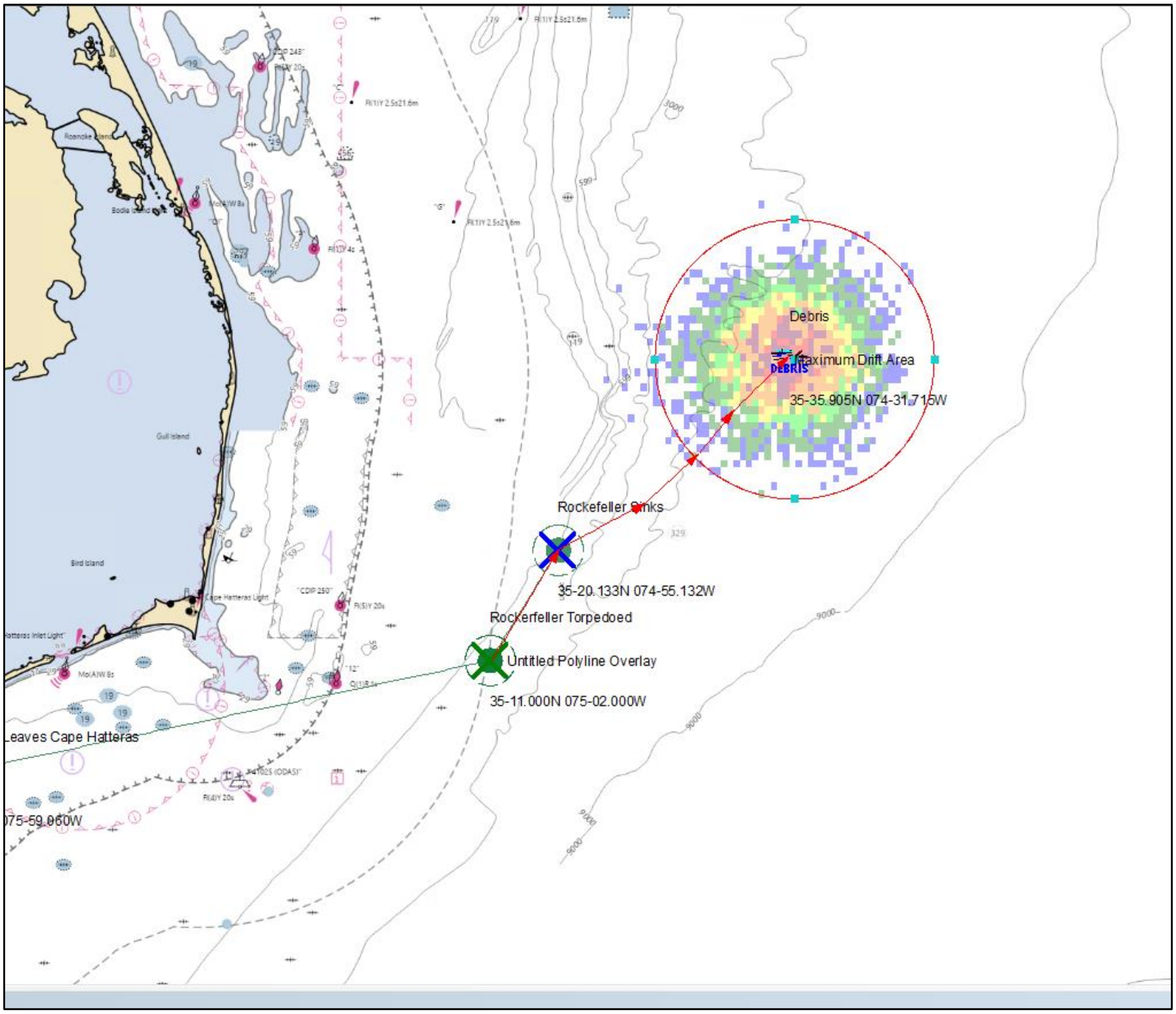
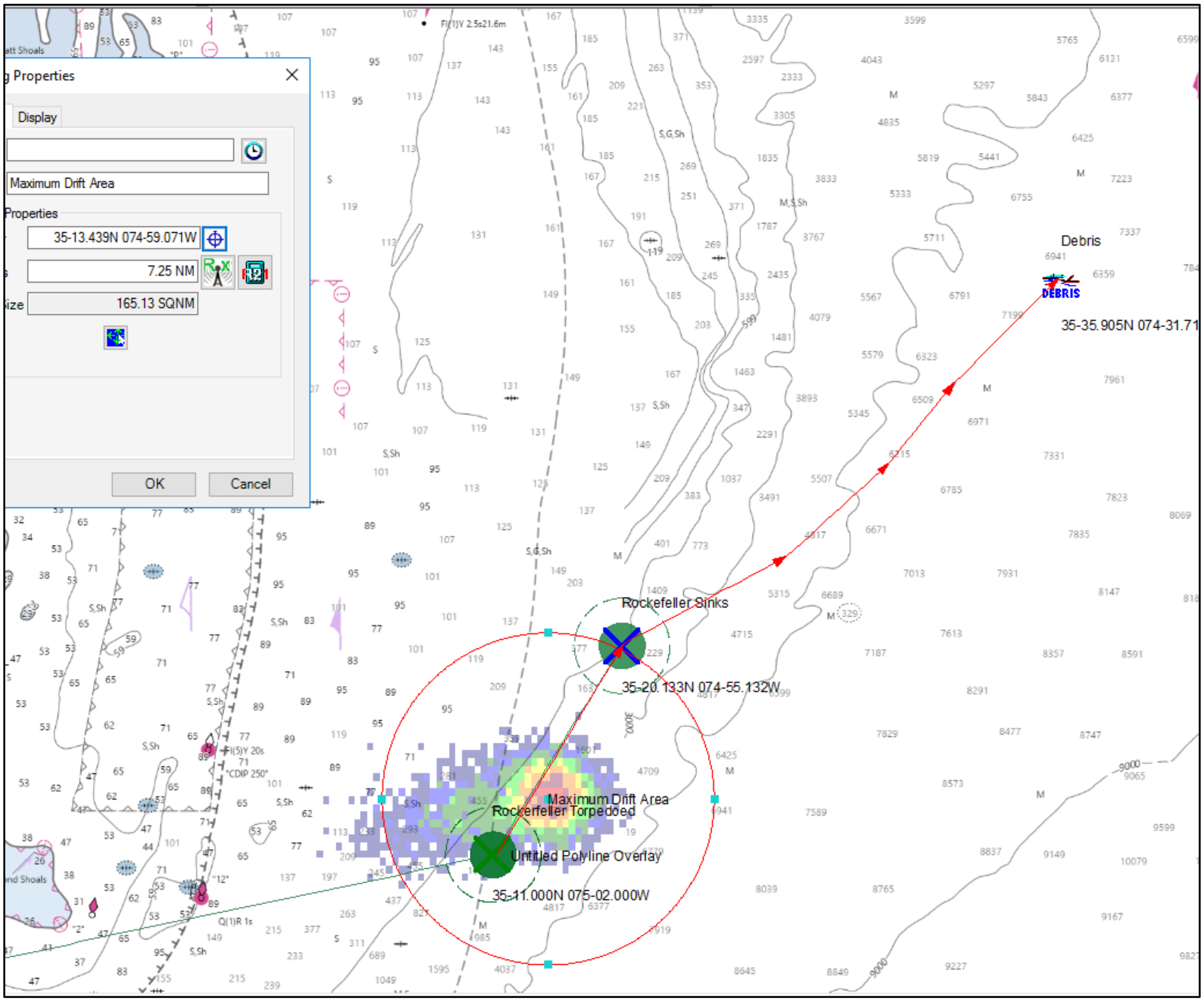


FIGURE 4.10. Probability density map for SAROPS scenario 2 at time index 1100 EWT 29 June (1600 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).



Maximum Drift Area

35-13.439N 074-59.071W

7.25 NM

ize 165.13 SQNM

FIGURE 4.11. Probability density map for SAROPS Scenario 3 at time index 1400 EWT 28 June (01900 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

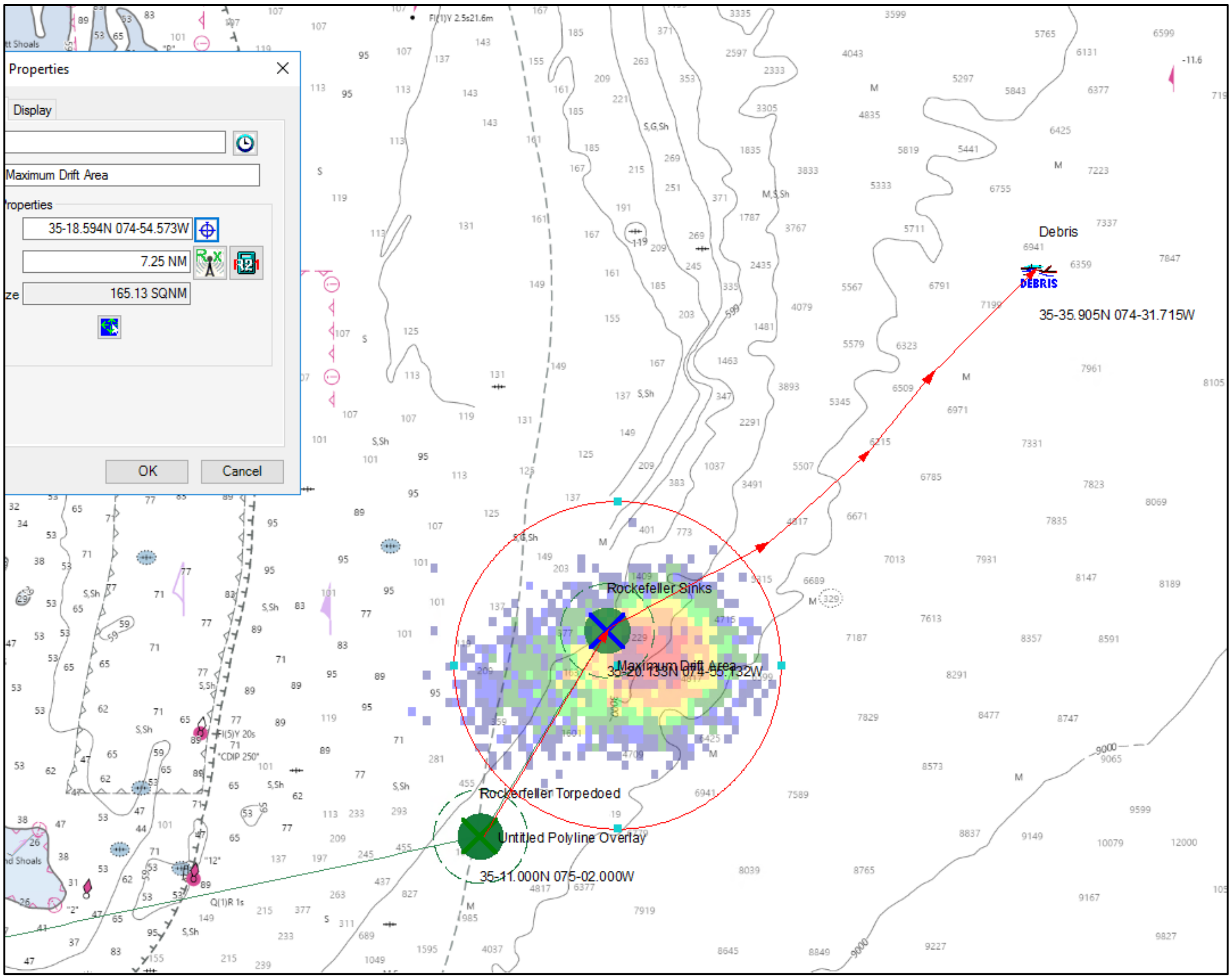
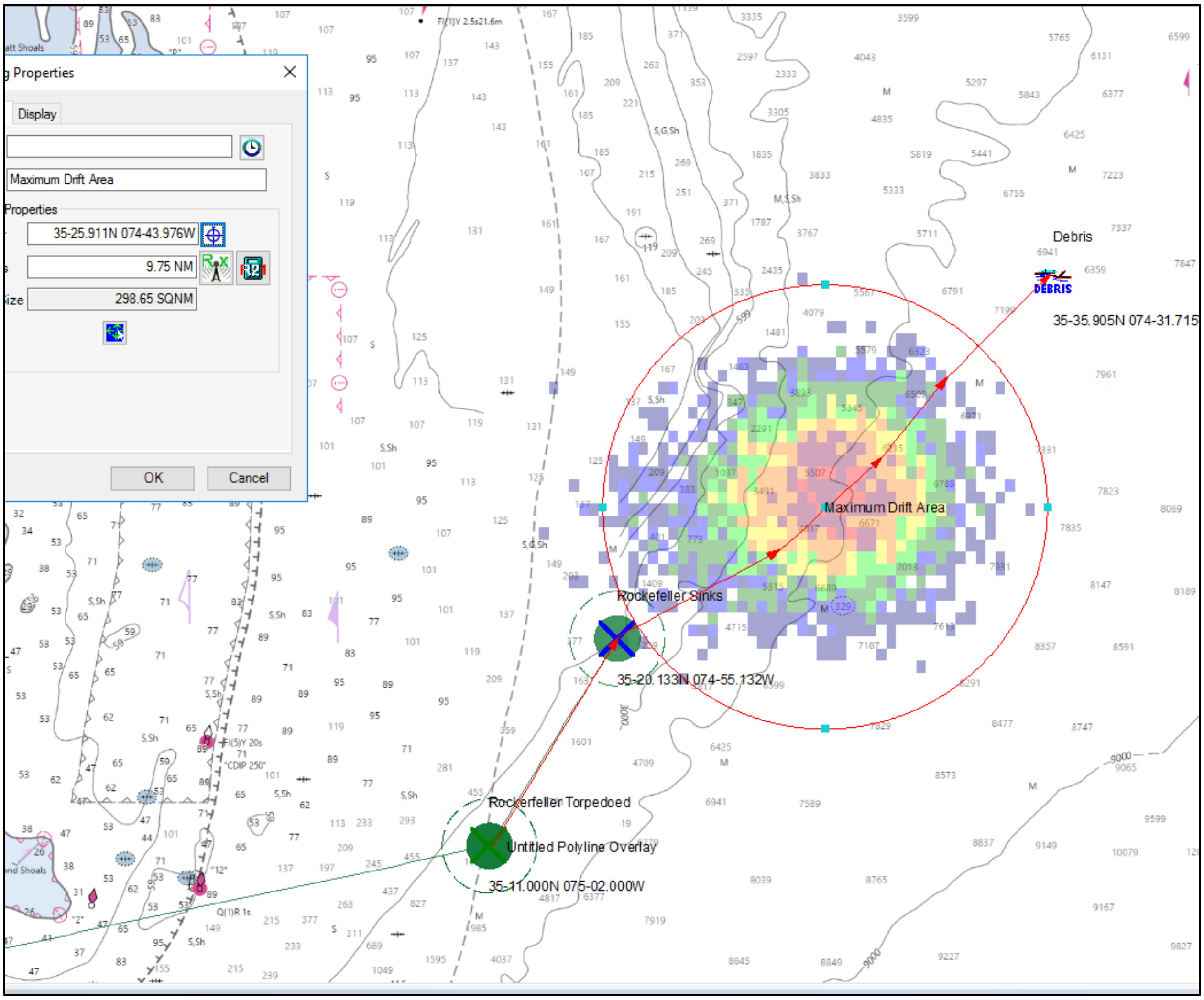


FIGURE 4.12. Probability density map for SAROPS Scenario 3 at time index 1900 EWT 29 June (0000 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).



Maximum Drift Area
35-25.911N 074-43.976W
9.75 NM
ize 298.65 SQNM

FIGURE 4.13. Probability density map for SAROPS Scenario 3 at time index 0200 EWT 29 June (0700 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

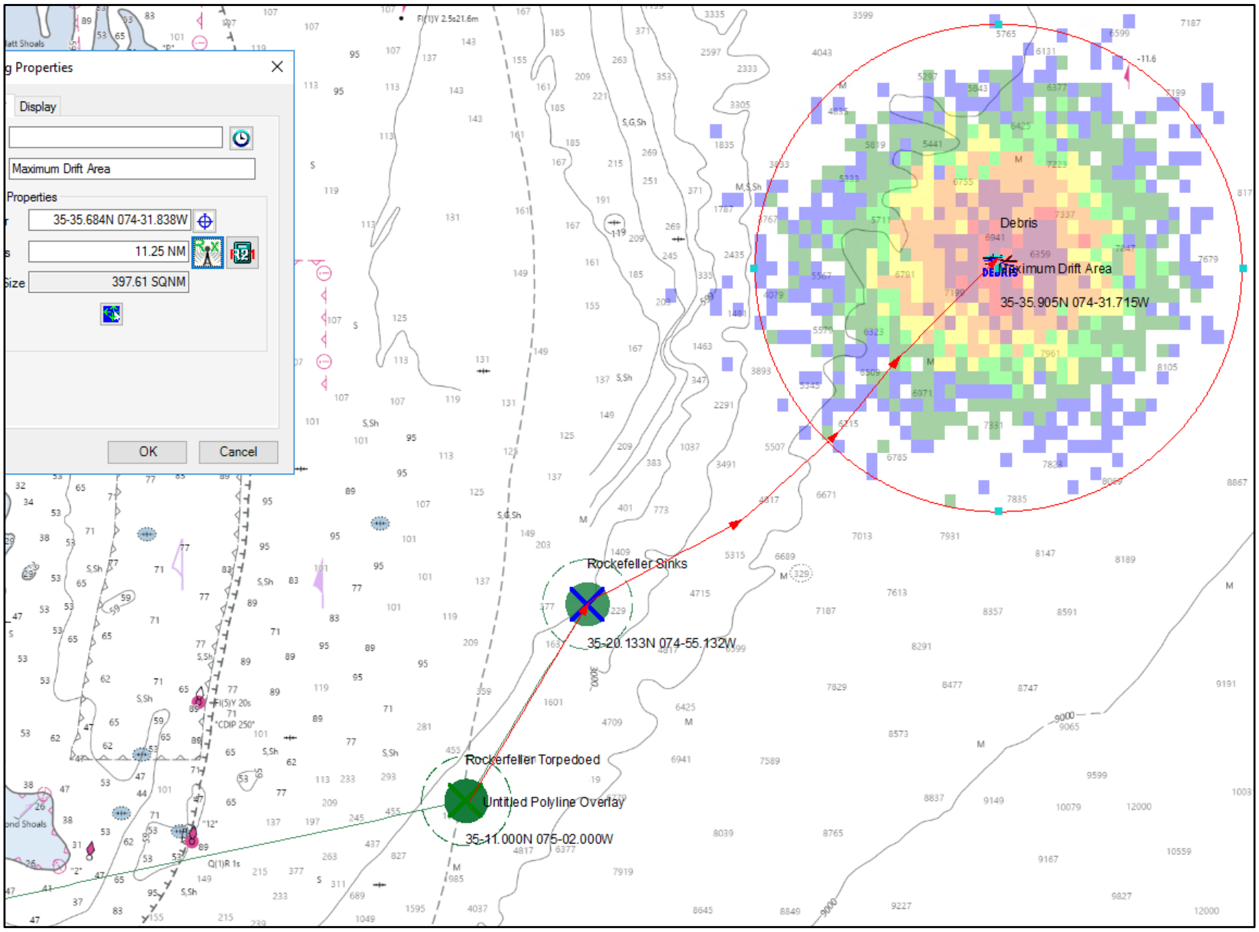


FIGURE 4.14. Probability density map for SAROPS Scenario 3 at time index 1100 EWT 29 June (1600 GMT 29 June). (Sources: Haight 1942; OCNO 1942b-d; ONI 1942a; USCG 1942; USCG 1944b; Standard Oil 1946; map created by Senior Chief Ian Brown, USCG).

Phase Three: Search

The third phase, which was not completed in the course of this research, is utilizing these maps and models to search for *Rockefeller*. When and if such a search is undertaken, it will be possible to test the theories and models developed during this study, refining them along the way with data acquired from field operations and hopefully leading to a successful conclusion for *William Rockefeller*'s story. A search may be some time coming, however; all available data indicates that *Rockefeller* probably lies in deep water off the edge of the American continental shelf, meaning that a dedicated survey platform and advanced remote sensing equipment will be needed. As a search expedition of this scale is beyond the equipment and funding available to ECU’s Maritime Studies program, it will require buy-in and funding from other interested parties, such as the Coast Guard, NOAA, or the Ocean Foundation. More will be said about this in Chapter Seven.

CHAPTER FIVE: A NEW PROPOSAL—DID X MARK THE SPOT?

Introduction

This study has collected and analyzed a variety of primary sources to reconstruct *William Rockefeller*'s movements during its last hours afloat and has used this data to generate explanatory models and maps that may one day enable a search for the wreck. Initial data processing has been accomplished, with historical, spatial, and analytical information collected from primary and secondary sources and used to define three probable scenarios as to *Rockefeller*'s sinking. These scenarios have been weighted according to the quality of the data used to develop them. Two of the scenarios align quite closely with each other and with what is known and accepted about *Rockefeller*'s loss, while the third is a spatial and historical outlier. While nothing will be discounted at this stage, this outlier scenario is considered less likely than the first two and has been weighted accordingly.

The scope of this chapter is necessarily limited. As mentioned previously, there is no way to test the soundness of the maps and models created in this study without undertaking a search for *Rockefeller*'s wreck, and such an expedition is not currently in the offing. That said, it is possible to examine the results of these maps and models to determine their points of agreement and disagreement with previous research.

Here will follow a breakdown of the data gleaned from the primary and secondary sources collected for use in this study, the construction of scenarios generated from this data, and a critical examination of the maps and models created using these scenarios. The first item that will be considered is the historical information collected from the primary sources on *Rockefeller*'s sinking, as this is the basis of all the work that has been done in this study. After this will be a discussion of the scenarios constructed using this information, as well as a discussion of their subjective probabilities as determined by the author’s analysis. Finally will come an examination of the maps and models created using these scenarios.

Historical Accounts of **Rockefeller***’s Sinking*

There exist several eyewitness accounts of *William Rockefeller*’s last day afloat, which has proven helpful in constructing possible scenarios for its loss. The following information has been derived from contemporary sources and publications:

a. *Rockefeller* was steering a course of 045 true (i.e., true north), or directly northeast, when torpedoed (OCNO 1942b).

b. Currents in the area were then known to be highly consistent in terms of flow and direction. Annual measurements from 1919-1928 indicated that the Gulf Stream flowed northeast at an average rate of ~0.66 knots during the month of June (Haight 1942:52).

c. Logged weather data from *Rockefeller*’s escort indicates that the weather on 28 June was generally fair and calm, with winds from the southeast at speeds not exceeding 3 mph or 3 knots (kt) the entire day (note that 1 mi = 0.86 kt) (USCG 1942b).

d. *Rockefeller*’s engines were shut down prior to the crew abandoning ship, and when *CG-470* departed the scene of the attack, the tanker was moving no faster than 1.5 kt, a rate of speed commensurate with the known and estimated current and weather variables (OCNO 1942b; USCG 1944b).

This information militates against any direction of travel for *Rockefeller* other than northeast. In turn, this means that three quarters of the compass can be safely eliminated from subsequent calculations and all efforts focused on *Rockefeller*’s known direction of travel. This is a considerable advantage over some of the other maritime search efforts discussed in previous chapters, including *Scorpion*, *Titanic*, and *Central America*, all of which had large and ill-defined search areas (Ballard 1986; Stone 1992; Craven 2001).

Discounting the unusual outlier of the coordinates as given by uboat.net, the accumulated data from the various scenarios has further narrowed the search area. NOAA's risk assessment package originally proposed that it might be necessary to search up to 33 miles out from *Rockefeller*'s last known position (LKP), giving a total search area of 750 nautical miles (Basta et al 2013b:6) (Refer to FIGURE 2.9). This study has determined that this is likely not the case. Taken together, the available data on wind and currents suggests that *Rockefeller* did not drift far before it sank. In a supplement to the official summary of statements taken from the tanker's crew, the US Navy estimated that the ship drifted no more than 15 nautical miles (nmi) from the place where it was attacked before foundering (OCNO 1942c). A calculation of just over 11 hours of drift at 1.5 kt, from 1216 to 2338, returns a distance of ~16.5 nmi, quite close to this estimate. Even Scenario 3, which suggests that the tanker was sunk sometime early the following morning, still does not allow a great degree of drift; a calculation of 17 hours of drift at ~1.5 kt gives a distance of ~25.5 nautical miles. It is almost certain that *Rockefeller* drifted no farther than this before sinking. Given the weight of the data, it is probable that it drifted no more than 16-17 nm. Processing this data into a set of GIS maps and predictive models has made it possible to narrow the potential search area even further.

Another set of variables concerned the positions given for *Rockefeller* when it was attacked, as this position varies from source to source. This is to be expected, given the previously mentioned confusion that typically accompanies wrecking events and the fact that position-fixing technology of the time was relatively primitive. Captain Stewart was logging

Rockefeller's position in the chart room when *U-701* torpedoed the ship. He later gave this position as 35° 11' N 75° 02' W, approximately 16 miles east-northeast of the Diamond Shoals Lighted Buoy (OCNO 1942d). The supplement to the summary of statements made by *Rockefeller*'s crew alternatively gives the ship's position when attacked as 35° 07' N 75° 05' W, to the south and west of Stewart's position (OCNO 1942c). Another position is given by uboat.net, 35° 11' N 75° 07' W, which is to the south of both previously mentioned (uboat.net 2021). This study assumes that Stewart's data is the most reliable, given that he had just taken a noon position fix and was logging it when his ship was hit, but does not discount the others given.

Rockefeller*'s Sinking: Three Possible Scenarios*

The data derived from this information has further eliminated several other possibilities. Here are presented three scenarios created using all acquired data regarding what is known or conjectured about *Rockefeller*'s final hours afloat. These scenarios have been the basis of the mapping and modeling work done in this study. They can be summarized thus:

- Scenario 1: *Rockefeller* sinking on its own after drifting and burning for just over 11 hours
- Scenario 2: *Rockefeller* being sunk by a second torpedo from *U-701* after ~12 hours adrift
- Scenario 3: *Rockefeller* being scuttled by Coast Guard aircraft on the morning of 29 June

The first scenario is *prima facie* the most reliable, since it is supported by the majority of primary sources on *Rockefeller*'s sinking. The only anomaly is the fact that *Rockefeller* apparently sank on its own in this scenario, which the Navy regarded as unusual, since the tanker had sustained "relatively minor damage". Indeed, several of *Rockefeller*'s stablemates in the Standard tanker fleet had survived torpedo strikes and were later repaired and put back into service, like *Paul H. Harwood*, *Esso Bolivar*, *Esso Nashville*, and *J.A. Mowinckel*. Other tankers, like *Esso Boston* and *R.W. Gallagher*, had been hit by multiple torpedoes or shells before going down, and even then, it had taken them hours to sink (Standard Oil 1946:113-124, 155-160, 190-192, 328-330, 356-358, 364-371).

It is certainly possible that Degen's account of events is unreliable or inaccurate, since it was first acquired after he had endured 49 hours adrift in the ocean, an ordeal which nearly killed him and likely had a deleterious impact on his memory and cognitive processes. Nevertheless, he is quite clear as to many details of his alleged second attack, claiming to have closed in on the surface and sunk the burning tanker from 1,000 yards, allowing several members of his crew to watch the attack from the submarine's bridge (Offley 2014:210-212). On this basis alone, his account is persuasive. Also, there were no other damaged ships known to be in the area at the time; if Degen did not fire on *Rockefeller*, then what was he shooting at?

The only alternative is to suggest that he invented the story from whole cloth to boost his own reputation. U-boat skippers, as with their contemporaries in the American and Japanese navies, are known to have made exaggerated or mistaken claims regarding their attacks on enemy shipping, but it was unheard of for one to blatantly lie about a successful sinking. Moreover, Degen had up to this time conducted what was considered an exceptional patrol, having sunk a Coast Guard patrol vessel with his U-boat's deck gun and claimed sinkings on two freighters with torpedoes (both ships managed to limp into port). He had also laid a minefield just outside the approaches to Chesapeake Bay that sank or damaged five more vessels, earning him a congratulatory message from Admiral Karl Dönitz. Indeed, this proved to be the most successful mining operation undertaken in American waters during the war (Morison 1946:156;

Blair 1996:607-608; Hoyt 2008:3-4). The idea that Degen would feel the need to invent a successful sinking to burnish his record seems unlikely, to say the least.

On the other hand, it is difficult to credit the idea that the Coast Guard would be so mistaken in their own account of the event, but the weight of evidence and opinion seems to be against them. The same questions arise regarding their account, however. As there were no other damaged ships in the area, what else could they have bombarded? It further seems highly unlikely that the Coast Guard would have invented the account. There is no good reason for them to do such a thing. If they had been claiming to have sunk Degen's U-boat, the case might be made that they were accidentally or deliberately exaggerating an unsuccessful attack. Given that they were planning to scuttle a burnt-out derelict, however, it is unlikely that they would do such a thing. Nevertheless, it is significant that few secondary sources accept this account of events, or even bother to mention it.

A caveat emerges here, of course; just because something is improbable does not mean it is impossible, and historians and other authoritative sources have been wrong before. As an example: *U-869* was a Type IXC/40 U-boat that was sunk off the coast of New Jersey in 1945, relocated in 1991, and positively identified in 1996 by a group of sport divers. Accountings of postwar U-boat losses undertaken by British, German, and American sources had all concluded that *U-869* was sunk off Casablanca by the American destroyer USS *Fowler* and the French patrol craft *L'Indiscret.* This was based on the premise that the U-boat had received updated orders from BdU instructing it to reroute to Gibraltar from its original patrol area off the approaches to New York, due to a greater expenditure of fuel than expected on its transatlantic crossing. At the time US naval intelligence had not accepted the kill claims from either ship, but during the postwar assessment process, the attack had been upgraded to a probable sinking in order to account for the missing U-boat (Admiralty 1946:23; OCNO 1963:172; Hessler 1989:115; Hoyt 1989:222; Kemp 1997:235; Kurson 2004:253-258). However, once positive identification had been made through the recovery of a knife engraved with a crewmember's surname and a spare parts box bearing the U-boat's hull number, the official histories had to be revised. *U-869* had apparently not received its updated orders and proceeded to its original patrol area off the New York approaches, where it was lost with all hands to unknown causes (Niestlé 1998:239; Kurson 2004:168, 253-258, 321-323). This case illustrates that the accepted or "authoritative" history can be quite wide of the mark, and therefore one should not discount any possibility, no matter how remote it seems.

As of now, based on all available information, this study accepts that Scenario 2 is the most likely scenario for *Rockefeller*'s loss, and will proceed accordingly. Scenario 1 is considered the second most likely, and indeed overlaps with Scenario 2 in most of its particulars. Scenario 3 is considered the least likely of the three. Nevertheless, it will be included in the predictive modeling. As in the case of *Central America*, where the least likely scenario according to Dr. Stone's research proved to be the most accurate, and in the case of *U-869*, where the accepted narrative was simply wrong, it may indeed be that Scenario 3 is in fact what happened to *Rockefeller*. One of the strengths of Bayesian search is that it factors in all possibilities, no matter how remote; therefore, none of the scenarios will be dismissed out of hand. The famous maxim of Sherlock Holmes springs to mind: "[W]hen you have eliminated the impossible, whatever remains, however improbable, must be the truth" (Doyle 1900:93).

The relative weighting of each scenario is given as follows:

- Number 2, or the "Degen Scenario," will be weighted at 45% probability. Degen's account is coherent, complete, and aligns closely with the known facts regarding *Rockefeller*'s sinking. Since it is possible that it overlaps with Scenario 1, it is being weighted at 50/50 odds against that scenario.

- Number 1, or the "Long Goodbye," will also be weighted at 45% probability; as with the Degen Scenario, the facts given in support of this scenario are complete, coherent, and align closely with what is known about *Rockefeller*'s sinking. Since it is possible, even probable, that Scenarios 1 and 2 overlap, they are being weighted at equal odds against each other.
- Number 3, the "Scuttling Scenario," is considered less likely than the first two and is being weighted at 10%. The information of this scenario is not generally accepted by most secondary sources and only appears in a few primary sources, but it is not outside the realm of possibility and will therefore be included.

This weighting is preliminary and may change as further research is done and the author acquires a better understanding of Bayesian statistical modeling. As of now, further work will proceed on this basis. Here follows a more detailed breakdown of the three scenarios.

Scenario 1, or the "Long Goodbye Scenario," is constructed as follows: *Rockefeller* is torpedoed at 1216 EWT and abandoned by the crew shortly thereafter. With its engines shut down, it begins drifting north and east, propelled by prevailing winds and the Gulf Stream. *U-701*, according to Degen's account, is driven away by the Coast Guard escorts, preventing it from making a follow-up attack. At least one Coast Guard ship from Norfolk stands by *Rockefeller* for the remainder of the day, awaiting the arrival of a salvage vessel to attempt towing the disabled tanker into port. *Rockefeller* continues to drift and burn during this time. Finally, with its hull flooded and weakened by the torpedo strike and subsequent fires, something gives way and it sinks at 2338 EWT, just under twelve hours after it was torpedoed. This is duly reported to *Rockefeller*'s captain and is recorded in the Eastern Sea Frontier's war diaries (OCNO 1942d; Standard Oil 1946:322).

Scenario 2, what may be called the "Degen Scenario," is constructed as follows: *Rockefeller* is torpedoed at 1216 and abandoned shortly thereafter. With its engines shut down, it begins drifting north and east with the prevailing winds and the Gulf Stream. *U-701* is driven away by the tanker's escorts, preventing it from making an immediate follow-up attack. At least one Coast Guard ship stands by *Rockefeller* for the remainder of the day, awaiting the arrival of a salvage vessel. Degen, having remained in the area and evaded repeated attacks from the escorts, circles back to the tanker approximately 12 hours after his first attack. It is still on fire and burning so brightly that "[t]he night was bright like a sunny day," according to Degen (Offley 2014:210-211). Surfacing his U-boat, Degen allows several of his crew to come to the bridge to witness *Rockefeller*'s final moments. He closes to 1,000 yards and delivers a *coup de grâce* at approximately 2330, watching as the tanker sinks stern first (ONI 1942a:13-14; Offley 2014:210-212).

Scenario 3, the "Scuttling Scenario," runs as follows: *Rockefeller* is torpedoed at 1216 and abandoned shortly thereafter. With its engines shut down, it begins drifting north and east, propelled by prevailing winds and the Gulf Stream. *U-701* is driven away by the Coast Guard escorts, preventing it from making a follow-up attack. At least one ship stands by *Rockefeller* to await the arrival of a salvage vessel. *Rockefeller* continues to drift and burn for the remainder of the day. Unlike Scenarios 1 and 2, however, *Rockefeller* survives the night of 28 June and is still afloat the following morning, though it has burned itself out and is now a blackened hulk. The Coast Guard, recognizing that the tanker is unsalvageable and a hazard to navigation, dispatches aircraft to scuttle the wreck, which duly occurs on the morning of 29 June (USCG 1945:101).

The evidence for Scenario 1 is based on the war diaries of the Eastern Sea Frontier and the eyewitness account of Captain William Stewart, *Rockefeller*’s master (DIO 1942; OCNO 1942d). Evidence for Scenario 2 is based on the statements taken from KptLt Degen during the interrogations conducted by Office of Naval Intelligence (ONI) personnel after he and his six surviving crew were picked up by the Coast Guard, the reconstructed Kriegstagebüch of *U-701*’s final patrol, and excerpts from an unpublished manuscript written by Degen after the war and used by Ed Offley for his book *The Burning Shore* (Degen 1942c; USONI 1942b; Offley 2014). Evidence for Scenario 3 is based on the records of the Coast Guard (USCG 1945).

As may be obvious, Scenario 3 is mutually exclusive with Scenarios 1 and 2. Scenarios 1 and 2, however, can be reconciled to some degree. It is certainly possible for KptLt Degen to have found and sunk *Rockefeller* with another torpedo, and for this attack to have been seen and processed as the ship sinking on its own. Too, the timelines match up, as *Rockefeller* is recorded as having sunk at 2338 EWT, while Degen claimed to have sunk it around the same time; any small differences in timekeeping can be attributed to the idiosyncrasies of individual timepieces, none of which are likely to have been in sync with each other.

A curious anomaly appears in an account of the sinking as given by the private website uboat.net, which states that Degen sank *Rockefeller* at 0525 on 29 January at coordinates 35°11N, 75°07W. The time difference can be explained by the fact that the U-boat KTBs on which this account is apparently based were kept according to Central European Time, which was six hours ahead of the East Coast, but the coordinates given by the website lie well to the south and west of the coordinates given in other narratives of the event (Degen 1942c; Gannon 1990:214; uboat.net 2021).

Scenario 3 is difficult to reconcile with the bulk of the information available on the tanker's loss, and are consequently least accepted by secondary sources, most of whom prefer either Scenarios 1 or 2. When Scenario 3 is mentioned, it appears to be mainly for the sake of completeness. There is also the matter of the uboat.net account, which aligns closely with Scenario 2 but contains some notable errors of fact, which will be discussed below.

Those who accept Scenario 2 include the naval histories written by Clay Blair, Edwin Hoyt, and Samuel Eliot Morison, and the accounts of *Rockefeller* and *U-701* written by Joseph Hoyt and Paul Hudy, among others (Morison 1947:156; Balison 1954:314-315; Hoyt 1978:194-195; Blair 1996:607; Hudy 2007; Hoyt 2008:9). Ed Offley is possibly an exception, as he notes in his book *The Burning Shore* that Degen's account is considered controversial by some, given the Coast Guard reports. Even he, however, seems to lean toward this account, as he had acquired an unpublished manuscript from Degen's son in which Degen recounted watching *Rockefeller* sink from his U-boat's bridge after hitting it with a second torpedo (Offley 2014:208-212).

Standard Oil, in a 1946 account of its tanker fleet's activities during the war, accepted Scenario 1, recording that *Rockefeller*'s captain was told that the ship had sunk on its own at about 11:30 (quite close to the official time of 2338) on the night of the 28th. (OCNO 1942d; Standard Oil 1946:322). Following in their footsteps, Homer Hickam recorded that Degen tracked *Rockefeller* for twelve hours until it sank on its own, indicating that he too leaned toward Scenario 1 (Hickam 1989:275). An accounting of all American merchant marine casualties during WWII written by historian Robert Browning also accepted this scenario (Browning 2011:130).

A report on the Battle of the Atlantic in North Carolinian waters produced by Joseph Hoyt and others in 2021 mentions Scenarios 1, 2, and 3 without choosing one over the others, making it one of the very few sources to do so (Hoyt et al. 2021:7-278). As previously mentioned, there is also an unusual anomaly in one of the sources that can be used to support Scenario 2. The narrative of events on the private website uboat.net states that *Rockefeller* drifted until 0525 on the morning of 29 June before being sunk by Degen. At first it appeared that the site had conflated Degen's account of his second attack with the reports that the Coast Guard scuttled the ship the following morning, which would have made it a hybrid of scenarios 2 and 3 (uboat.net 2021). However, a review of KTBs from other U-boats that were operating off the East Coast indicates that these war diaries were kept according to Berlin time; the attack on the tanker *Norness*, for example, is known to have occurred at 2:30 AM on the morning of January, while the KTB of its attacker, *U-123*, records the attack as beginning at 8:34 AM (Hardegen 1942:12-12; Gannon 1990:216-217). The coordinates given in the website's narrative are at odds with the rest of the known data; the attack location is further south and west than the other LKPs, and the sinking location would indicate that *Rockefeller* drifted almost directly north before going down, which is at variance with the known wind and current directions on the day of the attack.

The account also contains a few errors of fact; first, it states that *Rockefeller* was being escorted by the Coast Guard vessel *CG-460*, not *CG-470*. As a review of *CG-470*'s logs confirmed that it was indeed the ship escorting *Rockefeller* on 28 June, this may be put down to a simple typographical error. It further states that the crew escaped in four lifeboats, which is inaccurate. Two of the lifeboats were fouled during launching, and as a result the crew had to employ the tanker's rafts also (OCNO 1942b-d; USCG 1942b; Standard Oil 1946:306; Hickam

1989; Offley 2014). These errors, while not serious, indicate that the coordinate data given in this version of events may also be less than accurate, and this data will be weighted accordingly.

Search Maps and Models

The search map as generated in ArcGIS has already yielded interesting results. The potential sinking points derived from this study's research were in some cases quite close to those previously determined by NOAA in its risk assessment package for *Rockefeller*, which suggests that the methods employed herein are sound and reasonably effective in recreating the tanker's potential drift tracks (See FIGURES 5.1-5.5).

It should here be noted that the reconstructed tracklines used in this study are only an approximation of *Rockefeller*'s movements on 28 June 1942, since there is no detailed information available for the course the ship was steering. To keep clear of the recently laid Cape Hatteras minefield, *Rockefeller* would briefly have sailed southwest before looping east and north around the minefield's outer extent and the shallow waters around Diamond Shoals en route to its destination in New York (See FIGURE 5.1 for an overlay of the minefield on the GIS map, along with the reconstructed tracklines and convoy routes). The data used to approximate this route was acquired from John Wagner's study of the convoy routes in the area (Wagner 2010).

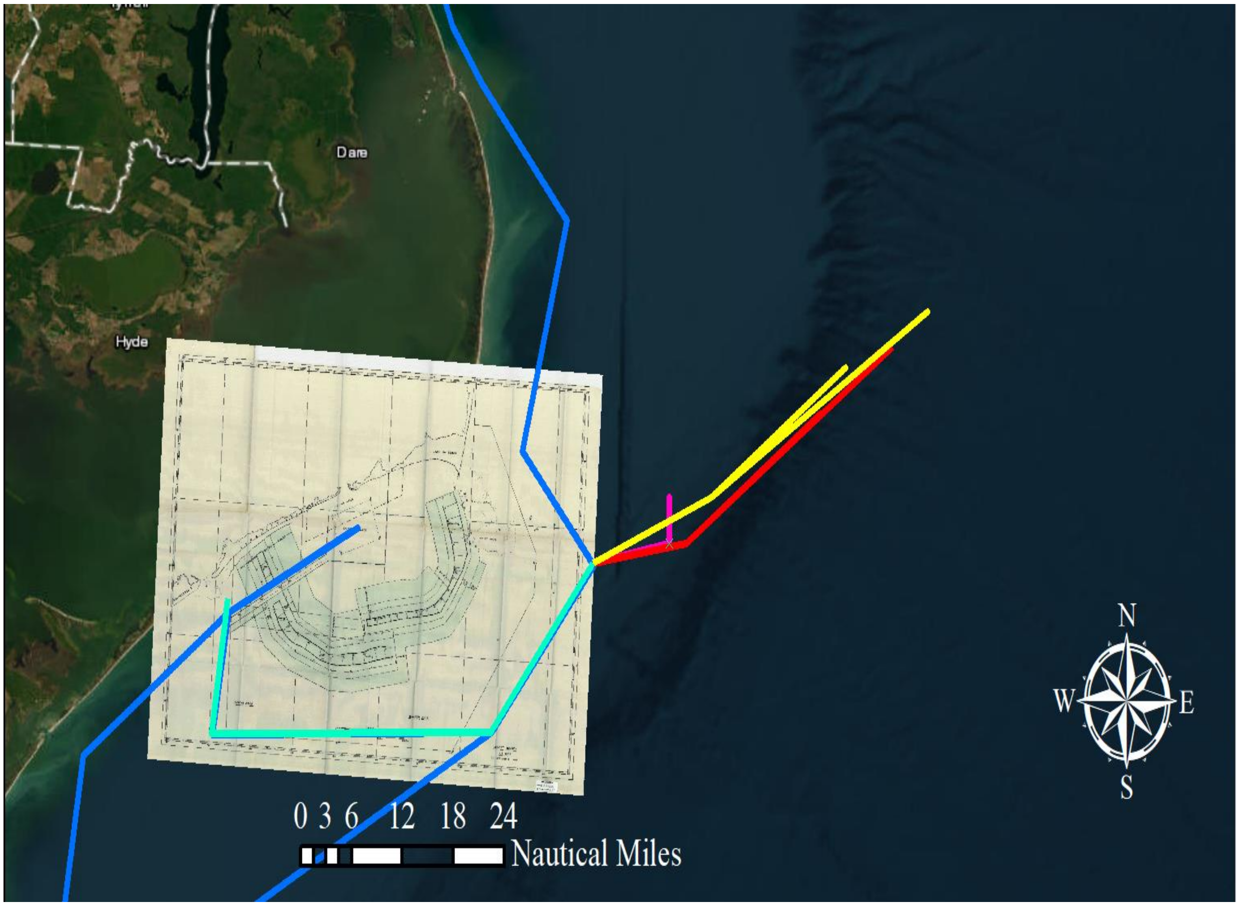


FIGURE 5.1. Reconstructed tracklines displayed over a map of the Cape Hatteras minefield, along with the prescribed merchant shipping routes from May 1943 (in blue). *Rockefeller*'s final course most likely followed the latter until its deviation out to the 100-fathom curve (OCNO 1942b, 1942c, 1942d; Wagner 2010; Bright 2012; uboat.net 2021. Hatteras minefield image courtesy of John Bright. Map drawn by the author)

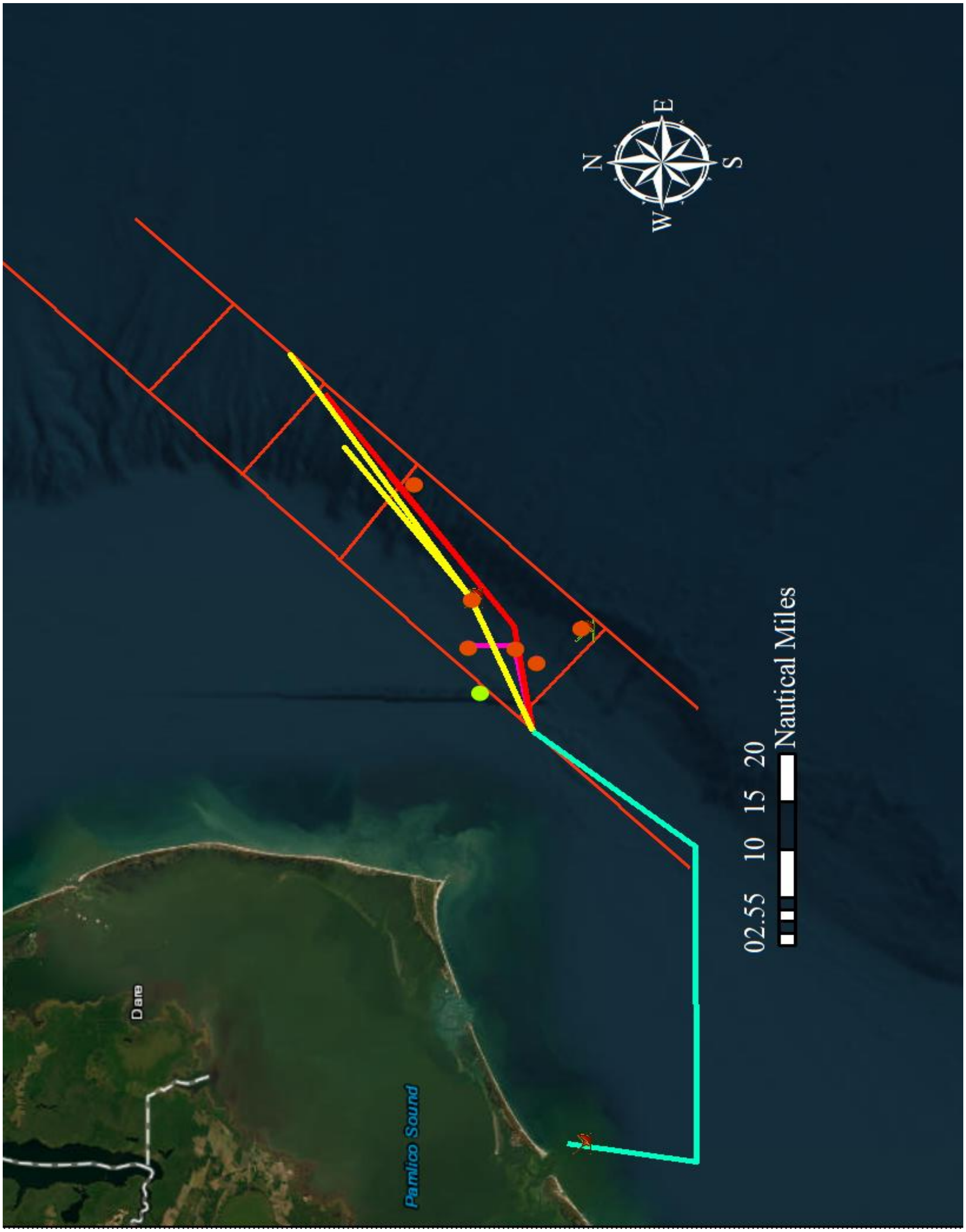


FIGURE 5.2. NOAA’s map as recreated in ArcGIS, with reconstructed tracklines added. (Source: Basta et al. 2013b. Map drawn by the author)

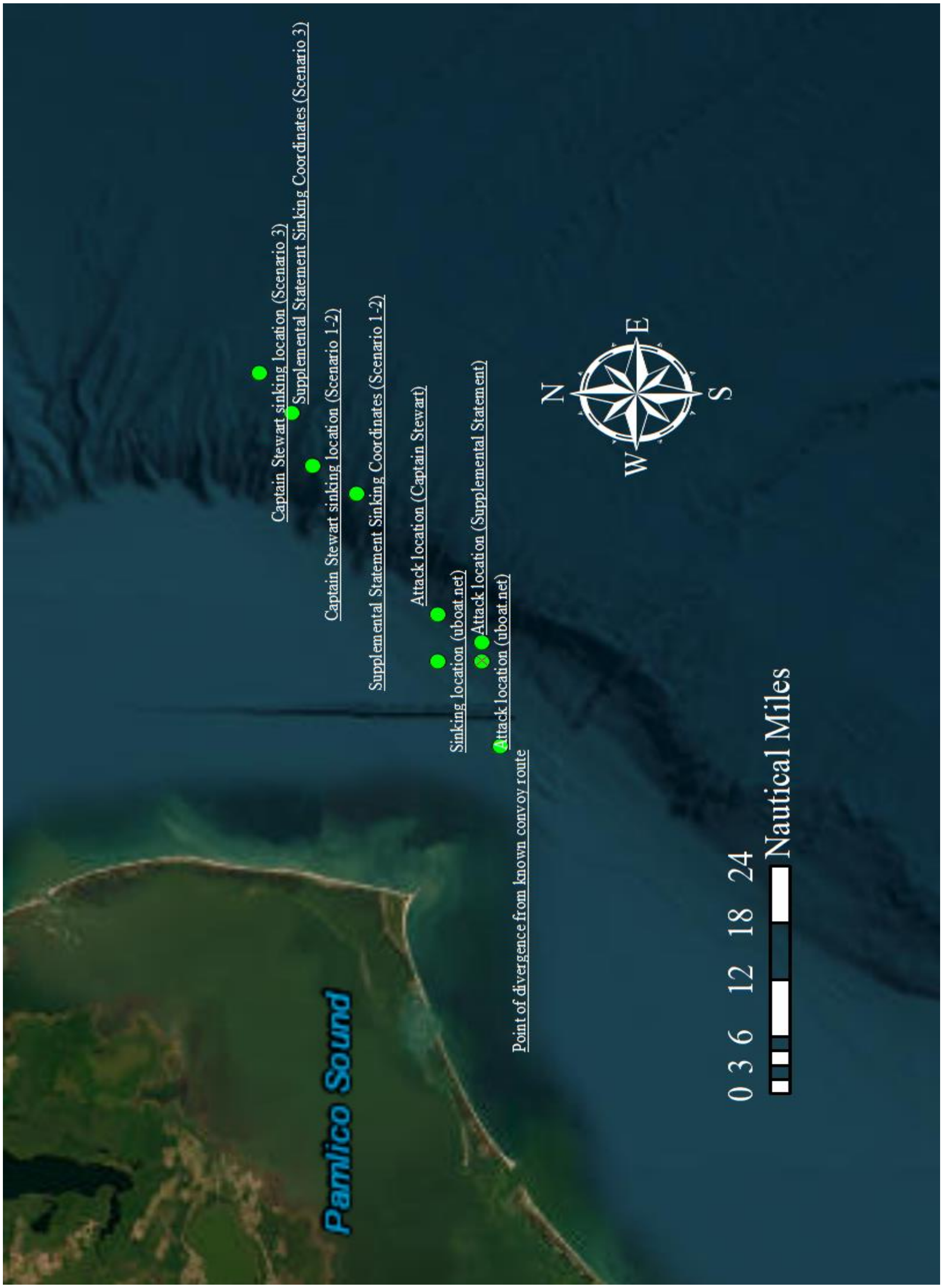


FIGURE 5.3. Position map created by the author using various sources, with potential sinking locations marked. (Sources: OCNO 1942b, 1942c, 1942d; USCG 1944b; DIO 1945; Basta et al 2013b; Hoyt et al. 2021; uboat.net 2021. Map drawn by the author)

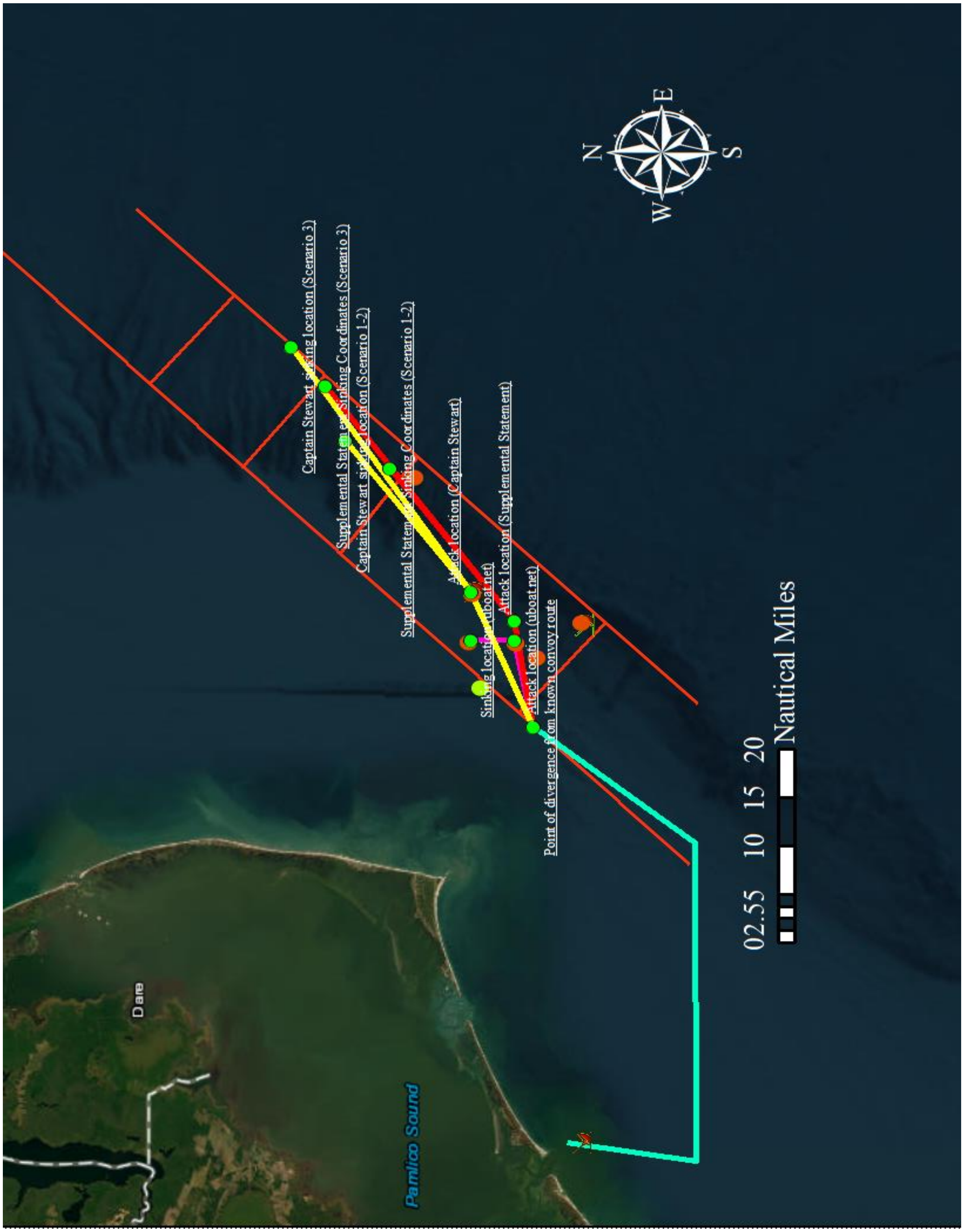


FIGURE 5.4. Combined position map displaying both NOAA’s coordinates and this study’s coordinates. Note the overlap between many of the data points. (Sources: OCNO 1942b, 1942c, 1942d; USCG 1944b; DIO 1945; Basta et al 2013b; Hoyt et al. 2021; uboat.net 2021. Map drawn by the author)

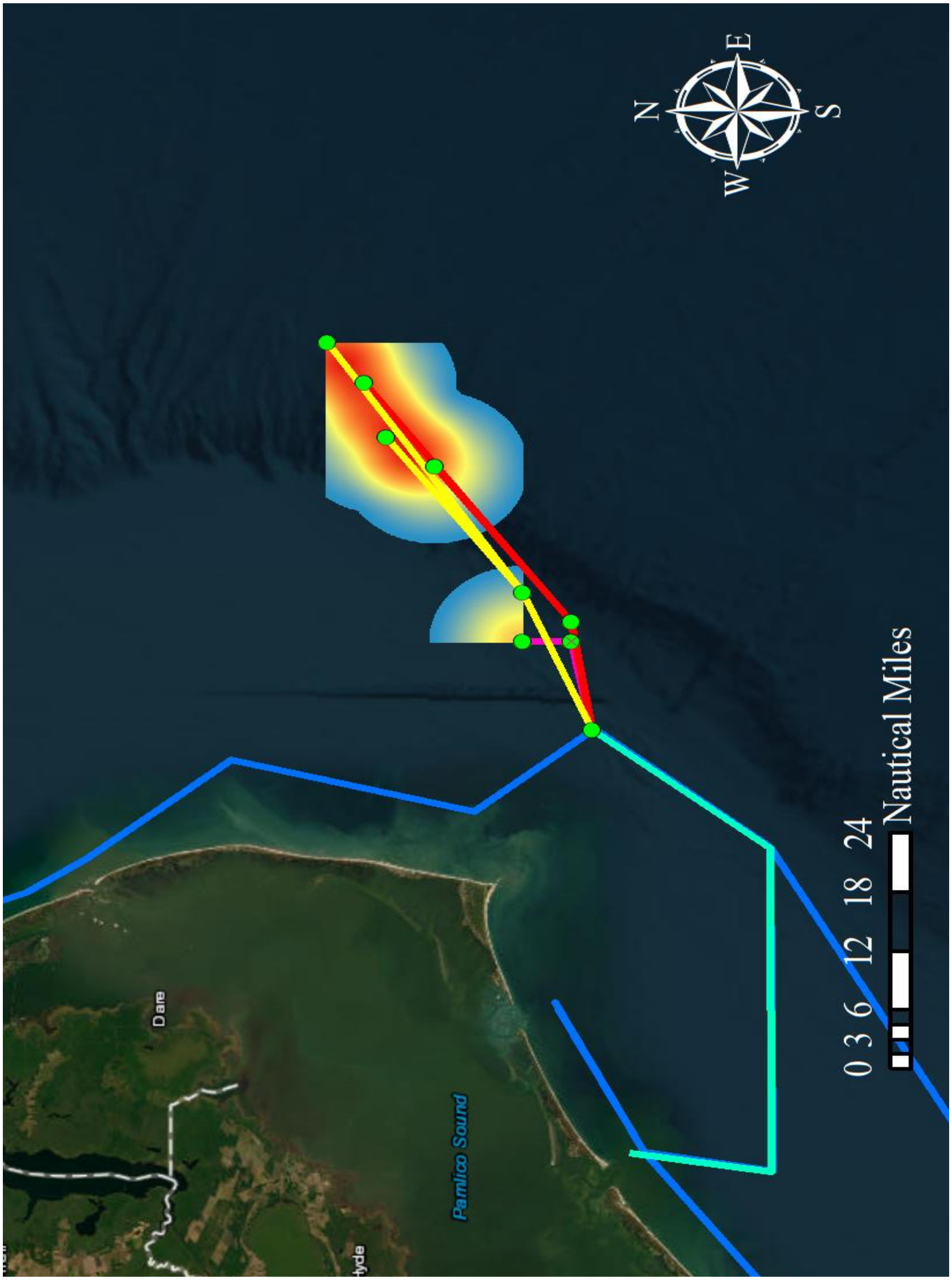


FIGURE 5.5. Density cloud generated around the potential sinking locations. (Drawn by the author)

Results of Mapping and Modeling

The grid drawn around the potential sinking locations as derived from the three primary scenarios encompasses a total of 384 square nautical miles. At a stroke, then, the potential search area has been almost halved from NOAA's original estimate of 750 nautical miles. If sectioned into a grid of 4 by 4 nmi segments, this gives 24 cells in which to search within this box. These cells represent the highest priority search areas for *Rockefeller*'s wreck according to this study's m apping and modeling work. A second grid laid over the uboat.net coordinates and providing a margin for error gives an area of 64 square nautical miles, which can be sectioned into four 4x4 nmi cells (see FIGURE 5.6). As mentioned previously, the accuracy of these coordinates is suspect, so the cells in this grid will be given the lowest priority.

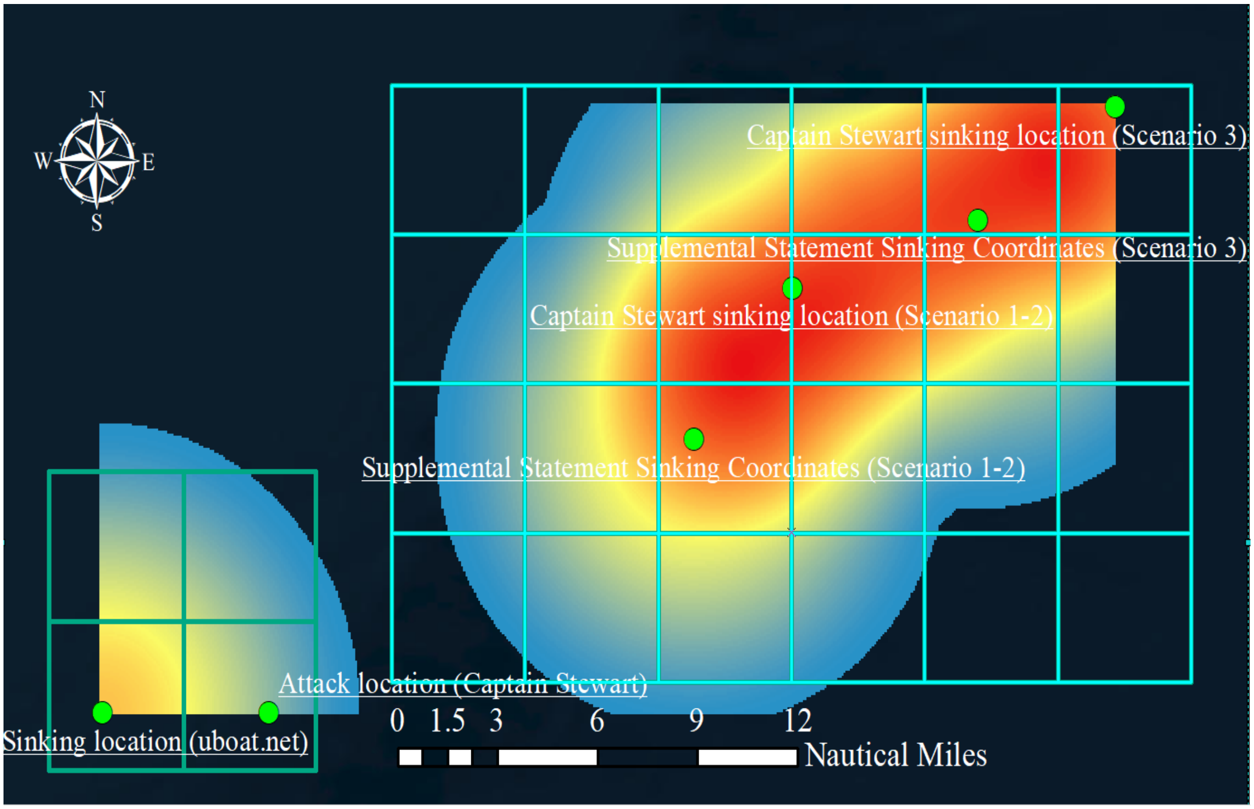


FIGURE 5.6. Grids drawn over possible sinking locations for *Rockefeller* (Sources: OCNO 1942d; Standard Oil 1946; uboat.net 2021. Map drawn by the author).

With the grids created and rough priorities assigned, the question that follows is how to further prioritize the search area to maximize the chances of success. According to Bayesian methods, the factors that must be considered here are the following: the *prior distribution* of information, the *subjective probabilities* of the occurrence of given events, and *posterior distribution* of data obtained from previous search efforts (Stone 2011; Stone et al. 2014; Rossmo et al. 2019).

When speaking of maritime search, the *prior distribution* consists of any data collected prior to the current operation. As an example, we may consider the prior distribution of the 2011 search for Air France Flight 447's black box, which was conducted by Dr. Lawrence Stone using Bayesian methods. In that case, the prior distribution consisted of the last GPS ping received from Flight 447 before its disappearance, the estimated distance the plane might have traveled from its LKP based on the cessation of signal data, and the recovery locations of debris and victims from the wreck, which was used to plot a reverse-drift scenario to estimate the crash location (Stone et al. 2014:72-75).

In the context of this study, the prior distribution consists of the historical and spatial data assembled regarding *Rockefeller*'s loss and the maps and models created from this data. The specifics of this information have already been delineated and need not be repeated here. The balance of the data suggests strongly that *Rockefeller* drifted slowly northeastward after being abandoned, probably not more than 17 nmi and almost certainly no more than 25 nmi. There is some margin for error here; *Rockefeller*'s given drift speed of 1.5 kt is only an approximation based on the Coast Guard casualty report, and it is possible that the winds may have shifted, pushing it in another direction. This factor was accounted for in the Coast Guard's SAROPS probability maps, which posited three different wind speeds and applied different current speeds as well throughout the scenario.

The next factor to be considered is the *probability of events occurring*. This is a subjective, not objective factor, since in this case the probability is based on what the person conducting the study knows or believes to be true. As stated previously, this study has accepted KptLt Degen's account of sinking *Rockefeller* at or around 2338 EWT on the night of 28 June as the most probable scenario, with allowance for the fact that it may also have sunk on its own around the same time. The third scenario is regarded as less probable and has been weighted accordingly. Each scenario was given a percentage, all of which added to 100: Scenario 1 = 45%, Scenario 2 = 45%, Scenario 3 = 10%. When search operations begin, these probability percentages can be fed into the basic Bayesian probability equation, which runs as follows:

$$P(A|B) = \frac{P(B|A)P\ (A)}{P(B)}$$

where P (A|B) is the conditional probability of event A given event B;

P (B|A) is the conditional probability of event B given event A;

P(A) is the probability of Event A;

P(B) is the probability of Event B (Rossmo et al. 2019:45).

In this case, there are three events to solve for, those being the scenarios described previously. Event A may be given as Scenario 1 (the Long Goodbye), Event B as Scenario 2 (the Degen Scenario), and Event C as Scenario 3 (the Scuttling Scenario). Some of these equations are zero-sum games. For example, the Degen and Scuttling scenarios cannot both be true, thus the conditional probability of Event B given Event C would be zero, and vice versa. The only way to know for sure is to go and look. When a search operation is launched, this equation and its derivatives may be used to update the probabilities according to the search finds, with the results fed into the predictive model in ArcGIS to create an updated search map.

The *posterior distribution* of information is assembled from all data acquired during previous search efforts. In the case of AF Flight 447, the posterior distribution included various unsuccessful searches for the plane's wreckage in 2009 and 2010, which Dr. Stone and his colleagues factored into their probability maps (Stone et al. 2014:75-79). In the context of this study, there is no posterior distribution to consider, as there have been no searches conducted for *Rockefeller*'s remains. However, the map and model created for this study may one day become the basis of a posterior distribution. That is, it may be the case that this study's conclusions are in error and a search based on them fails to locate *Rockefeller*'s wreck. Should this be the case, the probability map can subsequently be updated with this data, creating a posterior distribution, and further reducing the search area for future expeditions. For now, the calculation of posterior distribution may be ignored.

Having considered these three factors, it is now possible to turn to the assigning of individual priorities for the cells in the two search grids. Each cell was assigned an ordinal ranking from 1 to 28 based on the probabilities derived from the data assembled and calculations made thus far. The cells in the areas of highest density and those containing the sinking locations based on Captain Stewart's position report were assigned the highest priority, followed by the cells containing the position reports based on the coordinate data from OCNO's supplement to the statements of *Rockefeller*'s survivors. The remaining cells were assigned their ordinal rankings based on the relative strength of the density cloud in that area. The second grid was numbered in similar fashion, with the highest relative priority assigned to the cell containing the sinking location from uboat.net and the remaining cells assigned priority based on the collected historical, spatial, and analytical data. (See FIGURE 5.8).

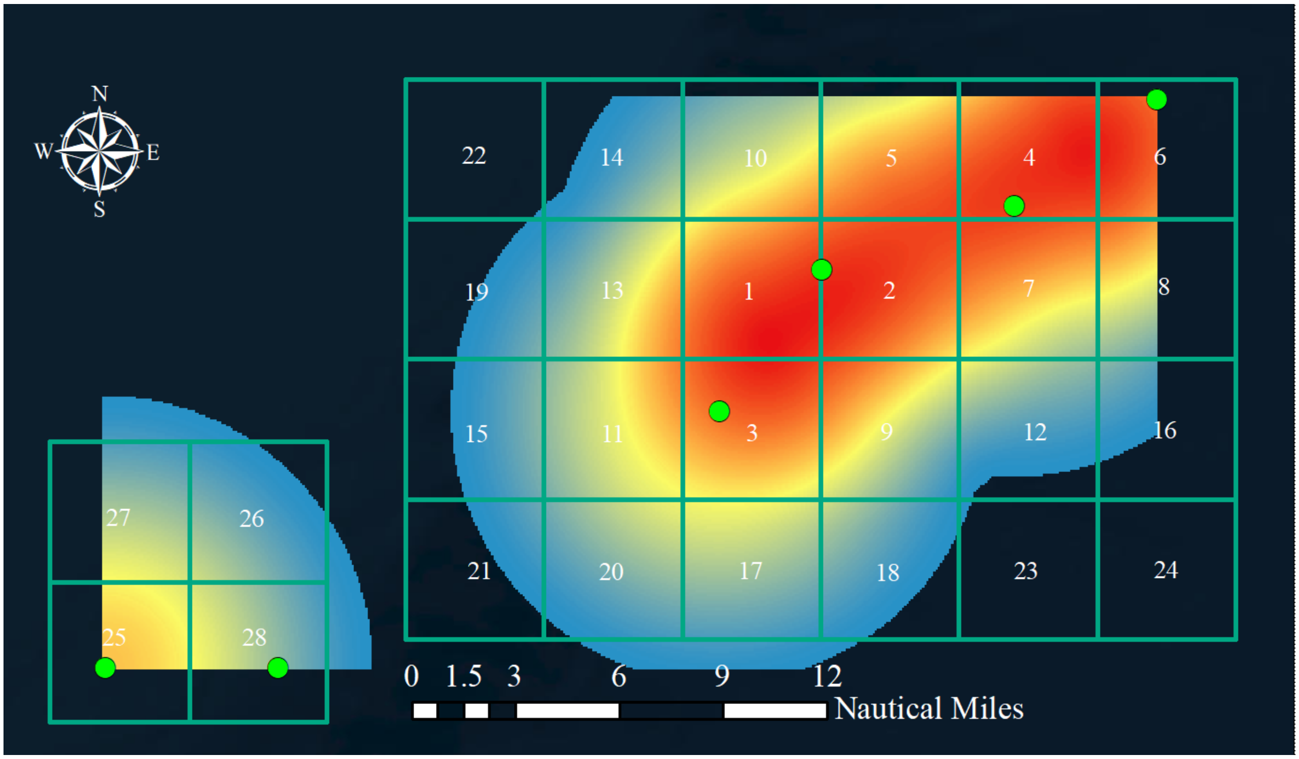


FIGURE 5.7. Search grids with ordinal rankings assigned based on density cloud and subjective probability analysis. (Drawn by the author)

The main difficulty in searching for *Rockefeller*, aside from the uncertainty regarding the search area, will be the probable depth of water in which it sank. Overlaying the possible sinking coordinates on a bathymetric chart of the area indicates that *Rockefeller*'s wreck most probably lies in deep water off the edge of the American continental shelf. According to bathymetric charts of the area, the potential sinking locations mapped for Scenarios 1 and 2 (the "Long Goodbye" and the Degen Scenario) place *Rockefeller* in water between 803-886 fathoms (1,486-1,620 m, or 4,818-5,316 ft). The locations mapped for Scenario 3 (the Scuttling Scenario) instead place it in approximately 1169 fathoms (2,137 m, or 7,014 ft). By good fortune, most of the highest probability cells in the primary search grid also happen to be those in the relatively shallower depths of water in the area (See FIGURES 5.8-5.9).

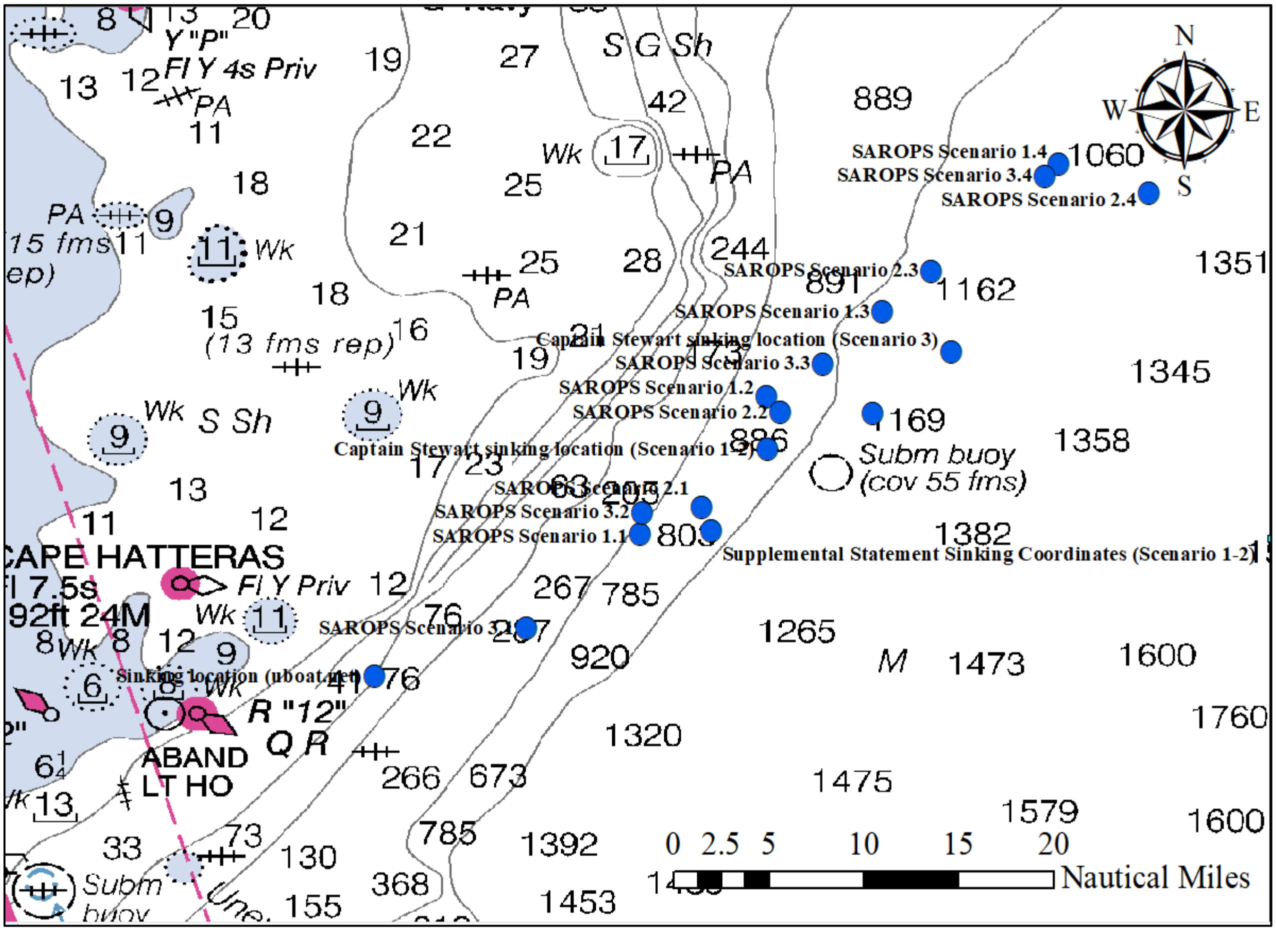


FIGURE 5.8. Map of *Rockefeller*'s sinking locations overlaid on NOAA chart (Wagner 2010; NOAA 2022; Ian Brown 2022. Map drawn by the author).

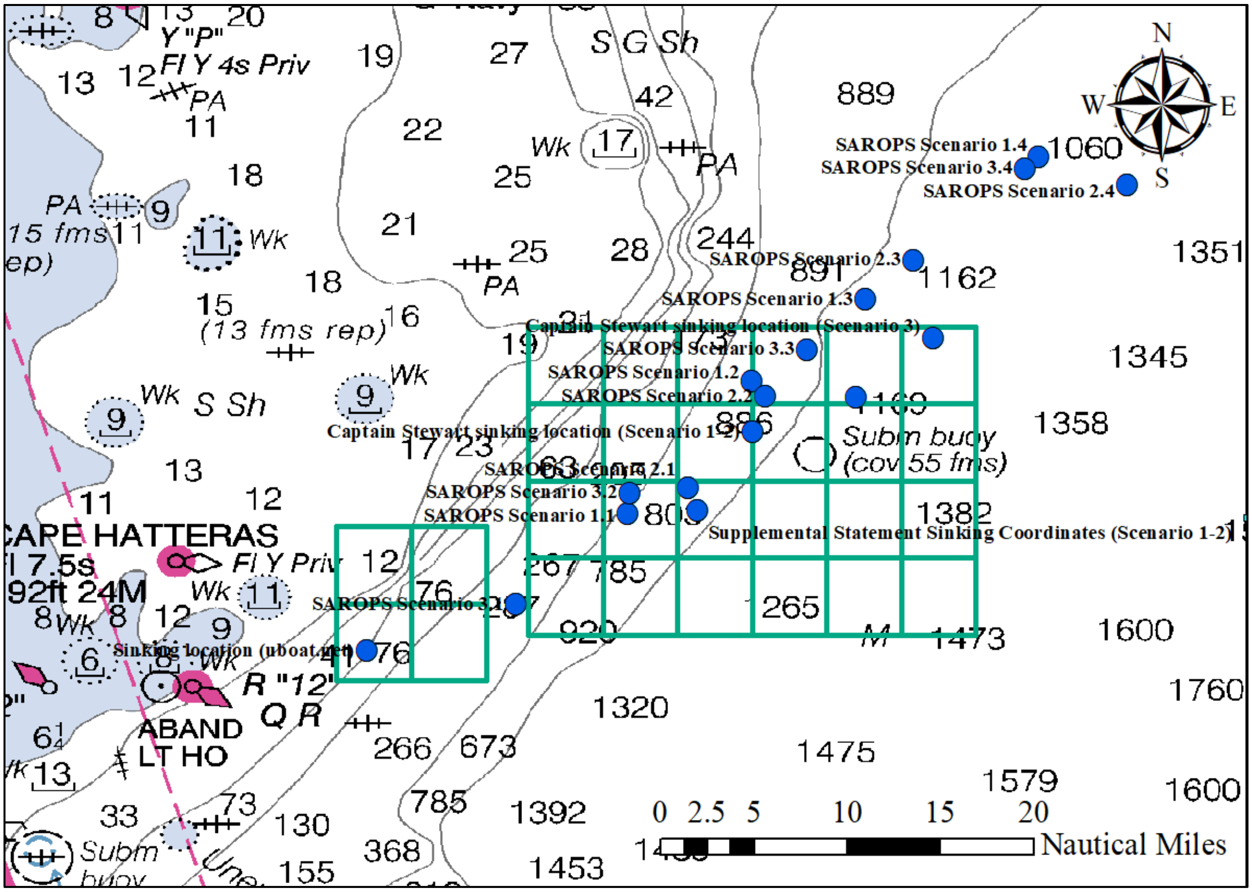


FIGURE 5.9. Previous figure with search grids overlaid (Map drawn by the author).

It is possible, though unlikely, that *Rockefeller* lies in shallower water somewhere along the edge of the continental shelf. Indeed, if the coordinates given by uboat.net are to be believed, *Rockefeller* sank in water between 41 and 76 fathoms deep (74m-138m, or 246 ft-456 ft). This seems unlikely, for several reasons.

First, the uboat.net coordinates are at variance with what is generally known and accepted about *Rockefeller*'s loss; indeed, it remains unclear from where their coordinate data was derived, making it suspect from a historical/archaeological standpoint. It has been included here for the sake of completeness, and on the slim chance that it is an accurate depiction of *Rockefeller*'s loss.

Second, if *Rockefeller* was indeed in shallow water, it likely would have been positively identified or at least relocated by now. The waters off Cape Hatteras are some of the most heavily trafficked along the American coast, and the area is home to large and active communities of fishers, wreck divers, naval personnel, and maritime researchers, all of whom have vested interests in the many WWII wrecks off the Outer Banks. Many of these WWII-era wrecks were identified and marked shortly after their losses due to eyewitness evidence and contemporaneous US Navy or Coast Guard surveys, such as *Marore*, *Norvana*, *Suloide*, and *Senateur Duhamel*, and their locations are still common knowledge today (Hoyt et al. 2021:7-218, 7-231, 7-257, 8-12).

The sport and commercial fishing industries are a common source of shipwreck discoveries. Fishers will naturally go where their quarry is located, and wrecks provide excellent habitats for fish of all sizes. Many wrecks of historic significance have been first relocated by fishers who stumbled across a rich fishing ground or who snagged their gear or hauled up ship parts while trawling, including the early British submarine *Resurgam*, the Spanish treasure wreck *El Cazador*, and the German submarine *U-869* (Broad 1993:28; Kurson 2004:12-16; McKie 2012). If it were in shallow water, *Rockefeller* would doubtless be a magnet for fish and fishers alike, but no fishing crew or captain has yet reported a wreck or anomaly of *Rockefeller*'s size.

Likewise, sport divers and amateur historians will often investigate so-called "mystery numbers" that they have identified or received from other divers, fishers, or boaters in hopes of finding a new wreck. Many lost wrecks of the Great Lakes have been relocated in this way by a small and dedicated team of technical divers and local historians led by Ken Merryman and Jerry Eliason; the same is true of *U-352* and *U-701* (Kurson 2004:12-16; Hoyt 2008:10; Gowan 2017).

As with the local fishing community, no Outer Banks diver in the last 80 years has reported finding a wreck that matches *Rockefeller*'s colossal dimensions.

In recent years, NOAA has scoured the area off Cape Hatteras and Cape Lookout and has relocated or positively identified many wrecks from the Battle of the Atlantic, including *Ario, Bluefields,* HMT *Bedfordshire, Byron D. Benson, Caribsea, Cassimir, E.M. Clark, Empire Gem, Lancing, Liberator, Naeco, U-576,* and *YP-389* (Hoyt et al. 2021:4-1-4-20). Their surveys also located several unidentified wrecks and identified 47 anomalies with potential material culture remains, three of which they knew for certain were shipwrecks, but did not believe any of these to be *Rockefeller*'s wreck (Hoyt et al. 2021:11-19-12-1).

Finally, there is the Office of Coast Survey's (OCS) Automated Wrecks and Obstructions Information System (AWOIS), a database containing positions and information for over 10,000 wrecks and marine obstructions in American waters, a resource which has frequently been employed by all the above groups to locate shipwrecks. *Rockefeller* had not been identified as any of the charted wrecks or obstructions in AWOIS at the time that the Coast Survey stopped updating the database in 2016, and none of the recorded obstructions or wrecks lie anywhere near the potential search area delineated in this study (OCS 2022).

Given all this, it is highly unlikely that *Rockefeller* lies on the continental shelf. It is simply too large a wreck to have remained undetected for so long in such a heavily trafficked and explored area of ocean. Hoyt et al. have made the same assessment in their report on the Battle of the Atlantic Project (2021:7-278). It may be safely assumed, then, that *Rockefeller* indeed lies in deep waters off the edge of the shelf. A potential search expedition will require more planning, forethought, and funding than would be the case if the ship had sunk in shallow water, but the depth alone is not an insuperable difficulty. Other wrecks have been relocated in much deeper waters, including USS *Scorpion* (3,000 m/9,800 ft), *Titanic* (3,800 m/12,500 ft), the German battleship *Bismarck* (4,572 m/15,700 ft), USS *Yorktown* (5,074 m/16,650 ft), USS *Johnston* (6,456 m/21,180 ft) and USS *Samuel B. Roberts* (6,895 m/22,621 ft) (Ballard 1987; Ballard and Archbold 1991; Ballard 1999; Craven 2001; Morelle 2021; Suliman 2022).

Conclusion

The initial results of the research, mapping, and modeling have all shown promise. Data processing has been completed, with historical, analytical, spatial, and statistical data all combined to produce a set of scenarios that have in turn been used to generate a predictive model and series of search maps that have defined two compact search areas for *Rockefeller*'s wreck. In turn, these areas have been sectioned into grids of 4x4 nmi cells, with ordinal rankings assigned to each one based on the analysis of the data and the subjective probability of the three identified scenarios.

The scenarios themselves have been devised in accordance with all the information, factual and conjectural, that can be found on *William Rockefeller*'s sinking. Some of these scenarios are more rooted in the primary sources than others and have accordingly been given greater weight by this study, while others rely on information whose provenance is unclear and are less likely to be the true course of events regarding *Rockefeller*'s loss. None of them will be discounted until they have been investigated; as stated in the methodology chapter, one of the key advantages of Bayesian maritime search is that it requires one to account for *all* possible wrecking scenarios, no matter how unlikely they may seem. Thus, even though it *prima facie* does not appear that the Scuttling Scenario is likely to be an accurate depiction of the tanker's last hours, it can still be accounted for and its position data investigated, provided that sufficient time and funding is still available after searching the primary grid area.

It is unfortunate that more concrete results cannot yet be presented, for the author would like nothing more than to end this chapter on a triumphant note, with side-scan images or photos of *Rockefeller*’s wreck on the seafloor. However, such will have to wait for a future expedition.

CHAPTER SIX: MODEL COMPARISONS – STANDARD GIS INTERPOLATION vs SAROPS

Introduction

This study has explored two different methods for using ArcGIS to generate search maps and explanatory/predictive models according to Bayesian search theory. The first method required the author to perform manual data entry and calculations using the acquired data to generate a search map. This is a method not so far removed from the first days of SAR technology, though it was made simpler thanks to programs like Excel and ArcGIS itself, which functionally automated much of the process. The second method leveraged the advanced search-and-rescue technology developed by the United States Coast Guard to predict the most probable drift path for *Rockefeller* based on the acquired data. This method is more rigorous than the first, relying as it does on advanced computer simulations and modeling to achieve its results rather than manual calculations of drift.

Since both methods would be using the same data, convergent results would suggest that the methods used were fundamentally sound, while a radically divergent result would suggest that there were flaws in one or the other. In short, the results of the two methodologies were broadly convergent, which is a promising indication of their soundness. This chapter will discuss the points of convergence and divergence between these results and will further examine the quality of the data used to obtain these results.

Analyzing the Models and Maps

Whenever one is creating maps and models to search for a shipwreck, it is wise to keep in mind that they will only be as good as the data that is used to make them. In the context of this study, some of the data obtained has been of relatively high quality, while other data has been less so. Here follows a discussion of the quality of the data that was used to construct each scenario, as well as an analysis of their strengths and weaknesses.

Scenario 1: Strengths and Weaknesses

Scenario 1 (the “Long Goodbye”) is one of the strongest of the scenarios. It is backed by a majority of the available data and is the one most commonly accepted by secondary sources on *Rockefeller*’s sinking. It also overlaps with Scenario 2, in that the times of sinking recorded for each scenario are within a few minutes of each other: 2338 and shortly after 2330, respectively (Standard Oil 1946:323; Offley 2014:212). It is based on eyewitness testimony and records: the statements given by Captain Stewart, KptLt Degen’s interrogation and memoir, the logs of *CG-470*, the Coast Guard captain at Ocracoke, and the commander of the Coast Guard vessel that was standing out from Norfolk to assist *Rockefeller* (OCNO 1942b-d; ONI 1942; Standard Oil 1946; Offley 2014) As four of these individuals were direct witnesses to the event, the quality of the evidence in this scenario is about as strong as one might wish.

Scenario 1 does have a few weaknesses, however. It remains unclear which ship was standing by *Rockefeller* when it sank; the only information given in any of the primary sources was that it was a Coast Guard ship from Norfolk, without specifying its name or hull number. Without logs or other records from this ship, the scenario is effectively reliant on hearsay for its conclusion. That is, the Coast Guard CO of the Ocracoke station heard from his opposite number on the Norfolk ship that *Rockefeller* had sunk, then relayed this information to Captain Stewart and his superiors, from whence it entered the historical record. This is still a relatively reliable chain of evidence, if less solid than might be hoped. It should also be noted that an examination of Captain Stewart and KptLt Degen’s accounts of the sinking revealed some discrepancies in their narratives. This required reanalysis of both accounts to check whether these discrepancies had affected the overall narrative that was used to construct the scenario. They ultimately did not, but this incident was a salutary reminder that one should not take eyewitness accounts at face value. A detailed discussion of these issues follows.

Despite the overall coherence of Captain Stewart's account, some notable discrepancies appear in his version of *Rockefeller*'s loss as given to the Coast Guard investigators and the version later published in Standard Oil's *Ships of the Esso Fleet in World War II*. In his 1942 affidavit, Captain Stewart stated that he ordered the general alarm to be sounded but gave no orders to shut down the engines:

> Immediately after the explosion I instructed Third Mate Sullivan to sound the general alarm and the engine was stopped by Chief Engineer Snyder; the fuel oil valves were closed and the steam smothering line opened . . . I attempted to order the crew to stand-by with a view to seeing if the ship could not be saved, but my orders could not be heard aft due to fire and smoke amidship . . . Nos. 2 and 4 lifeboats were launched as were the two after rafts; Nos. 1 and 3 boats were attempted to be launched but fouled owing to what I believe to be undue haste. (OCNO 1942d:2)

In this version of events, Captain Stewart did not give the order to shut down the engines or to abandon ship. Indeed, his stated desire to attempt beaching *Rockefeller* suggests that neither idea occurred to him. OCNO's summary of statements reinforces this impression, as it notes that Capt. Stewart had gone below to secure the ship's papers and found that the crew had abandoned ship without orders when he returned to the deck (OCNO 1942c:1, 1942d:2-3).

Four years later, Stewart recounted the event for Standard Oil's book on their tanker fleet's accomplishments during the war. While the bulk of his statement remains the same, there are some notable differences:

> At 12:16 p.m., while I was in the chart room, a torpedo suddenly struck the tanker without warning on the port side amidships in way of the pumproom. I went into the wheelhouse and ordered the general alarm sounded *and the engines stopped*. The fuel oil valves were closed and the steam smothering lines opened. Our position was then 16 miles east northeast of Diamond Shoal Lighted Buoy,

> Latitude 35 ° 11 ' North, Longitude 75 ° 02 ' West. . . . At first I concluded that there was no emergency requiring the abandonment of the ship and was planning to turn the *Wm. Rockefeller* landward and beach her if necessary. However, when I realized that the fire amidships prevented anyone from passing between the forward and after parts of the vessel, *I decided there was no alternative to abandoning the ship.* About 12:28 p.m. *all the boats were lowered*; I took a final walk around the lower bridge to make sure that no one remained on board. (Standard Oil 1946:321-322, italics added).

In this version of events, Captain Stewart assumes responsibility for the engines being shut down; he also implies (but does not state outright) that he gave the order to abandon ship and omits the loss of two lifeboats due to "undue haste," as he phrased it in his earlier statement. It is unknown why Captain Stewart chose to own his crew's actions, especially given his apparent belief that they had given up on saving *Rockefeller* too soon (OCNO 1942c:2, 1942d:2-3). It is possible that his recollection of events had become blurred in the intervening period, and he genuinely believed (or wanted to believe) that he had given the order to shut down the engines and abandon ship. There may also have been an element of pride at work. No captain wishes to acknowledge having lost control of their crew, however briefly, and if the original account of events is to be believed, *Rockefeller*'s crew was certainly acting on their own initiative in the immediate aftermath of the attack.

Alternatively, Stewart may have been acting in accordance with the longstanding maritime tradition that the captain is ultimately responsible for their ship and everything that happens on board. Stewart's conduct on 28 June certainly suggests that he had this tradition foremost in his mind. He had secured *Rockefeller*'s codebooks and papers and walked the decks to ensure that he was the last person on board before joining his crew in the lifeboats. He also repeatedly requested that he be allowed to reboard his ship until told that some of his crew needed medical treatment. After being landed at Ocracoke, he again asked to be taken back out to *Rockefeller* and remained hopeful of saving the ship until he was told that it had sunk that night. One of the Coast Guard officers at Ocracoke noted that the loss of his ship affected him deeply (OCNO 1942 c-d; Standard Oil 1946:322-323). Considering this, it seems likely that Stewart chose to claim responsibility for his crew's actions because he felt that it was his duty as captain to do so.

These discrepancies did not immediately discredit Stewart as an eyewitness, but they required a careful reexamination of the sources to ensure that there were no other differences in the two accounts that might have negatively influenced the data used to create the maps and models. In the end, the differences had no direct impact on this study's research and modeling, since the result was the same no matter who was responsible: *Rockefeller*'s engines were shut down, and it was left to drift with the currents and wind after its crew abandoned ship. However, this incident is an excellent illustration of the mutability of the historical record, especially where firsthand accounts are concerned.

Regarding KptLt Degen's original version of events, there are two factors to consider. First, his initial account of the attack on *Rockefeller* was given to interrogators from the Office of Naval Intelligence. Second, he was being interrogated after he had spent 49 hours adrift in the Atlantic Ocean, nearly out of his mind from exhaustion, dehydration, and exposure. The former factor would have likely induced him to withhold the entire truth from his interrogators, while the latter could have negatively impacted his memory and recall. Indeed, there is a notable falsehood contained in these interviews. Degen and his surviving crew all repeatedly denied that *U-701* had been carrying mines on its last patrol, which was a lie (Degen 1942c:2; USONI 1942a:10-12). The second factor certainly influenced his memory to some degree, as the ONI interrogators noted that Degen and the other survivors could give no coherent account of their submarine's last moments. Degen himself admitted that by the start of their second day in the water, he was becoming delirious and losing his grip on reality, such that he would most likely have drowned if not for his quartermaster Gunther Künert (USONI 1942a:15, 60).

On the other hand, the reports from Degen's interrogation suggest that his memory was still generally reliable even after his ordeal. His account of *U-701*'s last patrol tracked with what was known about his submarine's activities (the attacks on *YP-389, British Freedom*, and *Rockefeller*), and the interrogators were able to use some of the information he gave them to confirm intelligence collected from other prisoners, signal intercepts, and sources in occupied France. He was able to recall details of his first two war patrols and conversations he had had months prior to the sinking, as well as the current assignments of many of his fellow U-boat commanders (USONI 1942a:11-14, 21-40).

As for his later narrative, it was written many years after the war, when time and distance may have combined to fog his recollection of events. Under the circumstances, it is not surprising that Degen altered some parts of his narrative, whether accidentally or intentionally. One notable discrepancy appears in the book *The Burning Shore*, which uses Degen's unpublished memoir as one of its primary sources. A review of the reconstructed war diary for *U-701*'s last patrol indicates that Degen received a message from BdU informing him that one ship had been sunk by the minefield he laid off Chesapeake Bay, whereas his memoir states that the message informed him that four ships had been sunk (Degen 1942c:2; Offley 2014:162). It is probable that Degen was speaking with the benefit of hindsight in the latter case. By the time he wrote his memoir in 1965, he would likely have been aware that his minefield sank two ships and damaged three more, suggesting that he may have conflated the numbers in his memory over the years.

Scenario 2: Strengths and Weaknesses

Scenario 2 is the second strongest of the scenarios presented in this study. It mostly overlaps with Scenario 1, and so is backed by the same primary source data listed above. Its only major deviation is that it attributes *Rockefeller*'s sinking to a second torpedo fired by *U-701*, rather than the ship going down by itself. The scenario's strengths are the primary source data that it shares with Scenario 1 and the fact that its version of *Rockefeller*'s sinking is derived from the testimony of KptLt Degen, an eyewitness whose account is reasonably complete, coherent, and detailed.

That said, Degen's account is also the scenario's primary weakness. As noted previously, eyewitnesses are not always reliable recorders of events, and one must consider the conditions under which this account was produced. His first account was produced under stressful conditions, as noted in the discussion for Scenario 1, while his second account was written 25 years later, when time and distance from the events of 28 June 1942 could have intervened to blur his memory of the day (USONI 1942a:13-14; Offley 2014). Despite this, Degen's account remains generally coherent across both versions.

It is possible that he invented this second attack to burnish his patrol record and perhaps expiate the failure of losing his U-boat and so many of his crew, but the author regards this as unlikely. By the time *U-701* was sunk, Degen had already conducted a successful patrol. As far as he knew, he had sunk three ships other than *Rockefeller* with torpedoes and gunfire and at least one more with the minefield he laid outside Chesapeake Bay; the latter had even earned him a congratulatory message from BdU (Degen 1942c:2-3). Any submariner of the period would have been pleased with this record, especially given the increasing strength and efficacy of antisubmarine patrols in the area off Cape Hatteras (Degen 1942c:2-3). While two of his claimed sinkings had not actually occurred, he would have had no way of knowing this at the time (USONI 1942a:13-14).

Further, it seems reasonable to assume that he did indeed sink *Rockefeller* with a second torpedo. Many other tankers, including some of *Rockefeller*'s stablemates in the Standard Oil fleet, survived single torpedo strikes and remained afloat for a considerable time. *U-701* had scored a hit on the Norwegian freighter *Tamesis* two days prior to attacking *Rockefeller*, but *Tamesis*' crew was able to beach the ship and it was later repaired and put back into service (USCG 1942c). Similarly, the Standard oil tanker *Paul H. Harwood*, torpedoed ten days after *Rockefeller*, managed to limp into port under its own power even though it had sustained damage comparable to that inflicted on *Rockefeller* (refer to FIGURE 2.7) (Standard Oil 1946:327-329).

Captain Stewart stated that *Rockefeller* had neither developed a list nor begun to settle after it was torpedoed, suggesting that the ship's watertight integrity beyond the immediate area of the torpedo strike was not compromised. Further, the Navy commented that it was unusual for *Rockefeller* to have sunk despite sustaining "relatively minor damage," and that no reason for this had yet been ascertained (OCNO 1942b; OCNO 1942d; USONI 1942a:14).

Given all this, a second successful attack from *U-701* is a plausible explanation for *Rockefeller*'s sinking. It is, of course, also plausible that *Rockefeller* did go down on its own, but the coincidence of timelines--2338 according to the Coast Guard vs. shortly after 2330 according to Degen--lends strength to the latter's account (USCG 1942c; Offley 2014:211-212). This study has assumed that this is the most probable scenario and proceeded accordingly, though a definitive answer will have to wait until the wreck is located and examined.

The matter of the coordinates as given by uboat.net also needs to be addressed here, since they are a notable outlier. The account given by uboat.net is as follows:

> At 18.16 hours on 28 June 1942 the **William Rockefeller** (Master William R. Stewart), escorted by the US Coast Guard vessel **USS CG-460**, was hit on the port side amidships by one torpedo from U-701 while steaming on a nonevasive course at 9.2 knots about 16 miles east-northeast of Diamond Shoals Light Buoy. The torpedo struck at the pump room, opened a hole about 20 feet in diameter, sprayed oil over the ship and caused the flooding of the pump room and the #5 tank. As the cargo caught fire and flames engulfed the stern, the nine officers, 35 crewmen and six armed guards (the ship was armed with one 3in gun) abandoned ship in four lifeboats and were picked up after 20 minutes by the escort, which landed them at the Ocracoke Coast Guard Station the same afternoon. The U-boat was unsuccessfully attacked by the escort and a US Coast Guard aircraft and sank the drifting and burning wreck with a *coup de grâce* in 35°11N/75°07W at 05.25 hours on 29 June (uboat.net 2021).

As noted in previous chapters, this account contains some errors of fact. Its statement that *Rockefeller* was attacked at 1816 and sunk at 0525 can be accounted for when one remembers that it is apparently based on *U-701*'s KTB, which was kept according to Central European Time (CET), six hours ahead of Eastern War Time (EWT) (Degen 1942c). Correcting for this gives an attack time of 1216 and a sinking time of 1225, matching the other accounts of *Rockefeller*'s loss. However, the other errors cannot be easily accounted for. *Rockefeller* was being escorted by *CG-470*, not *CG-460*, as confirmed by a review of the former's deck logs (USCG 1942). Another error is its statement that all four lifeboats were launched, when Captain Stewart's account confirms that two of the boats were lost due to hasty launching (OCNO 1942d).

It seems probable that the writer from uboat.net used Degen's reconstructed KTB as their primary source, given the time discrepancies. However, the website does not cite the war diary, nor does it provide any sources for any of its other information, especially the coordinate data it provides. By itself, this would be grounds for caution in using this account as a basis for historical research. The errors in the account also suggest that either the sources uboat.net used were flawed, or the website's writer did not double-check their writing. It seems probable that the latter is the case. Combined with the errors of fact, it becomes evident that this source should be given accordingly light weight. While none of these errors are grievous enough to warrant discarding the coordinate data out of hand, it is problematic that this data has no citation to back it up. Accordingly, these coordinates have been given the lowest priority in the search maps.

Scenario 3: Strengths and Weaknesses

Scenario 3 is not a particularly compelling version of events. There exists no evidence for it beyond a single primary source and a few references to this source in books and reports produced after the event (USCG 1945; Offley 2014; Hoyt et al. 2021). Unlike the first two scenarios, it is not frequently accepted by secondary sources; when it is mentioned, this appears to be mainly for the sake of completeness, as in Ed Offley's book and NOAA's report on the Battle of the Atlantic (Offley 2014:215; Hoyt et al. 2021:7-278).

It also conflicts with the majority of the primary sources, from Captain Stewart's affidavit to the documents filed by the Office of the Chief of Naval Operations to the Eastern Sea Frontier's war diary to KptLt Degen's memoir to the Coast Guard's own casualty report from 1944, which are unanimous in asserting that *Rockefeller* sank just before midnight on the 28th. This lends weight to the idea that *Rockefeller* was mistaken for another drifting ship, or that there was otherwise some miscommunication about what had occurred.

The scenario also has some logical holes. If *Rockefeller* really had survived to the following day, why would it be scuttled as a hazard to navigation? Despite the breached storage tank and fire, it was still carrying most of its cargo of heavy fuel oil, a precious commodity in wartime. *Rockefeller* itself was a valuable war asset, as it was one of the largest oil tankers in existence at a time when ships of that type were desperately needed to supply the Allied war machine and were being sunk on a near-daily basis. It seems unlikely that the Navy or the Coast Guard would have so quickly written off a potentially salvable ship and cargo. Indeed, a Navy tug had been dispatched from Norfolk to take *Rockefeller* in tow prior to its loss (OCNO 1942d:3). Active-duty members of the Coast Guard have agreed with this assessment (Ian Brown 2022, pers. comm.; Matthew Mitchell 2022, pers. comm.). Also, when a wreck is destroyed as a hazard to navigation, it is typically because it is obstructing a harbor or shipping lane. *Rockefeller* would have drifted well out of the normal shipping lanes by the morning of the 29th, so would not have presented a threat to any ship following those routes. Taken together, all these factors militate against accepting Scenario 3 as a plausible account of *Rockefeller*'s loss. It has been included for the sake of completeness and to ensure that all bases have been covered in terms of predictive modeling and mapping.

Findings

The maps and models created in this study have yet to be tested, but they have already produced some interesting preliminary results. The primary search box, encapsulating the coordinates obtained from Captain Stewart and the Office of the Chief of Naval Operations, is 384 square nautical miles (nmi), only slightly more than half (51.2%) of the original search area of 750 nautical miles as proposed by NOAA (Basta et al. 2013:6). The size of the area can be reduced even further by focusing on the highest priority cells in the search grid, grids 1 through 10. In this case the search area is reduced to 160 sq. nmi, an eminently practicable size. Likewise, the secondary search grid is only 64 sq. nmi, positively miniscule when compared with the search areas above. That said, it is the lowest priority search area and may not need to be investigated at all. It should be noted that the grid cells are relatively large (16 sq. nmi each), but they can be easily subdivided into smaller grid squares when and if a search operation is launched. They have been set at their present size for the sake of simplicity in demonstrating this study's methodology.

A comparison of the data acquired from the author's GIS work and the data obtained from the SAROPS program shows a relatively high level of agreement between the data points. A comparison of the possible sinking locations identified by the author and the probability density clouds generated by SAROPS show that the former generally lie within areas of high probability as assessed by the latter (See FIGURES 6.1-6.12). The data points are not an exact match, but the level of coincidence is high enough to suggest that the Bayesian subjective probability analysis used by the author was reasonably effective in reconstructing *Rockefeller*'s drift track.

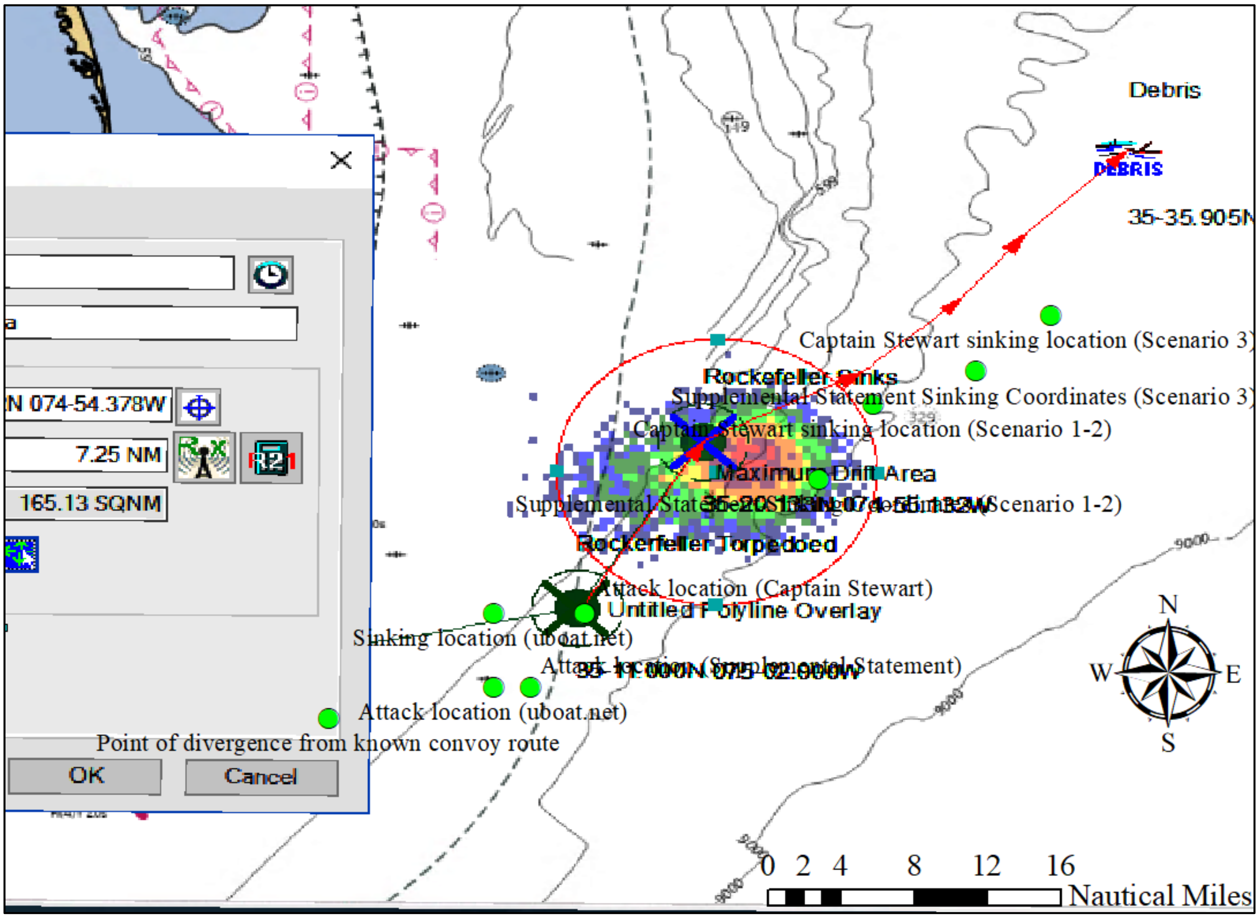


FIGURE 6.1. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 1 at time index 1900 EWT 28 June (0000 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

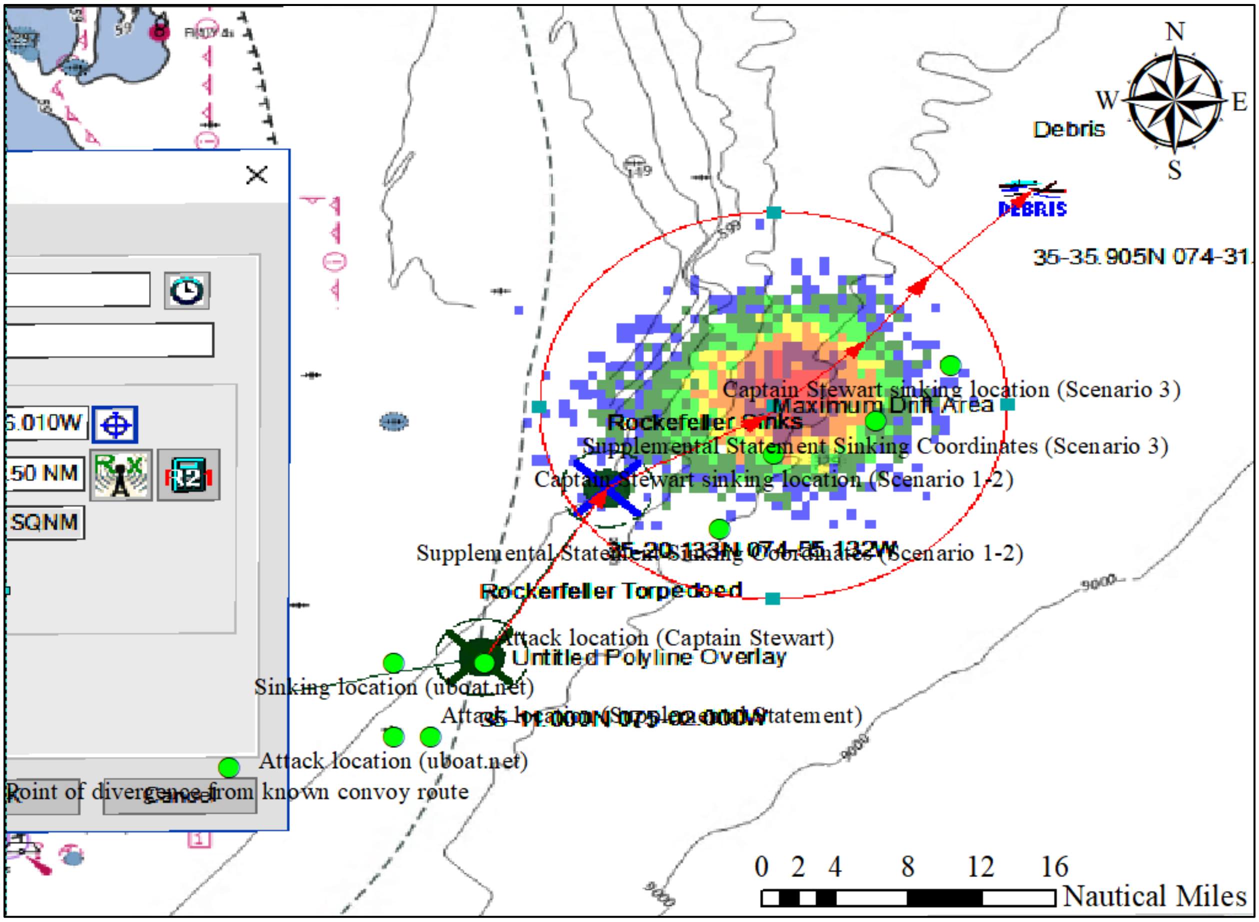


FIGURE 6.2. Comparison between the author’s sinking coordinates and probability density cloud from SAROPS Scenario 1 at time index 0100 EWT 29 June (0600 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

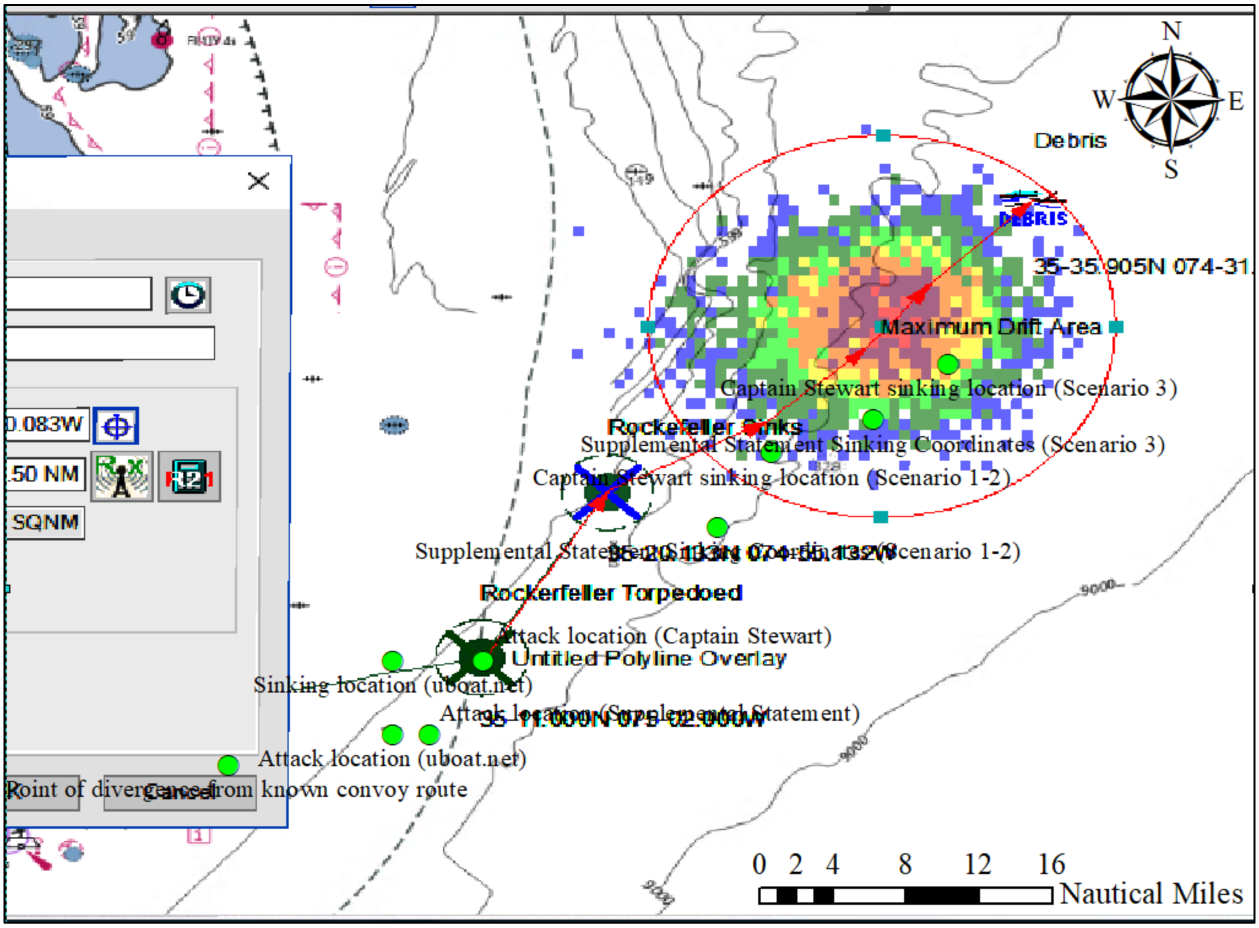


FIGURE 6.3. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 1 at time index 0500 EWT 29 June (1000 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

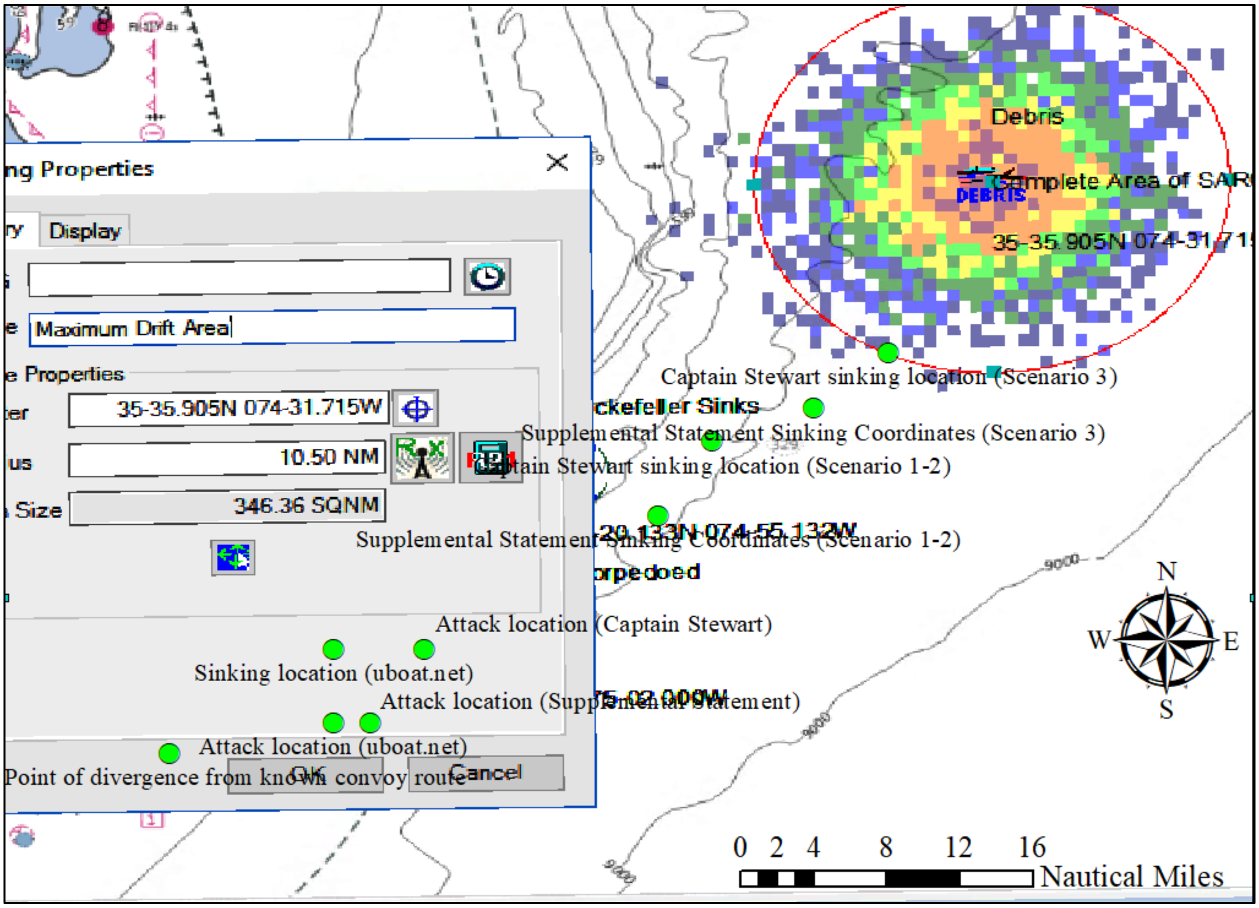


FIGURE 6.4. Comparison between the author’s sinking coordinates and probability density cloud from SAROPS Scenario 1 at time index 1100 EWT 29 June (1600 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

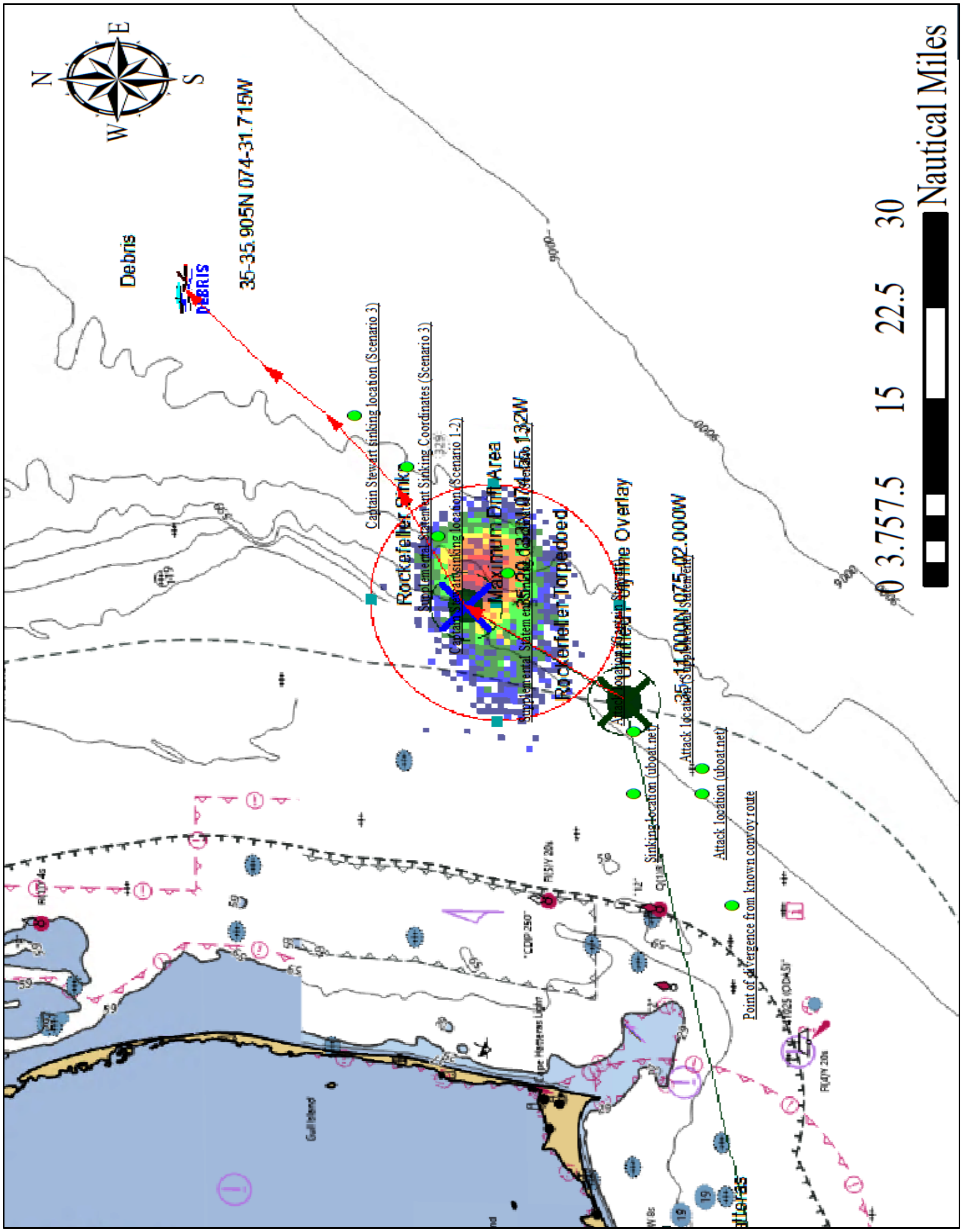


FIGURE 6.5. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 2 at time index 1900 28 June EWT (0000 29 June GMT). (Map created by the author and Senior Chief Ian Brown).

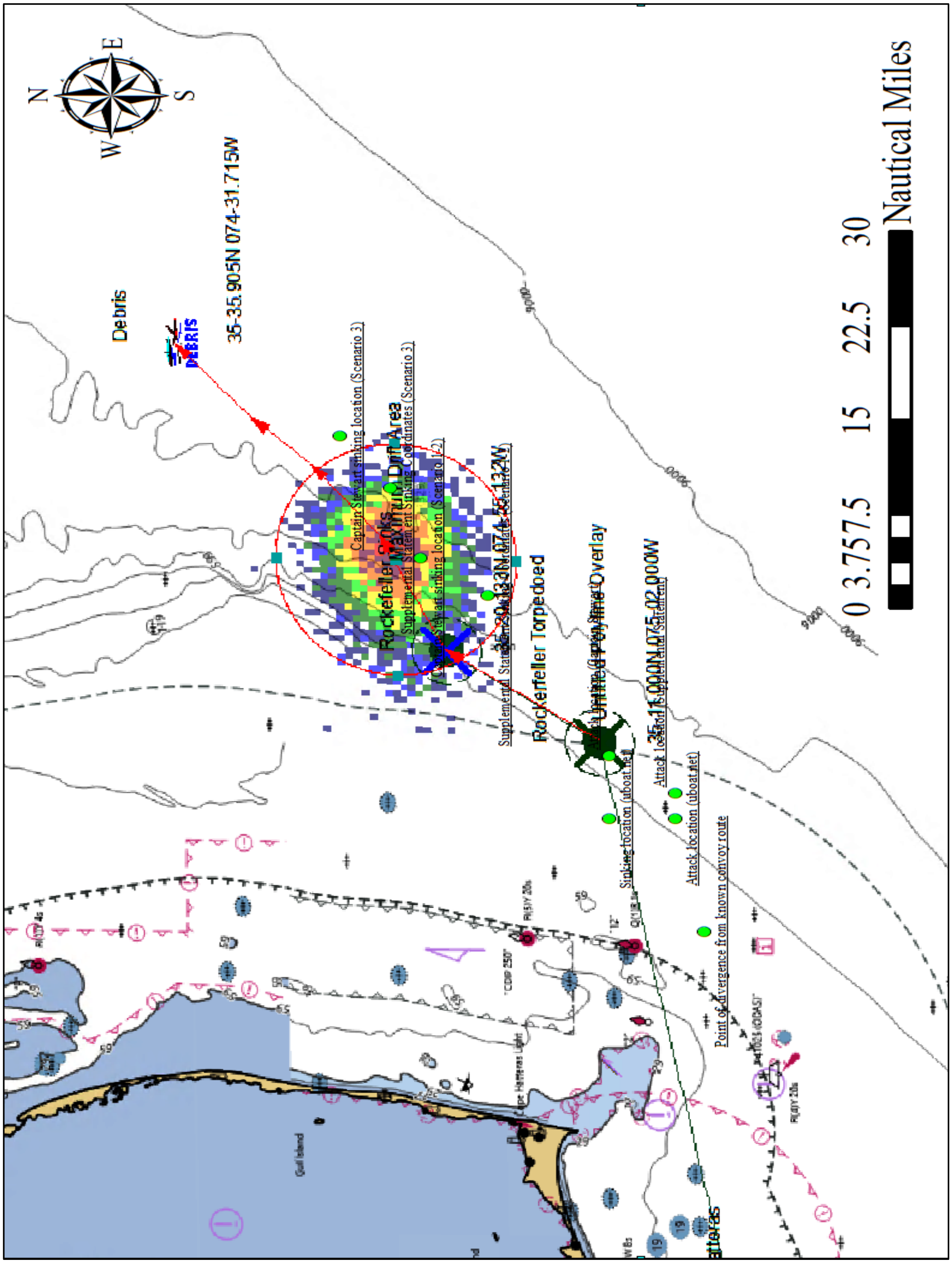


FIGURE 6.6. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 2 at time index 0100 29 June EWT (0600 29 June GMT). (Map created by the author and Senior Chief Ian Brown).

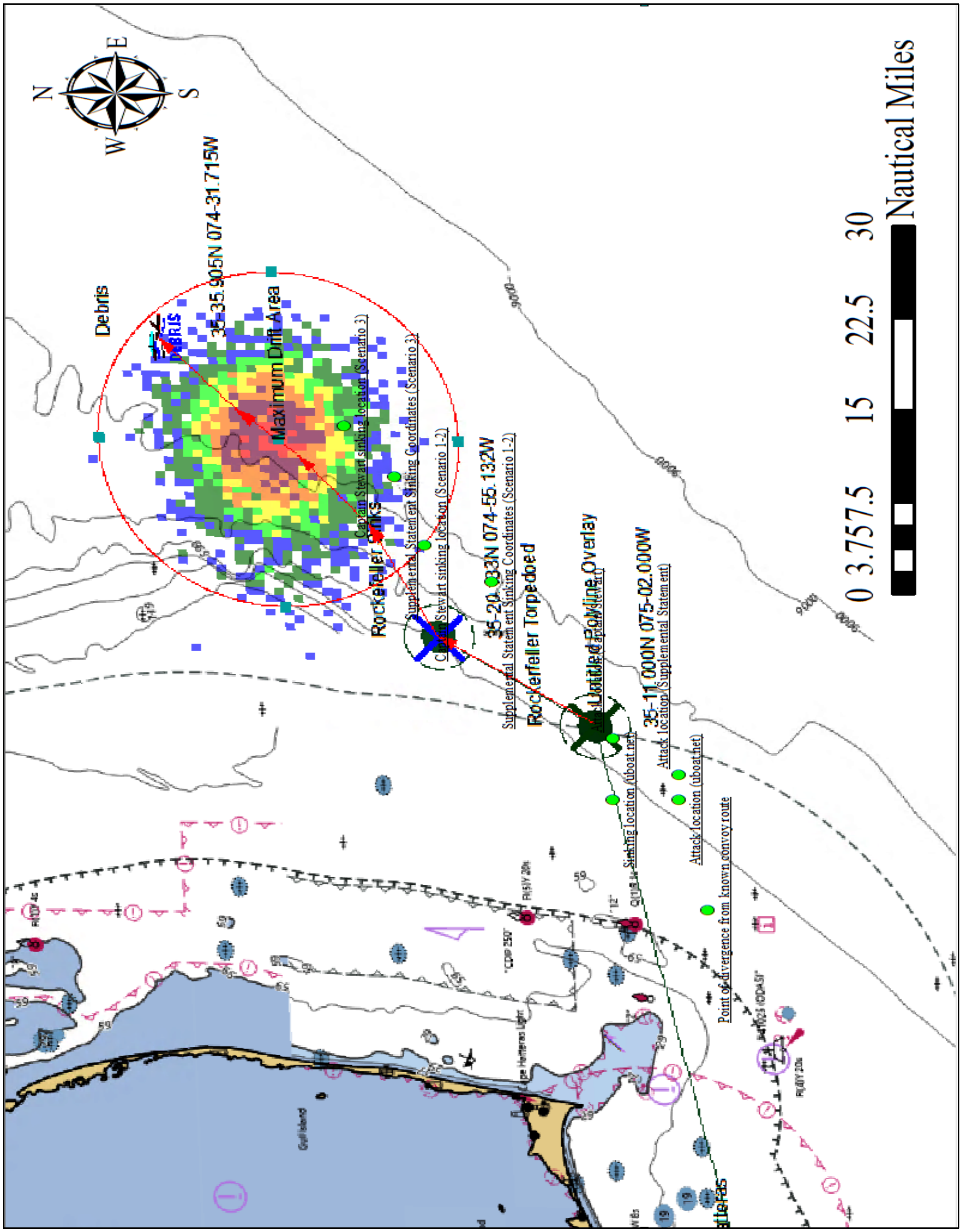


FIGURE 6.7. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 2 at time index 0500 29 June EWT (1000 GMT). (Map created by the author and Senior Chief Ian Brown).

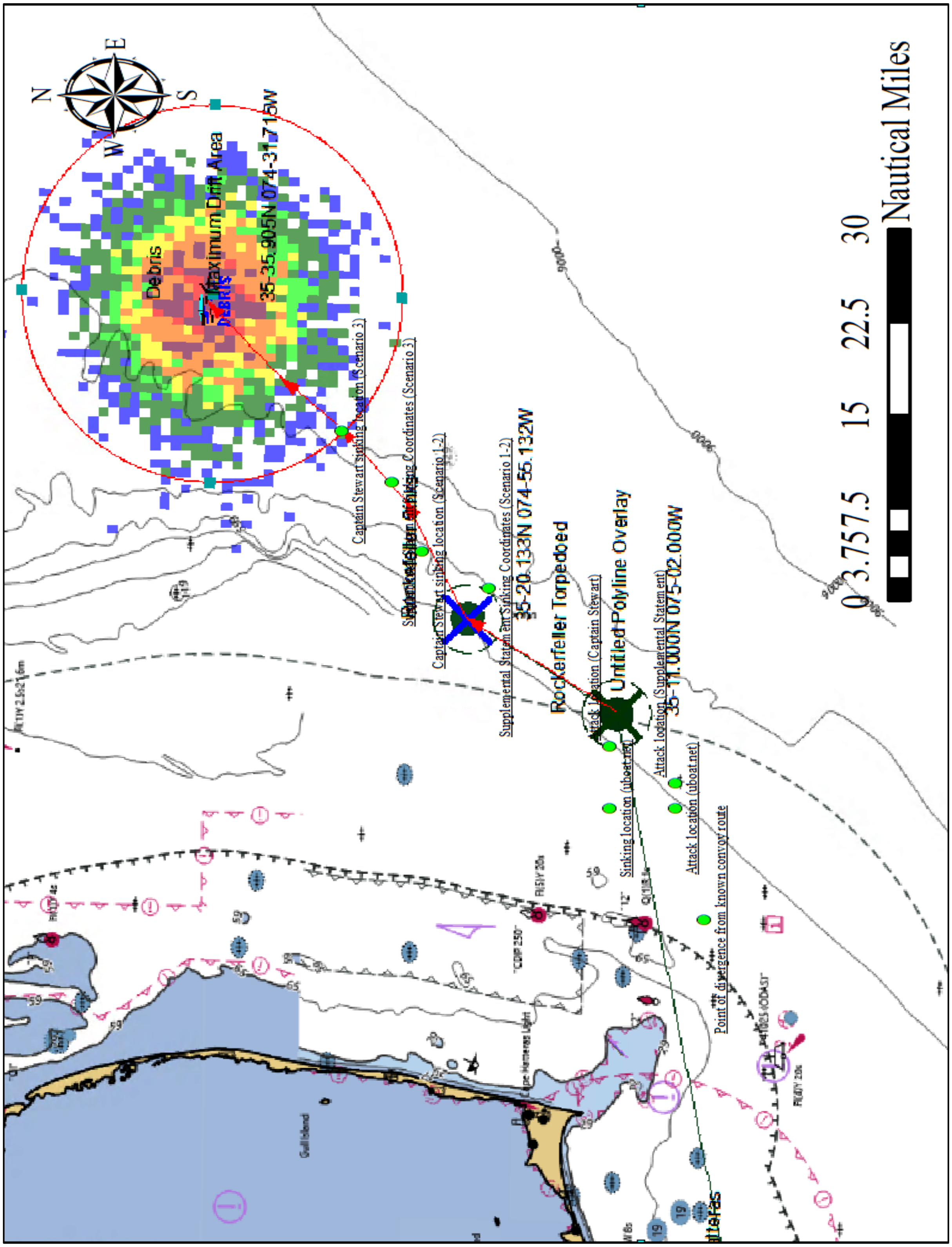


FIGURE 6.8. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 2 at time index 1000 29 June EWT (1600 GMT). (Map created by the author and Senior Chief Ian Brown).

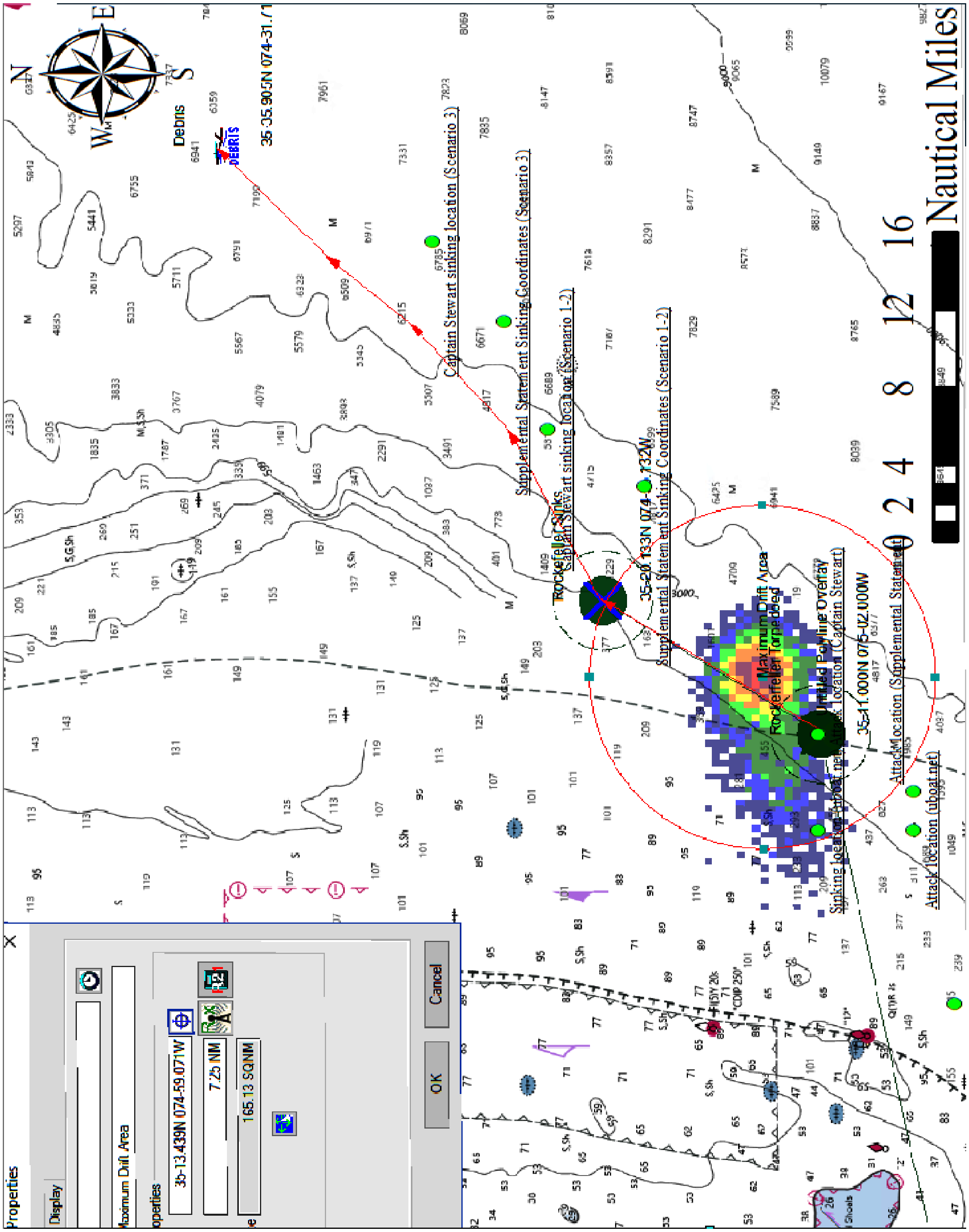


FIGURE 6.9. Comparison between the author's sinking coordinates and probability density cloud from SAROPS Scenario 3 at time index 1400 EWT 28 June (1900 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

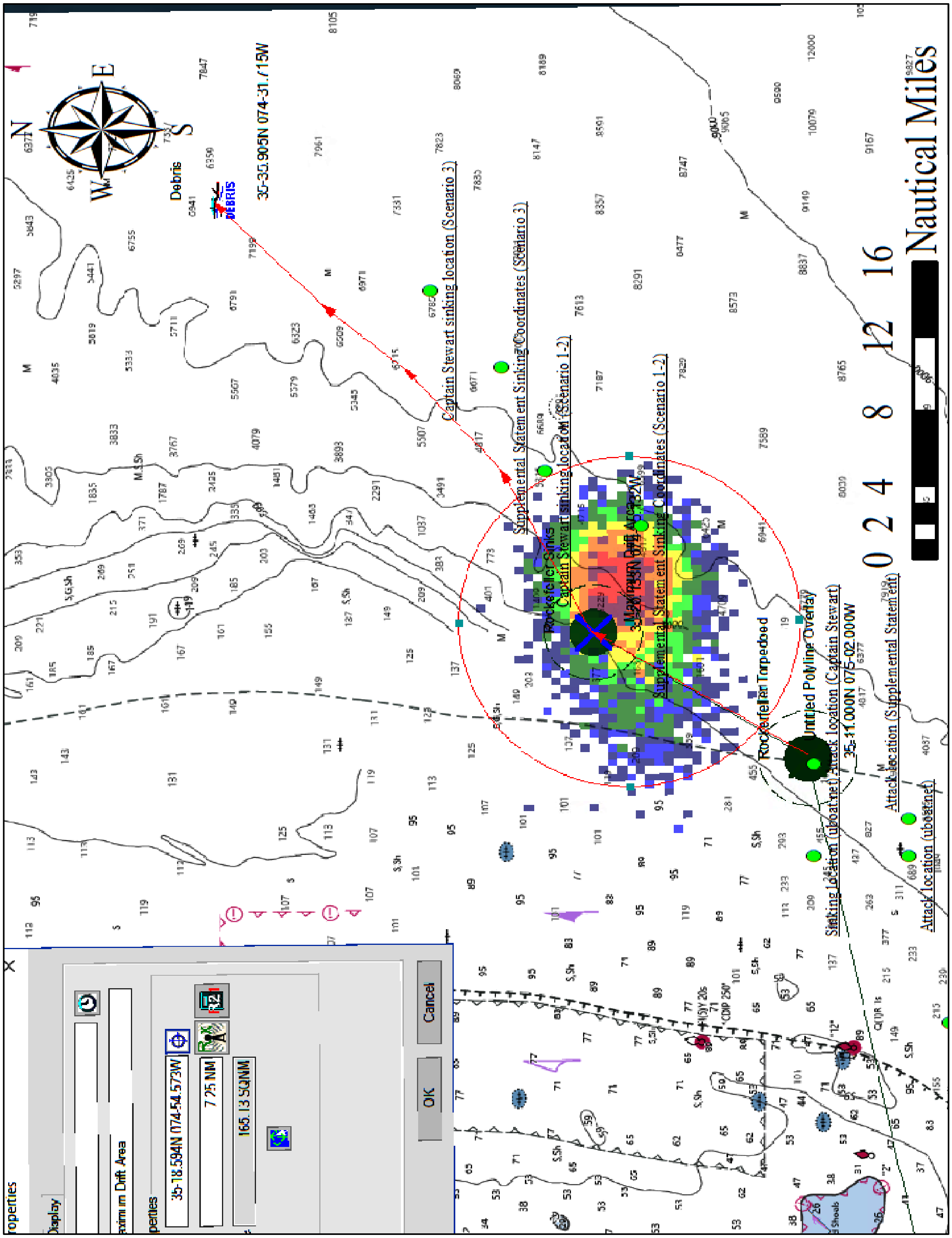


FIGURE 6.10. Comparison between the author’s sinking coordinates and probability density cloud from SAROPS Scenario 3 at time index 1900 EWT 29 June (0000 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

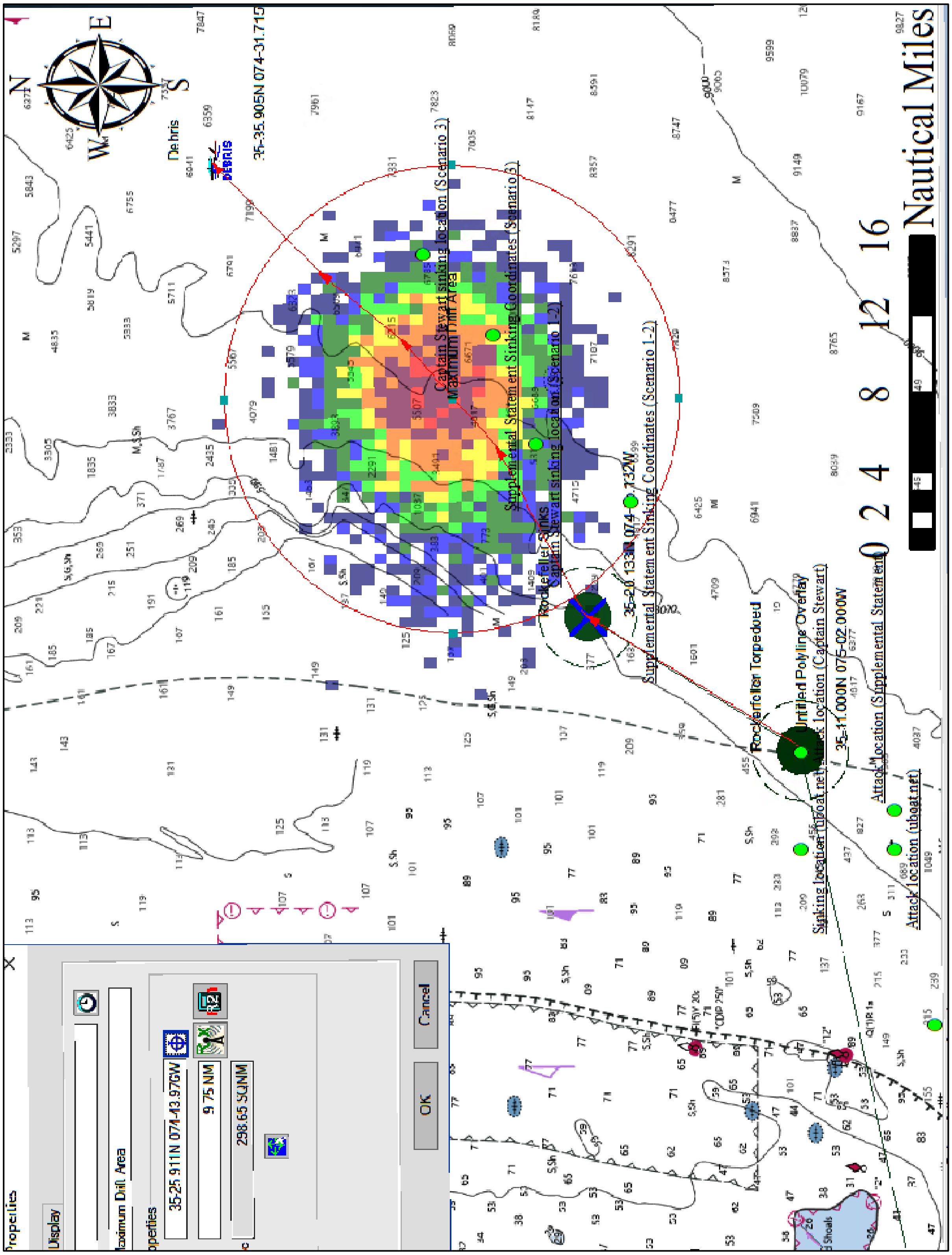


FIGURE 6.11. Comparison between the author’s sinking coordinates and probability density cloud from SAROPS Scenario 3 at time index 0200 EWT 29 June (0700 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

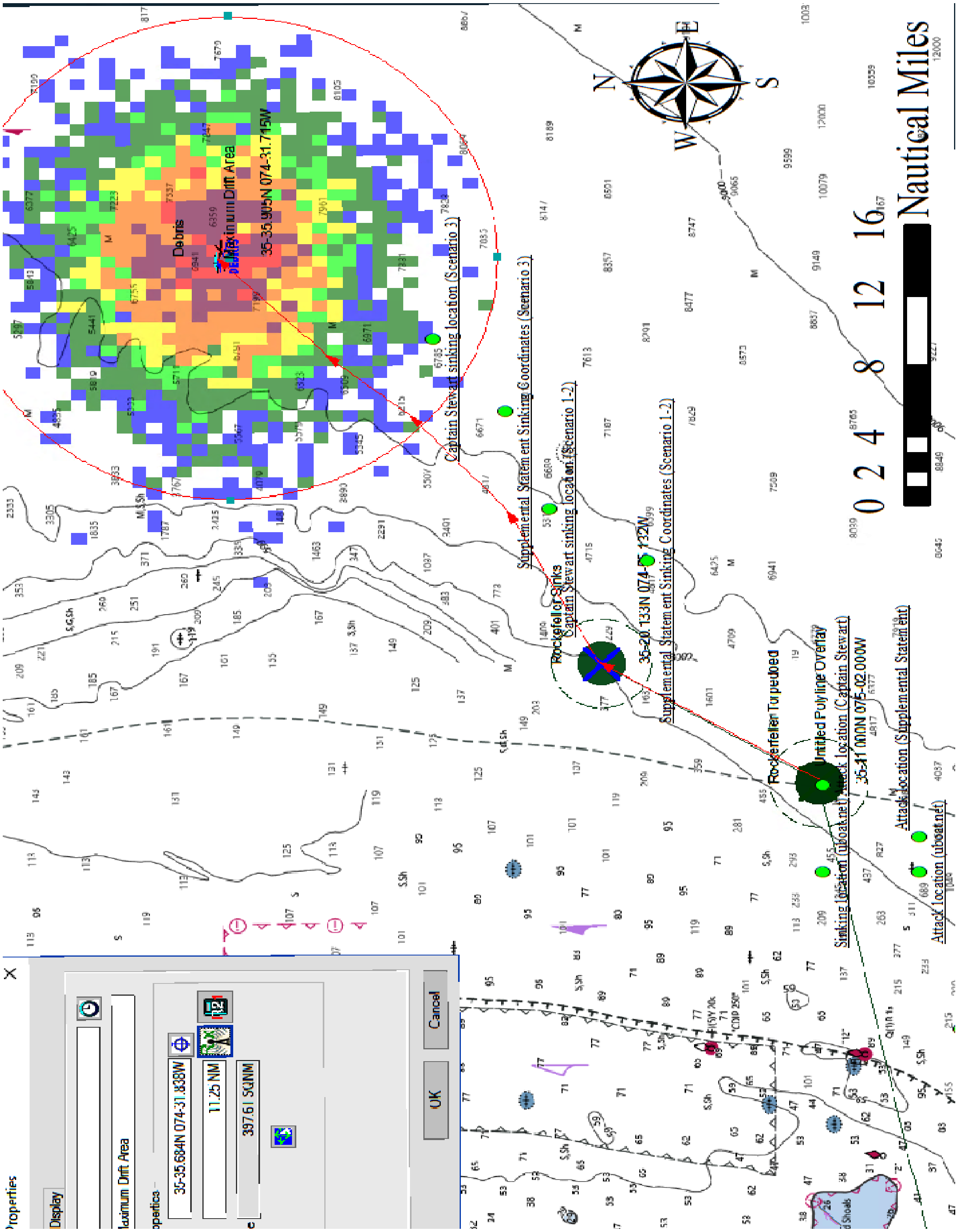


FIGURE 6.12. Comparison between the author’s sinking coordinates and probability density cloud from SAROPS Scenario 3 at time index 1100 EWT 29 June (1600 GMT 29 June). (Map created by the author and Senior Chief Ian Brown).

The third and fourth time stamps in each iteration of the SAROPS data represent a degree of drift that the author considers unlikely, as they suggest that *Rockefeller* remained afloat well into the morning of 29 June, against the evidence from the majority of the primary sources. Leaving aside these outliers, the highest density of probable sinking locations computed by both the author and SAROPS lies between 11 and 22 miles from the attack locations, which lends weight to the hypothesis that *Rockefeller* most probably drifted between 15-17 nmi and no more than 25 nmi before sinking (See FIGURE 6.13). The data points from SAROPS create a density cloud that is not so different from the cloud derived from the author’s GIS work. Combining all these points into a combined density cloud also yields a result that is not so different from the cloud derived from the author’s GIS study (see FIGURES 6.14-6.16 for a comparison). The SAROPS-only and combined density clouds extend further to the north due to the outlier scenarios, but the area of greatest density is broadly similar to that defined by the author’s work alone. Again, while this is by no means conclusive, it at least suggests that the methods used in this study are sound.

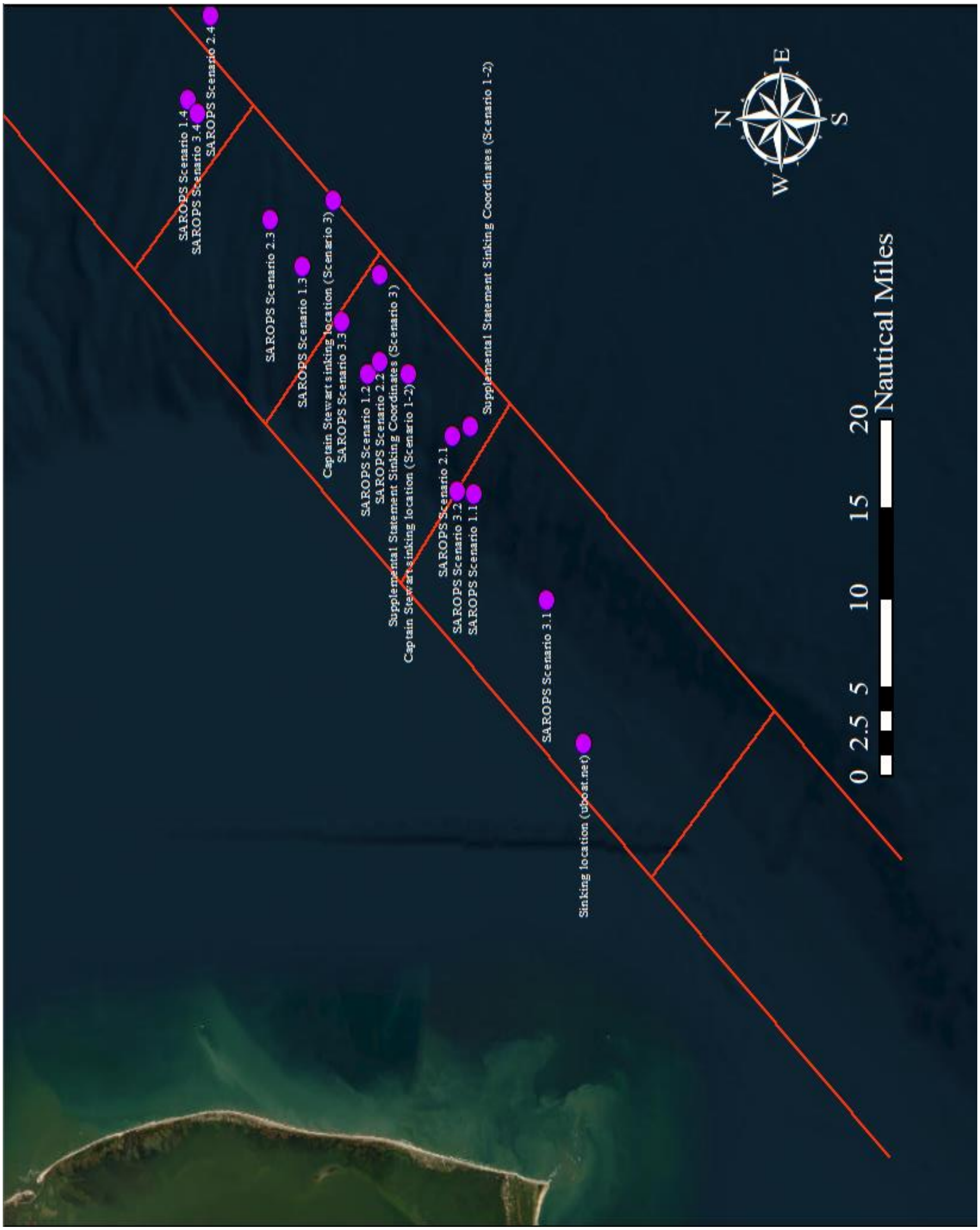


FIGURE 6.13. Point data derived from the author’s calculations and the center points of the density clouds created by Chief Brown, with the search grid from NOAA’s risk assessment package overlaid (Source: Basta et al. 2013b. Map created by the author and Senior Chief Ian Brown).

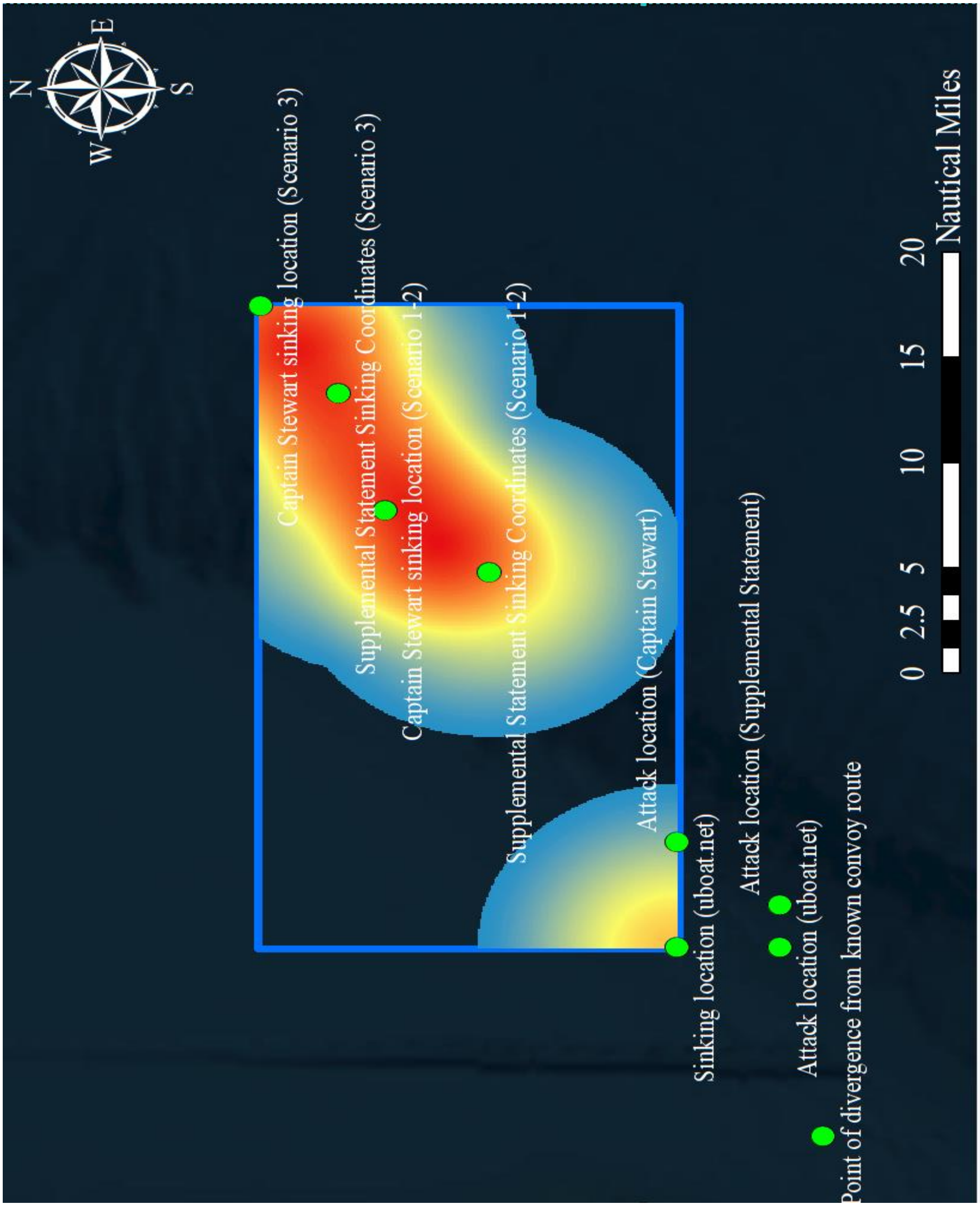


FIGURE 6.14. Density cloud created with points derived from the author’s GIS work (Map created by the author).

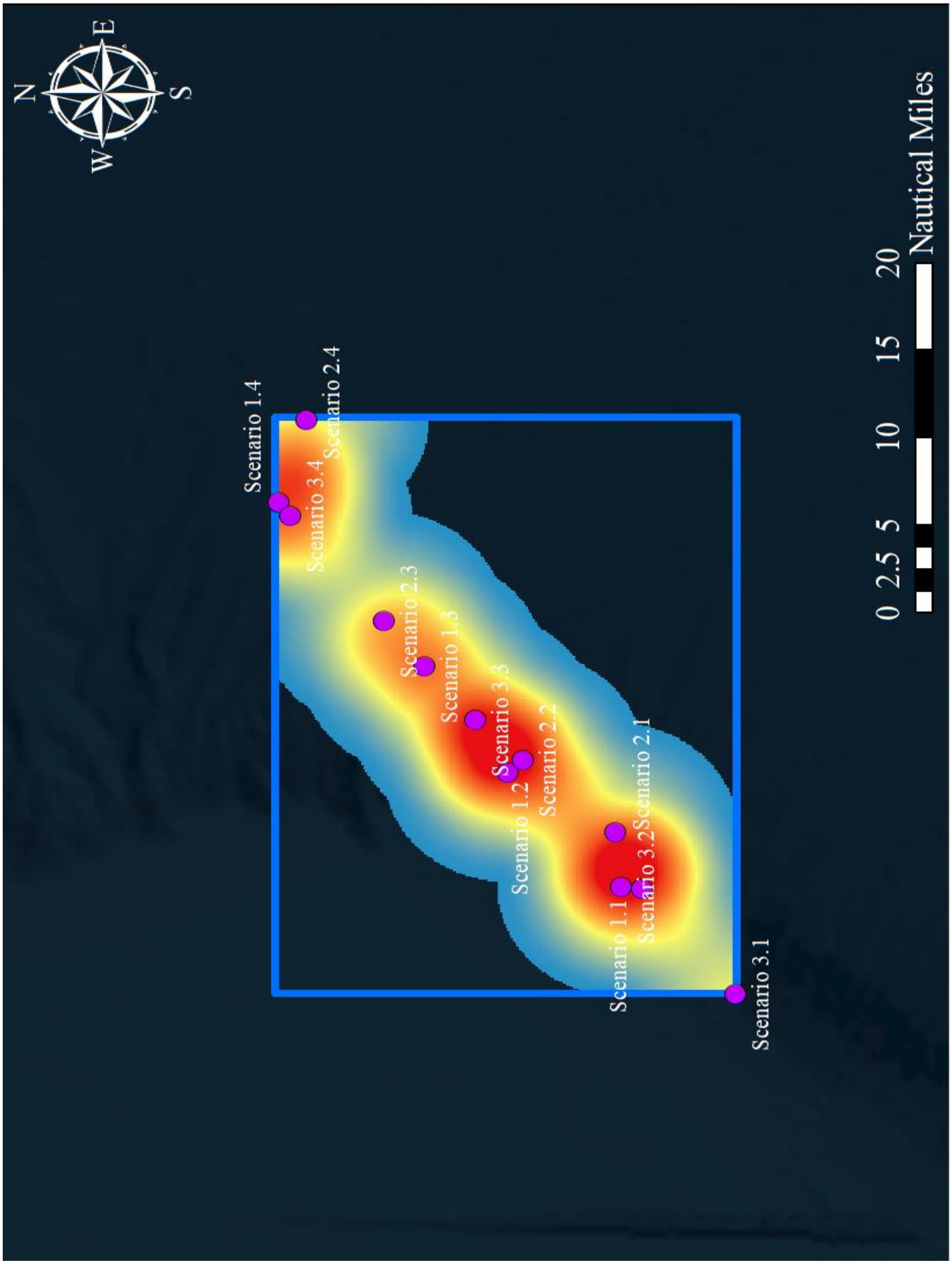


FIGURE 6.15. Density cloud created with points derived from Chief Ian Brown’s SAROPS simulations (Map created by the author and Senior Chief Ian Brown).

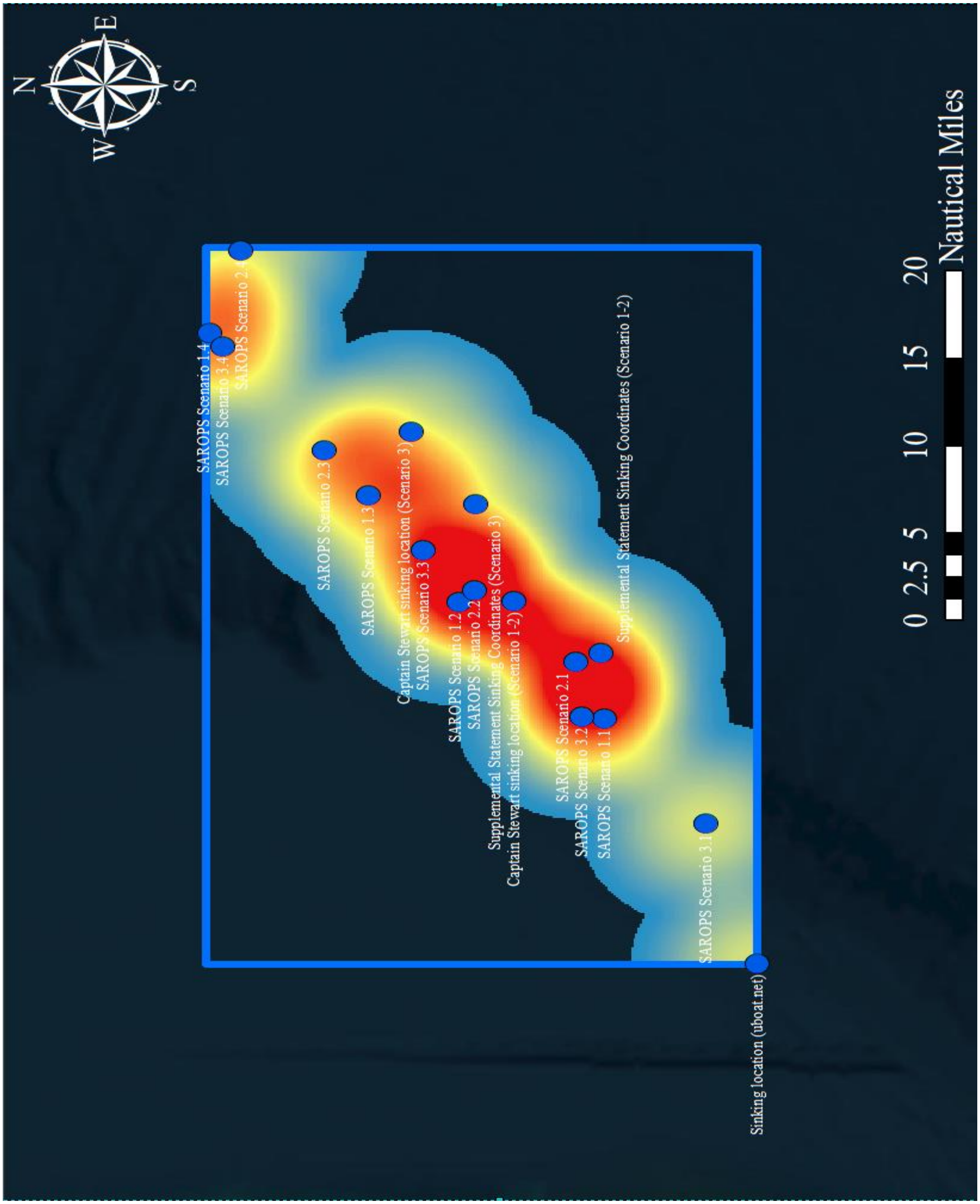


FIGURE 6.16. Combined density cloud containing data points from both the author's GIS work and Chief Ian Brown's SAROPS simulations (Map created by the author and Senior Chief Ian Brown).

The concept of the subjective probability assessment deserves consideration here, because it is at this point that art meets science in terms of search theory. While the underlying principles of search theory are scientific and rigorous in nature, there comes a point when one must weigh all the information for themselves and decide what they believe to be the most reliable data. This introduces the “human factor” into the system, for better and for worse. Humans can be taught to think scientifically and to organize their efforts along scientific lines, but intuition, preconceptions, biases, and other mental quirks will inevitably influence the result of any study. Even making what appears to be the most logical or rational choice available may still be the result of conscious or unconscious calculations and biases.

The *Central America* search expedition once again provides a relevant example of this phenomenon. Dr. Lawrence Stone and his colleagues acquired four different sets of coordinate data, two of which came from rescue ships that had responded to *Central America*’s distress signals and two of which came from members of the ship’s company. In their assessment of the relative reliability of these coordinates, they concluded that the coordinates from the rescue ship *Ellen* were most reliable, since that ship’s position fix was taken in clear weather and physically recorded in its log. It was also close to the position estimate given by one of the surviving passengers from *Central America* and by the work of Lieutenant Matthew Maury, who calculated a position from the data he acquired for his official report to the Secretary of the Navy on the sinking (Stone 1992:45-47). Taken together, these factors lent greater credibility to the *Ellen* scenario in Stone’s mind and that of his colleagues. Considering the weight of the evidence, it is hard to gainsay their decision even now. Despite this, Stone’s team did not discount the other scenarios they had developed, and when they successfully located *Central America*’s remains in 1987, they determined that the *Ellen* scenario was quite wide of the mark, and that the position estimate given by Captain William Herndon was in fact the most reliable, even though he had taken his fix during the height of the storm and passed it verbally to another vessel (Stone 1992:52-53).

Another instructive case is that of USS *Scorpion*. When that submarine was lost in 1968, the only solid evidence of its whereabouts was a series of acoustic anomalies recorded along the track that *Scorpion* was expected to take from its patrol station in the Mediterranean to its homeport of Norfolk, Virginia. The search team, led by Dr. John Craven, triangulated these anomalies via hydrophone data from monitoring stations in the Canary Islands and the Bahamas and identified the one which they believed represented *Scorpion*'s destruction, which was labeled "Point Oscar" (Sontag et al. 1998:95-100; Craven 2001:202-204).

Upon further examination of the data, Dr. Craven and some of his colleagues in the search team noted that the other acoustic anomalies, believed to be the sounds of the submarine's hull imploding, suggested that *Scorpion* had been traveling east, not west, when it sank; that is, it had been going in the wrong direction. If this were so, they wondered, why would it be going east? The conclusion that they reached was that *Scorpion* must have suffered a "hot run," a malfunction in one of its torpedoes that caused the weapon to arm itself while still inside the submarine. The standard procedure for disarming a hot-running torpedo was to execute a 180-degree turn, as this activated a set of failsafe systems that told the torpedo that it had reversed course and was in danger of striking its own ship. For whatever reason, they theorized, this emergency turn must not have been successful, and the torpedo must have detonated inside the pressure hull, triggering catastrophic flooding that doomed *Scorpion* and its crew (Sontag et al. 1998:98-100; Craven 2001:210-211).

Tests using explosive charges dropped at Point Oscar seemed to confirm the theory, as did a computer simulation of the scenario, the timing of which matched the acquired acoustic data almost exactly. With all this data in hand, Dr. Craven assembled a group of submarine experts and asked them to take bets on *Scorpion*'s fate, with bottles of Chivas Regal whisky wagered on the results. Craven once again brought in Dr. Lawrence Stone and his team, who used the betting results to produce a set of probability maps that placed *Scorpion*'s wreck east of Point Oscar, on the edge of the Sargasso Sea (Richardson and Stone 1971:143-145; Sontag et al. 1998:104-105; Craven 2001:212-213).

Despite this, no one else believed Dr. Craven and his team. Officers at the Ordnance Systems Command and Bureau of Ships insisted that a torpedo could not detonate inside a submarine's hull. The acoustic experts from whom Dr. Craven had obtained the data told him that he was chasing echoes. The chorus of dissent was so strong and unified that Dr. Craven himself began wondering whether he was wrong (Sontag et al. 1998:101-103; Craven 2001:208-210).

When a search ship was sent out, it focused its efforts to the west of Point Oscar, following the prevailing belief among the Navy officers and civilian scientists that *Scorpion* was traveling in that direction. When they found nothing but hull-shaped rocks in the area the Navy believed was most promising, the captain of the search vessel asked Craven to buy him time while he went east of Point Oscar. One week later, they located *Scorpion* only 237 meters from the grid cell in the search map with the highest probability (Richardson and Stone 1971:143-145; Sontag et al. 1998:104-106; Craven 2001:212-213).

While the truth of *Scorpion*'s loss remains a mystery, the results of the search were a vindication of Dr. Craven's methods and an excellent illustration of the way in which subjective human behavior can influence a search operation, both positively and negatively. The Navy understandably did not wish to accept that *Scorpion* might have been destroyed by a malfunctioning torpedo, as this could have suggested negligence or carelessness on their part. Thus, they completely discounted the possibility that *Scorpion* might have been running east to disable a hot-running torpedo. Meanwhile, the scientists that Dr. Craven consulted developed a different interpretation of the acoustic data and refused to budge even when he produced evidence that supported his theories. Craven himself acknowledged that he was operating on intuition, but pointed out that said intuition was backed by the data (Sontag et al. 1998:107-112; Craven 2001:210-211).

This factor of uncertainty and subjectivity has also been present in this study. As with the *Central America* search, the available datasets did not agree with each other, and as with *Scorpion* there was a relatively small amount of data to begin with. The essential facts of the case are not in doubt—*Rockefeller* was torpedoed at 1216, it drifted some distance before it sank, and its wreck remains missing—but there were three separate attack locations recorded, meaning that there were multiple potential sinking locations. Some of this data was of higher quality than the rest, and in the end the choice of which to trust most boiled down to a subjective choice on the part of the author. In this case, it was the choice to assume that Captain Stewart's position data was most reliable. The ship was attacked shortly after he had finished taking a position fix at noon; indeed, he was logging this position in the ship's chart room when *U-701*'s torpedo struck home (OCNO 1942d:2). Moreover, his version of events remained generally consistent across the years; though some details were altered in his later recollections, these were related to his actions and those of his crew and did not affect his recounting of the attack, the coordinates, or *Rockefeller*'s last hours.

Likewise, the author has chosen to assume that KptLt Degen was telling the truth when he claimed to have sunk *Rockefeller* with a second torpedo. The choice was made easier by the fact that most of the information supporting Degen's claim overlaps with that of the scenario in which the tanker sank on its own; as mentioned in previous chapters, it is entirely possible that the US Navy and Coast Guard processed Degen's second attack on *Rockefeller* as the tanker sinking on its own. Like Captain Stewart, Degen's account remained coherent and reasonably consistent, even when recounted 25 years *ex post facto*, and it is otherwise difficult to account for *Rockefeller* sinking after a single torpedo hit when other Standard Oil tankers like *Paul H. Harwood* and *Esso Nashville* survived equivalent or greater damage and remained afloat long enough to be brought into port (Standard Oil 1946:159-161, 328-330).

Discussions with interested individuals, including maritime historians and active-duty Coast Guard personnel, have tended to support the author's choices. Some have proposed that all three scenarios could be true. In this instance, it is suggested that Degen attacked *Rockefeller* a second time, after which the ship settled in the water to such a degree that Degen believed it had gone down. However, *Rockefeller* remained afloat long enough to be spotted and sunk the next day by the Coast Guard (Ian Brown 2022, pers. comm; Robert Browning 2022, pers. comm.; Matthew Mitchell 2022, pers. comm.; William Thiesen 2022, pers. comm.). The author concedes that this version of events is not outside the realm of possibility but again regards it as unlikely, since Degen stated that he personally observed *Rockefeller*'s sinking from the bridge of his U-boat (Offley 2014:212-214).

Conclusion

While no definitive conclusions can be drawn at this time, the initial results of this study's work show some promise. The two methods employed--manual calculations and mapping in ArcGIS and SAROPS Monte Carlo simulations--have produced a set of potential sinking locations which, while not in exact agreement, are clustered in a relatively small area. This suggests that both methods are fundamentally sound, even though there is no overlap between individual points. These differences can be attributed to the inherent uncertainty of manual calculations, which cannot quickly account for potential shifts in wind and current speeds over the period in question without being repeatedly recomputed. SAROPS is able to account for these shifts, and indeed the simulations were run using a variety of wind and current speeds across the total time of the scenario presented. This is not to say that the coordinates presented by SAROPS are more accurate, because there is no way to know this is the case without a search, but it may be said that they are more precise, in that the simulations can account for dynamically shifting variables in a way that the manual calculations cannot.

The clustering of the data points, however, is suggestive. The greatest concentration of potential sinking locations lies within the area that the author estimated was most likely for *Rockefeller* to have drifted prior to going down, suggesting that this estimate was reasonably accurate and that these data points can offer a basis for a full search expedition. Even if this study’s maps and model prove not to be successful in locating *Rockefeller*’s wreck, the results from an unsuccessful search can be fed into the model and used to plan a new search area.

CHAPTER SEVEN: CONCLUSION – WHERE DO WE GO FROM HERE?

Introduction

Several questions were posed at the beginning of this study, all of them relevant not only to the search for *William Rockefeller*, but also for maritime archaeology and history in general. These questions were as follows:

1. *What is the potential of GIS-based mapping software and predictive modeling methods for locating shipwrecks off the coast of North Carolina?*
2. *How can researchers account for inaccuracies in historical documents to refine shipwreck search models?*
3. *How can researchers account for the effects of ocean currents and vessel drift as reported in historical documents in order to refine the models they use to search for shipwrecks?*

There remain many wrecks around the Outer Banks and Cape Hatteras that have yet to be relocated, to say nothing of the many thousands of shipwrecks worldwide whose final resting places remain unknown. Developing a practical and repeatable search method with GIS or similar software will be of use to the North Carolina maritime research community as it seeks to find and chart these wrecks. Finding answers to the other questions is also important, since they are two of the biggest variables with which maritime archaeologists and researchers must contend when searching for shipwrecks.

Since there are no search results to analyze at this time, this concluding chapter will consider the three questions above, and whether they have been answered satisfactorily. It will also dissect the maps and models to identify their strengths, as well as any potential weaknesses or blind spots in their creation. Further, it will discuss the possibility of using these maps and models in a potential search expedition for *Rockefeller*’s wreck.

Questions and Answers

Question 1--*What is the potential of GIS-based mapping software and predictive modeling methods for locating shipwrecks off the coast of North Carolina?*--has already been answered prior to this study. John Bright’s 2012 thesis demonstrated that GIS-based mapping and modeling methods can indeed be successfully used to search for North Carolina shipwrecks, since his work led to the relocation of the wrecks of *Bluefields* and *U-576* off Cape Hatteras (Bright 2012; NOAA 2014; Dolan 2016). Thus, the potential of GIS-based mapping and modeling for shipwreck searches not only exists but has been proven, as Bright developed a sound, repeatable method for using GIS to plot a search area for missing shipwrecks. However, the differences between Bright’s case and this study’s mean that his methodology could not be repeated exactly, so a variant had to be developed which relied on different analytical techniques. Whereas Bright used line and kernel density analyses to generate his maps, this study depended primarily on kernel density analysis and Bayesian probability. The question of whether this study’s work will be useful remains open, but the variant presented herein still fulfills the criterion of repeatability; that is, given sufficient data, it is certainly possible to follow the steps outlined in the methodology chapter to create similar predictive models and search maps.

Question 2--*How can researchers account for inaccuracies in historical documents to refine shipwreck search models?*--is an issue for researcher working with primary sources. All eyewitness accounts are based on human memory, which is a flawed and fallible thing at the best of times. Shipwrecks, of course, are far from the best of times. Both Captain William Stewart and Kapitänleutnant Horst Degen provided eyewitness accounts of the initial attack on

Rockefeller that are consistent, coherent, and detailed; likewise, KptLt Degen recounted his claimed second attack on *Rockefeller* in a clear and precise manner, even down to remembering the distance from which he claims to have hit the tanker with a second torpedo (Offley 2014:213-214). Because of this, it is tempting to take their words at face value, without further fact-checking. However, there were several factors which militated against doing so. A discussion of these factors appears in the previous chapter and need not be repeated in detail here, but the essentials are as follows.

In the immediate aftermath of *Rockefeller*'s loss, Captain Stewart was interviewed by Navy officers and provided an affidavit containing his firsthand account of the sinking. Four years later, he altered some aspects of his account in order to take responsibility for his crew's actions during the attack, whether out of a captain's sense of propriety or a desire to obfuscate the fact that he had briefly lost control of his crew due to the circumstances (OCNO 1942c; OCNO 1942d; Standard Oil 1946:322-324). While the broad strokes of his account remained the same, these alterations required a reexamination of both versions of the story to ensure that no crucial details had been changed.

Likewise, KptLt Degen provided two separate accounts of his attack on *Rockefeller*. The first account was delivered to enemy interrogators after a 49-hour ordeal in the Atlantic which pushed him to his mental and physical limits. By his own admission, Degen was delirious and losing his grip on reality during the second day in the water. Either of these factors could have influenced his statements; indeed, Degen repeatedly lied to interrogators by stating that his submarine had not been carrying mines on its patrol. It is not outside the realm of possibility that he left out or obfuscated key details of his claimed attack, deliberately or accidentally (Degen 1942c:2; USONI 1942a:10-12, 15, 60). The second account was set down in his unpublished memoir *U-701: Glory and Tragedy*, which journalist Ed Offley later used as a source for his book *The Burning Shore*. This memoir was written 23 years after the events of 28 June 1942, and in it there are signs that Degen's memory of events may not have been clear; though some details are vivid and precise, others appear to have become blurred by the passage of time, such as his conflation of the number of ships sunk by his minefield (Offley 2014:162).

The mutability of human memory in times of crisis is a source of endless frustration for researchers and historians who must rely on primary sources produced under such conditions. Martin Gibbs offers an analysis of this phenomenon in his study of crew and passenger behavior during the 1629 shipwreck of the Dutch East India Company trading ship *Batavia* (Gibbs 2002). Following on from the work of survival psychologist John Leach, Gibbs proposes a five-stage framework for analyzing human behavior during crisis situations:

1. The pre-crisis stage – the sequence of events prior to the disaster.
2. The impact stage – the disaster and its immediate aftermath.
3. The recoil stage – the stage after the immediate threat to life has passed.
4. The rescue stage – when the person or persons involved are removed from danger.
5. The post-trauma stage – the medium and long-term effects of the event (Gibbs 2002:67).

All these stages have effects on human behavior, memory, and psychology, and Gibbs notes that they all influence how the event in question is recalled. Of particular importance in this case are the impact and post-trauma stages. Gibbs argues that humans, when confronted with unexpected crisis, will default to one of three behavioral patterns. Some (approximately 20%) will remain calm and focused, either through training and experience or natural mental resilience. Others (~75%) will tend to a state of bewilderment, in which their actions become mechanical and reflexive, and their thought processes and perceptions are impaired. Another group (~10-15%) will react with panic behaviors such as crying, screaming, or sinking into a mental paralysis that keeps them from acting to save themselves (Gibbs 2002:73-74). He further notes that the danger to life in a crisis may be compounded when people who are operating on reflex take actions that seem decisive and purposeful; people who are frozen or uncertain will often follow someone who seems to know what they are doing, even if that person is making unwise decisions (Gibbs 2002:74-75).

Based on Stewart's account, it seems probable that most of his crew fell into the second group. Chief Engineer Snyder seems to have been acting purely on reflex when he shut down the engines, since *Rockefeller* was hit amidships and was not in immediate danger of suffering a boiler explosion or other casualty in the engineering spaces, which Captain Stewart recognized. Likewise, it is probable that the rest of the crew had defaulted to reflexive behaviors, which in this case would be to escape the inferno swallowing their ship by any means available. It may also be the case that a few of the crew went for the lifeboats on reflex and brought the rest along with them, driven by the instinct to follow someone who looked like they knew what they were doing. It does not seem that anyone among the crew suffered a complete breakdown or nervous paralysis, since they were all able to evacuate the ship quickly and in relatively good order despite the fouled boats.

Captain Stewart, by contrast, appears to have kept his cool, though it is possible that he massaged his later account to present a better picture of his actions during the event. Gibbs notes that survivors of a crisis, especially those in positions of authority, often need or feel compelled to justify their actions in the post-trauma stage once the danger is past and they have had some chance to process their experiences. Captain Stewart may have wanted to justify abandoning his ship when he personally believed it could still be saved, especially since he was making a statement to his employer about the incident (Gibbs 2002:78-79).

The same questions may be asked of KptLt Degen's account, especially since he experienced a significantly greater degree of trauma than Captain Stewart. Both captains lost their ships, but only Degen spent two days in the water while his crew died around him before being captured and interrogated by the enemy. Even the steadiest of people will be mentally and emotionally affected by such a traumatic series of events. Some of the sailors who survived the U-boat's sinking appear to have fallen into Gibbs' second group, with impaired thought processes and reflexive actions contributing to their deaths, while others slid into the third group as exhaustion, exposure, and thirst took effect. Only a few of the survivors kept their heads all the way through; by his own admission, Degen was not one of them (USONI 1942a:15-17, 60).

On the other hand, though he was delirious for part of his time in the water, he does not seem to have succumbed to panic or despair as some of the other sailors did, and his recovery once on land was quick. Leaving aside his deliberate obfuscation *vis-à-vis* the mines, his statements regarding his second attack on *Rockefeller* from both 1942 and 1965 generally agree with each other, in broad strokes if not fine details. This study has previously considered the idea that he had invented his second attack on *Rockefeller* to inflate his tonnage record, but dismissed it on the grounds that it was unlikely for him to have done such a thing. Degen had already conducted a successful patrol up to that point; as far as he knew, he had sunk three ships with torpedoes and gunfire and a fourth with the minefield he laid outside Chesapeake Bay (Degen 1942c:1-3). It may be noted here that two of the ships Degen believed he sank were only damaged and were able to make port, but at the time he had no way of knowing this. Too, Degen's account of sinking *Rockefeller* aligns with other primary sources, which state that the wreck sank at about the same time he claimed to have made his second attack (USONI 1942a:13-14; Degen 1942c:2-3; Offley 2014:214-215). Thus, though Degen's account is not wholly reliable, there is no reason to doubt his version of the events surrounding *Rockefeller*'s sinking.

Another example of this question is the account of *Rockefeller*'s demise given by uboat.net. As noted previously, this account contains several errors of fact and does not cite any primary sources. It appears to have been based on *U-701*'s KTB, but without references or citations it is impossible to be sure. Likewise, it is unclear from where the website obtained the coordinates that it listed for the sinking locations, since they do not match any of the other coordinate sets given in other sources. These issues may be explained by the fact that this account was written for a private website that is maintained by and for enthusiasts of the Kriegsmarine's submarine arm; academic rigor is not a primary concern for this audience. Unfortunately, this is also one of the few accounts of *Rockefeller*'s loss that is readily available to the public without searching through archives and online databases. This may be why it was used in the NOAA risk assessment package. By appearing in an official document published by a government agency, the account may be given more weight than it is due.

This is a capsule illustration of the process by which errors or obfuscations can be repeated until they gain the weight of fact. An individual sets down an account that contains certain inaccuracies, omissions, or falsehoods, whether included accidentally or deliberately. A credible source repeats these errors, other credible sources cite the first, and eventually these inaccuracies become part of the historical record, accepted as fact in the minds of the general public, historians, and researchers until they are challenged by new research or other primary sources. It should be noted that this process need not occur out of malice or deliberate obfuscation, especially if the account in question has been produced many years after the event.

A modified version of Hanlon's Razor may be applied here: never attribute to malice that which is adequately explained by the fallibility of human memory.

The case of *U-869* is another example of this problem. The historical record stated that the U-boat had been sunk off Gibraltar, but the only evidence for this assertion was the reports of an American destroyer and French patrol boat that had depth-charged a suspicious sonar contact. Neither ship saw a submarine or recovered any bodies or debris; the only "proof" they could offer was a smell of oil that lingered in the air after their depth charges went off. At the time, Navy intelligence concluded that their attacks had no result. After the war, however, the need to account for missing U-boats led the postwar assessors to revise this initial conclusion, stating that the two vessels must have sunk *U-869*. Despite being based on sketchy data and faulty assumptions, this version of events was accepted as fact by many scholarly and governmental sources until it was proved false by a determined crew of divers in the 1990s (Admiralty 1946:23; OCNO 1963:172; Hessler 1989:115; Hoyt 1989:222; Kemp 1997:235; Niestlé 1998:239; Kurson 2004:253-258).

The answer to Question 2, then, is not so easy to determine. Though it is tempting to accept eyewitness accounts and similar primary sources at face value, it must be remembered that they are not always reflective of the actual course of events. They may even be outright fabrications, created *ex post facto* to justify the witness's behavior or paint themselves in a more positive light. One may say "trust, but verify"; that is, assume the source is truthful, or at least reflects what its author believes to be the truth, but check it against other primary sources for possible discrepancies or omissions. It is fortunate in this case that Captain Stewart and KptLt Degen both survived to produce accounts of *Rockefeller*'s sinking, as it allowed their recollections to be compared to each other and the other available sources. In this way it was discovered that, while Stewart had changed some parts of his account over the years and that Degen had lied to his interrogators, their general recollections of *Rockefeller*'s sinking agreed with each other and with the other available sources, suggesting that these portions of their accounts can be taken as reliable.

If there are no other sources available, or those that do exist have disagreements that cannot be easily reconciled, resolving discrepancies becomes a more difficult proposition. In this case, the researcher's task becomes subjective, as they must weigh the relative trustworthiness of the available sources, consider any corroborating evidence and the wider context of the event, and decide which of them seems to be most reliable in their eyes.

The search for *Central America* is an example of this process. In that case, Dr. Lawrence Stone and his team had four primary sources for the steamship's last moments, none of which agreed as to where *Central America* was when it went down. They had to balance these sources against each other, then consider the conditions under which each position estimate was produced. Dr. Stone and his colleagues ultimately decided to accept the account of the rescue ship *Ellen* as most reliable, as several factors militated in its favor, including other position estimates that tracked quite closely with that of *Ellen*'s captain. In that case, ironically, the most "reliable" source turned out to be wrong, and one of the other sources (that of *Central America*'s captain) turned out to be more accurate. This did not fatally undermine Stone's work, since he still incorporated the less likely scenarios into his probability map, but it does indicate the potential pitfalls that await even a meticulous researcher (Stone 1992:45-47, 52-53).

The answer to Question 3--*How can researchers account for the effects of ocean currents and vessel drift as reported in historical documents in order to refine the models they use to search for shipwrecks?*--is simple, in theory. In practice, it may be the hardest of the three to answer. The ocean is a dynamic and ever-changing environment. Even relatively stable currents like the Gulf Stream and the Humboldt Current have seasonal and yearly shifts in their strength and directional flow, influenced by climatic conditions and weather systems like El Niño. Likewise, while some types of wind may be relatively predictable, such as trade winds or monsoons, there are daily and even hourly shifts in wind speed and direction on the open ocean. It is therefore not enough to say that "SS *Fulgrim* sank at X latitude and Y longitude in the Azores Current, so it must have been traveling A direction at B speed," because this is not necessarily accurate, depending on local conditions at the time. The researcher or archaeologist must obtain current data, so to speak, in order to properly model the conditions on the spot where *Fulgrim* sank.

If one is searching for a recent wreck (i.e., a wreck from the early 20th century to present), this problem is simplified somewhat, as there now exist several repositories which collate monthly, daily, and even hourly observations on ocean waves, tides, atmospheric conditions, precipitation, and other weather-related data, including NOAA's National Centers for Environmental Information (NCEI), which hosts a variety of datasets on ocean conditions, weather patterns, climatic variations, and related topics. These databases are not a panacea for the issue, as their data is skewed toward certain regions of the globe. It may also lack detailed observations depending on the year; the farther back one goes in time, the sketchier the data becomes (NOAA 2022).

Returning to the example of *Central America*, Dr. Stone's team solved the problem by acquiring compiled wind and current data for the month in which the ship sank from the NCEI's predecessor, the Naval Oceanographic Data Center (NODC) and created a bivariate distribution of the current speeds to account for the uncertainty of their data. This distribution yielded an average current between 0.2-0.4 kt, with a standard deviation of 0.1kt in either direction (Stone 1992:41-42). Stone’s team was able to use a specialized computer program to create scenarios based on each of these current speeds, but such tools may not always be available to the researcher, in which case manual calculations will be required.

In the case of this study, the question was not insuperable. Another applicable quote from Sherlock Holmes springs to mind: “Data, data, data! I can’t make bricks without clay” (Doyle 1892:289). Here, the clay came from a combination of primary and secondary sources assembled from archives, libraries, personal collections, and the internet, all of which aided in the reconstruction of ocean and weather conditions on the day of the attack.

The primary sources, including *CG-470*’s deck logs and the statements collected from *Rockefeller*’s crew, indicated that the weather was calm and mostly clear on 28 June, with very light winds and scattered showers. *CG-470*’s logs were especially helpful, as its crew recorded general weather observations every four hours; it therefore captured a snapshot of the conditions at 1200, only a quarter of an hour prior to the attack. The author was also fortunate enough to locate a 1942 publication on the currents of the Atlantic coast which contained averaged observations and current maps of the portion of the Gulf Stream proximate to *Rockefeller*’s last known position, much like the data Dr. Stone and his team obtained from the NODC. Combined with other primary sources that gave information on *Rockefeller*’s drift speed after its abandonment and its probable direction, this enabled the construction of predictive models via ArcGIS and the Coast Guard’s SAROPS program, similarly to Dr. Stone and John Bright’s work (Stone 1992; Bright 2012).

In the end, it seems that there will almost always be a certain amount of interpretation or educated guesswork that goes into compensating for ocean conditions and vessel drift in shipwreck searches, even if one is fortunate enough to find data on the specific weather and current conditions of the day. In the case of this study, the best data that could be obtained stated that wind speeds were never higher than 3 kt on the day of *Rockefeller*'s sinking, and that the Gulf Stream was known to average 0.66 knots in the month of June. While not as specific as could have been hoped for, it was still valuable information that allowed the author to calculate *Rockefeller*'s most likely direction of travel and the approximate distance it could have drifted before sinking.

Next Steps and Final Thoughts

This study has aimed to present a methodology of shipwreck search based on the use of Bayesian theory, GIS mapping, and SAROPS software. This methodology has yielded interesting initial results, but there are some refinements that can be made to the process.

SAROPS' primary use is for search and rescue operations. It therefore has limitations which may affect its utility as a tool for shipwreck searches. One such limitation is its cap on vessel length; as previously mentioned, the maximum length that can be entered into SAROPS is 300 feet. In the context of this study, this meant that Senior Chief Brown had to find a way to run two separate versions of each of his scenarios and then combine the results (Ian Brown 2022, pers. comm.) It also depends on current data on weather and sea states; the program's internal database of weather and data conditions reaches back only to 1970, meaning that, as in the case of this study, using it for a wreck predating that year requires the researcher to obtain contemporary data on their own, which can be a challenge depending on the time period of the wreck in question (Ian Brown 2022, pers. comm.).

As mentioned in Chapter 3, there exists a modified version of SAROPS which has been tailored specifically for shipwreck searches (Roylance 2007:4D; Ryan 2015). Obtaining this version of the program and using it to test the data obtained for this study would be helpful in determining the validity of the methods employed herein, and this may be a future goal for the author.

The true acid test of this study's work, however, will be a search expedition that uses its maps and models to look for the wreck. Given the depths of water in which *Rockefeller* most probably lies (1463-2133 m), any such expedition would require significant funding, a dedicated survey platform, and remote sensing equipment capable of operating in deep water, such as remotely operated or autonomous underwater vehicles. NOAA is an obvious choice for obtaining funding and equipment. They have ships, personnel, and underwater vehicles suited for deepwater searches, and the organization has expressed interest in locating *Rockefeller* due to its historical significance and its status as a potential pollution risk (NOAA 2011a-b; Basta et al. 2013; Hoyt et al. 2021; NOAA 2023).

Also interested in a potential search are the Ocean Foundation and the United States Coast Guard, both of whom are concerned with *Rockefeller*'s pollution risk. Preliminary discussions with representatives of the Ocean Foundation and the Coast Guard have already indicated that funding and other support may be made available from these sources if the data from this study is deemed to be sufficient to launch a search with a reasonable expectation of success. Dr. Michael Brennan of SEARCH, Inc., has also expressed an interest in relocating *Rockefeller* as part of his ongoing project to locate potentially polluting wrecks in American waters (Ole Varmer 2022, pers. comm.; Matthew Mitchell 2022, pers. comm.; Michael Brennan 2023, pers. comm.).

The problem presented in this study is not a new one. For as long as ships have been sailing the world's oceans, they have been sinking in circumstances that leave a great deal of doubt or uncertainty as to their last hours or minutes afloat. Finding these wrecks has presented historians, archaeologists, and other interested parties with a conundrum that has no easy answers. However, the last forty years have seen the rise of technologies which have made solving these mysteries much easier. Combined with careful research and a bit of inventive thinking, the catalogue of relocated wrecks has been greatly expanded with the names of ships that were once deemed unlikely or impossible finds, such as HMS *Erebus* and HMS *Terror*, Shackleton's *Endurance*, USCGC *Bear*, and USS *Indianapolis* (Watson 2016; Nunez 2018; United States Naval Institute 2021; Endurance22 2022).

As stated in previous chapters, the author does not believe that the problems presented in this study are insuperable. Shipwrecks have been found in much deeper water and much larger search areas with much less data. The only issues that currently interfere with a search for *Rockefeller* are the same that complicate all shipwreck searches: time, money, and equipment. If these things can be obtained, the author believes that there is a reasonable chance of locating *Rockefeller*. The author does not promise instant success; indeed, it may be that the conclusions reached in this thesis are in error. Even if this proves to be the case, the data acquired in an unsuccessful search can be used to refine the maps and models created in this study and provide an updated search area for a future expedition.

William Rockefeller is a wreck worth finding, for several reasons. First is its historical value. As mentioned at the beginning of this thesis, *Rockefeller* and its sibling ship *John D. Archbold* were the largest oil tankers in the world when launched, a record they held for some time. It was involved in two notable historical events, the 1939 NMU tanker strike and the Battle of the Atlantic; it is one of six Battle of the Atlantic wrecks off the coast of North Carolina that remain missing (*Wall Street Journal* 1921; *Baltimore Sun* 1923; *New York Times* 1939; *Socialist*

Appeal 1939; Willett 1990; Dolan 2016). Moreover, it is now the only extant ship of its class in the world, since *Archbold* was scrapped in 1963 (Mariners' Museum 2022). This also means that it is probably the only remaining example of the Gatewood-type framing that was developed at Newport News Shipbuilding from Joseph Isherwood's patented framing system. This combination of historicity and uniqueness make *Rockefeller* a valuable historical artifact; indeed, NOAA officials have suggested that it should be considered for nomination to the National Register of Historic Places (Basta et al. 2013b:7)

That said, locating *William Rockefeller* is not just an issue for historians and archaeologists. The wreck's cargo of heavy fuel oil makes it a potential danger to the Outer Banks and the people, flora, and fauna who call the region home. Finding it will allow experts to assess *Rockefeller*'s condition after 80 years of immersion in the ocean and begin planning how best to remove the oil from the wreck or to mitigate the impact of potential leaks, should removal be unfeasible.

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