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Sustaining the Undersea Advantage: Disrupting Anti-Submarine Warfare Using Autonomous Systems

BRYAN CLARK, SETH CROPSEY, AND TIMOTHY A. WALTON

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Hudson Institute
1201 Pennsylvania Avenue, N.W.
Fourth Floor
Washington, D.C. 20004

+1.202.974.2400
info@hudson.org
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Cover: A pilot with the "Grey Knights" of VP-46 flies a P8-A Poseidon during intelligence surveillance reconnaissance drills on July 17, 2020. At the time of this photo, VP-46 had recently transitioned from the P-3C Orion platform to the P-8A and was preparing for an upcoming deployment to the 6th Fleet Area of Operations. (US Navy)

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ABOUT THE AUTHORS

Bryan Clark

Senior Fellow & Director, Center for Defense Concepts and Technology

Before joining Hudson Institute, Bryan Clark was a senior fellow at the Center for Strategic and Budgetary Assessments (CSBA) where he led studies for the DoD Office of Net Assessment, Office of the Secretary of Defense, and Defense Advanced Research Products Agency on new technologies and the future of warfare. Prior to joining CSBA in 2013, Mr. Clark was special assistant to the Chief of Naval Operations and director of his Commander's Action Group, where he led development of Navy strategy and implemented new initiatives in electromagnetic spectrum operations, undersea warfare, expeditionary operations, and personnel and readiness management. Mr. Clark served in the Navy headquarters staff from 2004 to 2011, leading studies in the Assessment Division and participating in the 2006 and 2010 Quadrennial Defense Reviews. Prior to retiring from the Navy in 2008, Mr. Clark was an enlisted and officer submariner, serving in afloat and ashore submarine operational and training assignments including tours as chief engineer and operations officer at the Navy's nuclear power training unit.

Seth Cropsey

Senior Fellow & Director, Center for American Seapower

Seth Cropsey began his career in government at the Defense Department as Assistant to the Secretary of Defense Caspar Weinberger and subsequently served as Deputy Undersecretary of the Navy in the Reagan and Bush administrations. In the Bush administration, Cropsey moved to the Office of the Secretary of Defense to become acting assistant secretary, and then principal deputy assistant Secretary of Defense for Special Operations and Low-Intensity Conflict. Cropsey served as a naval officer from1985-2004. From 1982 to 1984, Cropsey directed the editorial policy of the Voice of America. Returning to public diplomacy in 2002 as director of the US government's International Broadcasting Bureau, Cropsey supervised the agency as successful efforts were undertaken to increase radio and television broadcasting to the Muslim world. Cropsey's work in the private sector includes reporting for Fortune magazine and as a visiting fellow at the American Enterprise Institute, and as director of the Heritage Foundation's Asia Studies Center from 1991 to 1994.

Timothy A. Walton

Fellow, Center for Defense Concepts and Technology

Prior to joining Hudson, Timothy Walton was a research fellow at the Center for Strategic and Budgetary Assessments (CSBA) where he led and contributed to studies and war-games for the U.S. government and its allies on new operational concepts and force planning. Previously, Mr. Walton was a principal of Alios Consulting Group and an associate of Delex Consulting, Studies, and Analysis, both defense and business strategy firms. During this period, he led and supported studies for the U.S. Navy and Army that developed road maps for future technologies, analyzed Asia-Pacific security dynamics, and assessed U.S. and Chinese concepts. He also facilitated strategic planning, capture shaping, and acquisition due diligence for commercial and defense companies.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Submarines have posed a challenge to naval forces for more than a century, enabling weaker maritime powers to launch surprise attacks ashore or cut an opponent off from the sea. But submarine threats, and the difficulty of countering them, increased substantially for the United States and its allies during the past decade. The Chinese People's Liberation Army Navy (PLAN) is modernizing its fleet with conventional air-independent propulsion submarines (SSPs) that support its broader sensor and weapon networks. It is also fielding nuclear-powered attack submarines (SSNs) and ballistic missile submarines (SSBNs) capable of longer or more distant deployments. New generations of Russian Federation Navy (RFN) SSNs are difficult to track and could be employed for conventional or nuclear strikes during a conflict. Both China and Russia are augmenting their submarine fleets with large autonomous underwater vehicles (AUVs) incorporating submarine-like capabilities. Modern submarine technology has also proliferated, with the North Korean and Iranian navies using submarines and AUVs to level the playing field with their larger regional competitors and the United States.

Unfortunately, the current US and allied approach to anti-submarine warfare (ASW) is unlikely to be able to cope with the probable scale of undersea threats during a crisis or conflict. US Navy ASW concepts rely on fixed seabed sensors such as the Sound Surveillance System (SOSUS) or Surveillance Towed Array Sensor System (SURTASS) ships to detect and initially track submarines. Multiple maritime patrol aircraft and guided missile destroyers (DDGs) then monitor each adversary submarine before potentially passing it to an SSN for longer-term surveillance.

The Navy's current ASW approach works when opposing submarines deploy infrequently, but is likely to break down during a large-scale submarine deployment or as submarines become quieter and harder to track. When manned platforms and expendables such as sonobuoys or torpedoes run out or are needed elsewhere, ASW operations will necessarily collapse to a defensive strategy protecting high-value targets, instead of suppressing enemy submarine operations closer to the adversary's waters. This may result in unlocated adversary submarines operating in the open ocean, where they could threaten US and allied shipping and maritime operations.

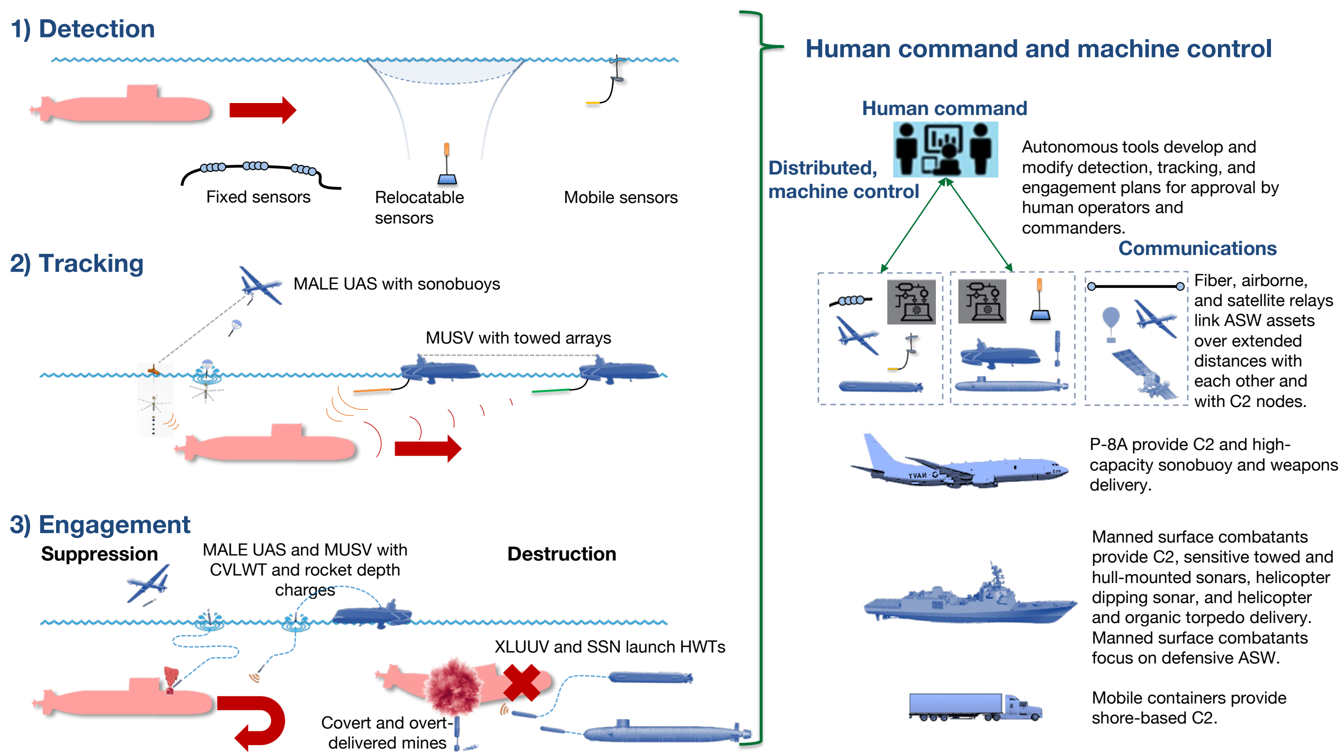
US and allied ASW concepts are also expensive, requiring significant manpower and tying up multi-mission platforms like DDGs and SSNs that are needed elsewhere for other operations, such as air defense or anti-surface warfare. These approaches may be unaffordable in a period of flat or declining defense budgets and would likely be unsustainable during confrontation or conflict against a capable submarine force. To address the rising submarine threat, US and allied militaries need a new approach to ASW that is more affordable and effective.

Leveraging Mature Unmanned Technologies

The US Navy and allied navies can regain an ASW advantage by adopting ASW concepts that focus on offensive ASW operations and rely primarily on unmanned systems for finding, tracking, and suppressing enemy submarines. By reducing the cost of ASW operations and enabling them to scale, an unmanned approach to ASW executes a classic business disruption strategy, whereby a cheaper and less sophisticated alternative displaces the incumbent as technologies improve and user needs stay the same.

Mature technologies for autonomous vehicles, deployable sonars, automated acoustic processing, and communications networking are creating new opportunities for submarine detection, tracking, and engagement. Combined with new, more offensively oriented ASW strategies and tactics that exploit submarines' inherent vulnerabilities, these technologies could allow ASW forces to suppress and marginalize submarines with greater effectiveness and at lower cost than today's predominant ASW concepts. This approach would free US SSNs to focus on engagement and destruction of enemy submarines when needed, rather than being tied up in ASW search and track.

Figure 1: Summary of the unmanned ASW concept[1]



A new unmanned ASW systems of systems would consist of the elements summarized in figure 1. If the US Navy and allied navies adopted more sustainable and risk-worthy unmanned systems, ASW operations could concentrate on choke points and an opponent's home waters. This would reduce the threat in open ocean or enable more effective monitoring of submarine deployments to allow rapid attacks on them when competition turns to conflict. Each phase of the proposed ASW approach is described displayed in figure 1 and described below:

- **Cueing and detection:** Several types of sensors would detect submarines as they pass through choke points and likely transit lanes: fixed sensors such as SOSUS; electronic intelligence (ELINT) or electro-optical/infrared (EO/IR) satellites; relocatable sensors, such as the transformational reliable acoustic path sensor (TRAPS); and mobile sensors, such as passive sonar arrays towed by glider unmanned surface vessels (USVs) or extra-large unmanned underwater vehicles (XLUUVs), and SURTASS arrays towed by medium USVs (MUSVs). Unmanned passive sonars would use automated target recognition algorithms, increasingly augmented with machine learning, to identify specific submarine or surface contact frequency tonals from the overall ocean noise.
- **Tracking:** Cued by detection sensors, MUSVs with towed active or passive sonars would continue to track adversary submarines. To reduce the threat to search platforms, active sonar would be employed multi-statically, with an MUSV serving as the transmitter and passive sonar arrays towed

by manned or unmanned platforms receiving the returns. To further localize or identify submarines, medium-altitude long endurance (MALE) unmanned aerial vehicles (UAVs) like the MQ-9B SeaGuardian would deploy sonobuoys, scan the ocean with mast detection radars, and employ passive SIGINT capabilities to detect electromagnetic transmissions. Search and track by unmanned systems would be complemented by fixed or deployable undersea sensors, existing SURTASS ships, or other vessels of opportunity with towed arrays.

- **Trail:** A significant limitation of today's ASW approach is that it cannot scale to address more than a few adversary submarines at a time after they leave choke points and deploy into the open ocean. During wartime, enemy submarines would be engaged before they leave choke points, but an opponent may sortie undersea forces before a planned offensive to create an open-ocean ASW demand on US and allied forces and a potential threat to sea lanes or US and allied home territory. To address this challenge, the proposed ASW concept would employ MUSVs towing active and passive arrays and MALE UAVs with radar; EO/IR; and visual sensors to loosely trail opposing submarines in the open ocean. Maintaining trail on submarines outside their home waters enables them to be more quickly engaged when conflict begins, and it simplifies the homeland defense ASW task by providing cueing from the trailing ASW sensor platforms.

- **Engagement:** When conditions warrant, ASW engagements would prioritize suppression of submarines over destruction, based on lessons from the First and Second World Wars and the Cold War. MALE UAVs would conduct suppression attacks using small, inexpensive, air-launched torpedoes such as the compact very light-weight torpedo (CVLWT), depth bombs like the Second World War–era Hedgehog, or rocket-propelled depth charges like the Russian RPK-8. Alternatively, MUSVs in trail could close on the target submarine at acceptable risk and launch short-range standoff ASW weapons such as anti-submarine rockets (ASROCs) with a CVLWT or depth-bomb payload. The smaller warheads of CVLWTs or depth bombs are less likely to destroy a submarine outright but could disrupt its operations by forcing it to evade or damage the target submarine and make it easier to track. Applying lessons from the Second World War's hunter-killer groups, less-expensive and more numerous unmanned vehicles could also collaborate to track and repeatedly engage submarines, increasing the eventual probability of destruction.

  When submarine destruction is necessary to impose greater costs or reduce the long-term threat, ASW attacks would focus on locations such as choke points, where unmanned systems could employ larger, more lethal weapons effectively. XLUUVs carrying heavyweight torpedoes and mines, such as the developmental Hammerhead mine, would be positioned outside ports, straits, and other choke points to engage transiting submarines. US and allied attack submarines would often be needed for higher-value missions such as anti-surface warfare or strike. However, they would be employed for ASW against opposing SSBNs to compel the adversary to use its own attack submarines for pro-SSBN operations.

- **Command and control (C2):** The unmanned ASW concept would employ a C2 approach combining human command with machine control. Unmanned search and track operations in an adversary's home waters and at choke points would be highly automated, with sensors following search plans developed and modified in real-time by AI-enabled tools to reduce operator workload. Human operators deployed to the region would manage offensive ASW operations by reviewing search plans before and during an operation, providing direction and guidance to the autonomous control systems and overriding them when necessary. Search plans would be approved by human commanders, who would also direct engagements. Operators and commanders could also manage unmanned ASW missions remotely from US territory in situations where host nation access may not be available, as could happen during far-forward ASW operations in the Black Sea or Persian Gulf.

P-8A maritime patrol aircraft would host operators to locally manage ASW operations in uncontested or moderately contested areas to ensure communications with unmanned systems and provide additional sonobuoy or weapons capacity. For C2 in contested airspace, operators could coordinate ASW operations via UAV-borne communication relays or satellites from ships or mobile ground-based C2 cells containing the P-8A processing and control systems. Human command and machine control would be more effective than either an all-manned or all-unmanned force and would focus highly skilled crews and their platforms on cognitive tasks and episodic action, rather than continuous search and track activities.

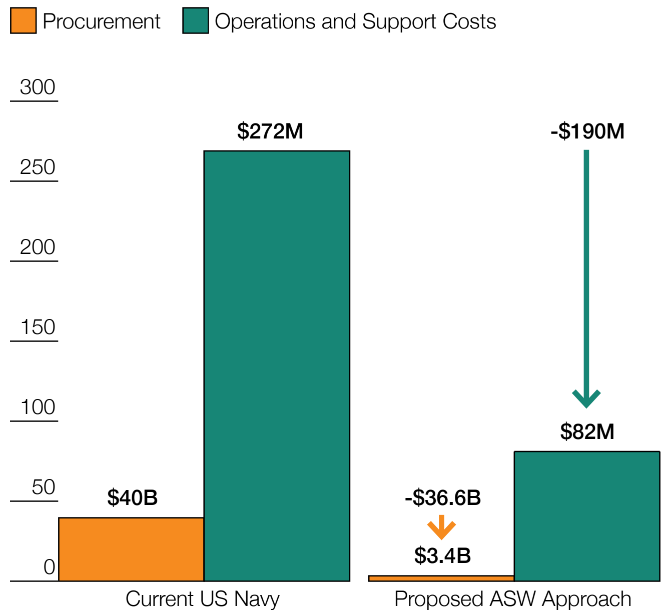
Offensive ASW operations like those described above should be the focus of US and allied ASW strategy, keeping adversary submarines bottled up in their local waters or busy evading tracking or attack. However, if offensive operations are unsuccessful or are overcome by submarine numbers, unmanned ASW systems of systems would enable maritime formations to disrupt enemy submarine attacks.

Implementing an Unmanned ASW Approach

Unmanned concepts would increase the US Navy's ASW capacity, make it more scalable, and improve its cost and sustainability over time. This report assessed force structure requirements to detect and track adversary submarines in a set of scenarios involving China and Russia. In each case, adversary submarines attempted to transit through straits in the Western Pacific or the Greenland, Iceland, United Kingdom (GIUK) gap and reach naval forces in the open ocean. Figure 2 summarizes the procurement costs and operations and support (O&S) costs associated with the current and proposed ASW concepts for one month in the China and Russia scenarios.

Figure 2: Procurement and O&S cost comparison between current US Navy approach and proposed ASW approach

Procurement and O&S costs (billions and millions of dollars, respectively)



The comparison is not meant to imply that manned platforms like DDGs, SSNs, or P-8As are not needed. These platforms are still needed for ASW C2, and more importantly, for operations where their multi-mission capabilities and onboard operators are more essential. Instead, the argument conveyed by figure 2 is that the unmanned ASW approach would not require the Navy to divest of manned platforms because the new concept could pay for itself with O&S savings in less than a year of sustained ASW operations.

The technologies used for the unmanned ASW approach are all in existence today, although some are not yet being employed operationally in the form proposed by this report. To provide time to mature these technologies, the unmanned ASW approach would be implemented over five to ten years, substituting manned

Table 1: Initial investment portfolio to support a US Navy unmanned ASW approach

SYSTEM	NUMBER	UNIT COST	TOTAL COST ($M FY2020)
"A" size ADAR sonobuoys	6,000	$3,156	$19
"A" size MAC sonobuoys	4,000	$4,999	$20
RAP VLA Sensors (e.g., TRAPS)	50	$2,000,000	$100
Small torpedoes like the CVLWT	2,250	$226,530	$510
Rocket-propelled depth bombs capable of being deployed by aircraft or shipboard trainable countermeasures launchers	2,250	$113,265	$255
Encapsulated torpedo mine	1,000	$1,812,240	$1,812
USV Glider with passive sensor	425	$800,000	$340
Land-based MALE UAVs equipped with sonobuoy launchers and ASW sensor processing	40	$29,000,000	$1,160
XLUUV	12	$80,000,000	$960
MUSVs equipped with trainable countermeasures launchers and LFA VDS or MFTA	12	$50,000,000	$600
LFA VDS or MFTA kits for vessels of convenience	12	$5,000,000	$60
		TOTAL	**$5,836**

platforms with unmanned systems over time in day-to-day and responsive ASW operations. In the process, manned US Navy platforms such as P-8As, DDGs, and SSNs would be freed to conduct other operations or to focus on C2 of ASW operations.

To enable a more rapid adoption of this approach, procurement funding could be shifted from a few manned platforms to buy the needed portfolio of unmanned systems. A slight deceleration in manned platform procurement could be justified by the improved ASW efficiency and effectiveness possible with unmanned systems. For example, by reducing procurement over the next several years by one FFG, one DDG and one SSN, the Navy could field the ASW portfolio of unmanned sensors, platforms, and expendables shown in table 1. Some aspects of this particular trade may not be desirable for industrial base or other reasons, but it illustrates the relatively modest change in investment needed to adopt an improved ASW concept.

A Closing Window for Transition

US and allied militaries should begin the shift now to unmanned-centric ASW concepts and increase their investment in unmanned ASW sensors and platforms. These and other technologies described in this report are mature and are being used by US or allied navies, or they are rapidly reaching maturity and can help create a force that is much more affordable, scalable, and effective.

However, the United States and its allies face a short window of opportunity. There is a risk that rising procurement and O&S costs for the current manned ASW portfolio and flat or declining budgets will prevent the adoption of new ASW concepts or investment in new unmanned systems. If US and allied navies fail to act during the next several years, they could lose their undersea advantage to surging fleets of adversary submarines.

CHAPTER 1: INTRODUCTION

In March 2018, Russian Federation president Vladimir Putin revealed six new strategic "superweapons" meant to provide Moscow more escalation options and to complement Russia's well-established capabilities for hybrid, or gray-zone, operations. One of these weapons, the Status-6 Oceanic Multipurpose System, or Poseidon, is a nuclear-powered and nuclear-armed undersea vehicle which, according to Russian state media, can autonomously navigate to attack the United States from European waters.[2] The Poseidon's operational feasibility remains unclear, but its possible existence should serve as a warning to the United States and its allies that undersea warfare remains central to global strategic competition.

While the air power revolution that characterized the twentieth century receives greater public attention, the advent of the torpedo and submarine during the early twentieth century had an equally significant effect on warfare. Today, submarines—not aircraft carriers or amphibious forces—provide the high-end capability in most navies. For example, while only three states operate strategic bombers and a dozen deploy aircraft carriers, more than forty countries field submarines.

The militaries of US rivals China and Russia include sizable submarine fleets, each employed in a distinct manner consistent with its nation's overall strategy. And although the design and employment of both nations' submarine fleets suggest a focus on the US military, their undersea forces also present significant

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Photo Caption: A Great Wall 236 submarine of the Chinese People's Liberation Army Navy participates in a naval parade to commemorate the 70th anniversary of the founding of China's PLA Navy in the sea near Qingdao, in eastern China's Shandong province on April 23, 2019. (Mark Schiefelbein/AFP via Getty Images) threats to the territory and maritime access of their neighbors, many of which are US allies.

The RFN fleet of fifty-eight submarines is the backbone of Moscow's maritime power.[3] Submarines play a largely offensive role in the RFN, with surface combatants and air forces focusing on coastal and homeland defense.[4] RFN nuclear ballistic missile submarines (SSBNs) are used to ensure a survivable second-strike deterrent. Russia's conventional attack submarines (SS) are employed as a complement to its hybrid operations in the Baltic and Mediterranean,[5] threatening North Atlantic Treaty Organization (NATO) naval forces, particularly those of eastern European countries that are the target of Russian military and paramilitary gray-zone engagement.

Most challenging for US ASW efforts, however, are modern Russian nuclear-powered attack submarines (SSNs), which the Russian government would rely on for conventional or nuclear strike options during a broader conflict with the United States.[6] Russian military strategy could also include using SSNs to threaten US SSBNs, thereby undermining American nuclear second-strike capability.

China's submarine doctrine, in contrast to Russia's, conducts offensive operations in support of an active defense strategy. The People's Liberation Army (PLA) relies on networks of sensors and long-range precision weapons, combined with aggressive sub-conventional or gray-zone activities, to expand China's influence and territorial control. In addition to threatening neighbors such as Japan, the PLA's sensor and weapons network could hinder US forces attempting to reinforce the region and thereby undermine American security assurances.

The submarine fleet of the Chinese People's Liberation Army Navy (PLAN) is primarily intended to support its overall sensor and weapons network with a combination of torpedoes and anti-ship cruise missiles that could be launched from inside US Navy air defenses.[7] Consistent with this priority, the PLAN's fleet of sixty-five to seventy submarines is predominantly composed of relatively quiet diesel-powered SS and conventional air-independent propulsion submarines (SSPs).[8] These submarines are inexpensive enough to be built in large numbers, and they can minimize the need to snorkel by staying close to home in the Western Pacific, where they are protected by long-range PLA weapons and can leverage PLA land, air, and space-based sensors for targeting. Although the PLAN's nuclear submarines are relatively noisy, it recently expanded its nuclear submarine construction capacity and is expected to double the size of its SSN and SSBN fleet over the coming decade.[9] Furthermore, the PLAN continues to expand global operations by sending naval expeditionary task forces further than the traditionally accepted norms, routinely transiting east of the Hawaiian Islands and west into the Indian Ocean and Gulf of Aden.

The proliferation of submarines and the introduction of autonomous underwater vehicles (AUVs) into more navies are prompting militaries to devote an increasing portion of their forces and funding to ASW. The tactics most navies employ, however, center on manned platforms searching for, and attempting to destroy, enemy submarines approaching vulnerable targets. Because of their high cost, these concepts cannot scale to counter large or capable submarine fleets, particularly if ASW forces are attempting to defend many targets. The objective of sinking submarines, rather than suppressing them, compounds the ASW scaling problem by requiring repeated and sustained engagements to ensure success.

US and allied militaries will need new concepts and capabilities to address the growing undersea threat facing their fleets, commercial shipping, and facilities ashore. Navies could leverage emerging technologies for autonomous vehicles, deployable sonars, automated acoustic processing, and communications networking that are creating new opportunities for submarine detection and tracking. Combined with new, more offensively oriented ASW strategies and tactics that exploit submarines' inherent vulnerabilities, these technologies could allow ASW forces to suppress and marginalize submarines at lower cost and with greater effectiveness than today's predominant ASW approaches.

This report will describe the evolution of undersea warfare; new strategies, concepts, and capabilities to address undersea threats using unmanned and autonomous systems; and how new ASW approaches could be more affordable and provide better results for US and allied navies than today's concepts. Without a substantial evolution in ASW, undersea threats will not only be an operational challenge for US and allied navies, but will also impose costs that reduce the ability of the Department of Defense (DoD) to invest in offensive capabilities such as strike, electronic warfare, or amphibious assault.

CHAPTER 2: THE EVOLUTION OF UNDERSEA WARFARE

The undersea has always provided opportunities for military operations. Thucydides describes diving teams clearing underwater obstructions during the Siege of Syracuse and Alexander the Great allegedly used divers and a diving bell to conduct reconnaissance during the siege of Tyre.[10] Chinese engineers developed land and naval mines in the fourteenth century, while England allegedly used mines in combat during the 1627 siege of La Rochelle. In 1775, American engineer David Bushnell created naval mines for use against British forces, and designed and built the Turtle, the first underwater vehicle used in combat.[11]

By the mid-nineteenth century, naval mine technology had matured enough to be used by advanced European navies of the day. During the Crimean War, the Russian Navy deployed mines in the Black Sea and the Gulf of Finland, prompting the Anglo-French coalition to conduct the first minesweeping operations.[12] The American Civil War saw the first widespread

Photo Caption: The US Coast Guard Cutter ship Spencer blasted by a German U-boat during World War Two, circa 1941-1945. (US Navy/FPG/Getty Images) use of naval mining by Confederate forces attempting to disrupt Union amphibious operations and attack Union ships in port.[13] Admiral David Farragut's likely apocryphal command, "Damn the torpedoes, full speed ahead," referred to the Confederate contact mines in Mobile Bay.[14] After the Civil War, the United States employed a network of ironclad warships, shore artillery emplacements, and naval mines for coastal defense.[15]

Early Operational Concepts: 1866–1900

Undersea warfare took a major technological step forward in 1866 with the Whitehead torpedo, essentially a naval mine attached to three compressed-air engines.[16] Although submarines of the time were limited by a lack of reliable propulsion and buoyancy control, the Whitehead torpedo required only a launching tube and could be attached to any warship. The concurrent introduction of steam propulsion and armored warships made torpedo boats, rather than submarines, the more reasonable tactical choice until the late nineteenth century.[17]

Post-imperial France was the first great power to exploit the torpedo's potential impact on the maritime balance. French naval planners needed creative strategies to counter Britain's maritime preeminence because France lacked the economic resources and industrial capacity to build a fleet equal to the United Kingdom's while also equipping an army to counter Germany.[18]

The French Navy constructed a fleet of fast torpedo boats and long-range commerce raiders, while also investing in long-term submarine development.[19] During combat, French torpedo boats would attack a British fleet, overwhelming and sinking expensive battleships. Simultaneous attacks by submarines on British shipping would force the United Kingdom to negotiate or face economic collapse.

This strategic approach, known as the "Young School" or Jeune École, was never tested in a great-power conflict. However, France's concerted development of submarines and torpedo boats prompted two military-technological outcomes. First, broad European investment in submarine technology led to the invention of electric propulsion systems, which by 1900 made large-scale employment of submarines viable. Second, as French torpedoes improved and torpedo boats became fast enough to evade gunboat pickets, the Royal Navy and German Navy developed torpedo boat destroyers with the seaworthiness to operate in a battleship squadron, but the speed and armament to pursue and destroy torpedo boats. European naval officers soon realized these destroyers were fast enough for them to conduct torpedo attacks themselves, leading to the advent of torpedo-equipped destroyers as a component of every navy's fleet.[20]

The Birth of Modern Undersea Warfare: 1901–1918

By the early 1900s the United Kingdom and Germany had eroded the French advantage through new strategies that emphasized undersea warfare in force planning and naval modernization. The United Kingdom's international position during the nineteenth century relied on sea power. By controlling international choke points such as the Suez Canal or Strait of Gibraltar and maintaining a European fleet able to dominate its two largest rivals, the Royal Navy protected the uninterrupted flow of goods between colonies and the Euro-Atlantic core.[21] The rise of German, French, Russian, and—most critically—Japanese and American navies transformed this strategic situation. Britain faced a choice between maintaining global sea control, which would have entailed doubling or tripling fleet size, or tacitly abdicating global naval dominance and refocusing its efforts on the European littorals.[22]

The British government chose to concentrate on Europe, and First Sea Lord John Arbuthnot "Jacky" Fisher developed a fleet architecture designed to match this new strategic priority. Incorporating the strategic innovations of naval theorist Sir Julian Corbett, Fisher divided the Royal Navy into three wartime arms.[23] First, the primary battle force—the Grand

Fleet—would operate in European waters, attempting to force an engagement with the United Kingdom's primary adversary, Germany. Second, destroyers and torpedo boats, so-called "defense flotillas," would prevent enemy cruisers from transiting the English Channel.[24] Third, Britain would dispatch hunter-killer ships to destroy enemy commerce raiders and protect British shipping abroad.

This fleet required several technological advances. The Dreadnought-class battleship and Invincible-class battlecruiser were designed to outperform any other ship of their class, resetting the Anglo-German naval arms race.[25] Fisher complemented the new capital ships with torpedo improvements, the Royal Navy's first submarines,[26] and a destroyer force designed to operate independently of a major fleet or screen one from enemy destroyers and submarines.

Considering the future importance of diesel-powered submarines in German naval doctrine, it is ironic that, until 1913, the German Navy, or Kaiserlichmarine, did not operate any. Grand Admiral Alfred Tirpitz's vision instead centered upon constructing a German High Fleet capable of defeating the Grand Fleet.[27] A strong enough battleship force, Tirpitz argued, would allow the German fleet to defeat its British counterpart, giving the German Empire access to the overseas colonies and international markets it needed to dominate world affairs.[28]

The Royal Navy's new battleship and battlecruiser, however, caught the German Navy by surprise. Tirpitz therefore modified his strategy to make torpedoes the High Fleet's primary offensive weapons. During a fleet action, German torpedo destroyers would disrupt British battle lines, while German submarines would ambush British dreadnoughts during gunnery duels or break away to attack British cruisers, fleet bases, or merchant shipping.

Tirpitz's approach became critical to Germany's strategy during the First World War when logistics challenges prevented the German Army from executing its plan to rapidly defeat the French Army.[29] If the German Navy could break the Royal Navy's wartime blockade, Britain would be vulnerable to invasion and might withdraw from the war. German commerce raiders could then destroy French shipping and the army could regain the initiative.

The German Naval Staff incorrectly predicted that Britain would conduct a "close blockade" along the German coastline, which could have been susceptible to relatively short-range German submarines and destroyers. However, recognizing this vulnerability, British planners conducted a "far blockade," with the Grand Fleet based at Scapa Flow, where it could intercept the German fleet if it attempted to break out of the North Sea via the Denmark Strait or English Channel.[30]

German naval planners recognized their inability to easily break the British blockade and began to expand their use of submarines. On February 4, 1915, Admiral Hugo von Pohl declared that German submarines would treat Ireland's Atlantic littorals and the western North Sea as a war zone and attack any shipping in the area. To reduce the likelihood of US involvement in the war, Germany refrained from a large-scale anti-shipping campaign and instead tried to ambush the Grand Fleet's battleships with submarines to even the odds between British and German formations.[31]

Aside from picking off isolated cruisers, German submarines had little combat effect during the First World War.[32] Technological limitations constrained the range and speed of submarines, preventing them from pursuing warships or quickly repositioning to engage them.

With British warships largely out of reach and German cruisers outclassed by the new British battlecruisers, the German Navy shifted to a strategy of using submarines to attack merchant shipping.[33] German U-boats, primarily based in occupied Belgium at Ostend, sortied into the Atlantic and North Sea, attacking any shipping they could locate. As Churchill recounts in The World Crisis, the U-boat threat nearly crippled the British economy. German U-boats sank nearly thirteen million gross tons from 1914 to 1918. The worst year by far was 1917. From April to July 1917, U-boats sank more tonnage than they had in 1916 and double the tonnage of 1915.[34]

The Allied powers responded with five anti-submarine tactics, several of which form the basis of modern ASW:

- **Convoys:** After much internal debate, Britain and the United States adopted the convoy system, in which non-combat ships sailed in large groups instead of proceeding as soon as they were loaded.[35] Grouping ships together reduced the time a submarine could devote to each target and concentrated escorts in space and time to improve their effectiveness.
- **Escort patrols:** The Royal Navy and US Navy deployed destroyers and maritime patrol aircraft to escort convoys through known submarine hunting grounds, like the Hook of Holland to Harwich convoy route.[36]
- **Independent destroyer operations and depth charges:** Allied navies deployed independent destroyer squadrons to hunt down enemy submarines in likely operating areas.
- **Base targeting:** Britain attempted to sink older warships to block the entrances to Ostend and Bruges-Zeebrugge submarine bases. If this had been successful, the German Navy would have needed to redeploy submarines to the major North Sea fleet base at Wilhelmshaven. This would have forced German U-boats to transit along the Dutch coastline, exposing them to British attack.[37]
- **Q-ships:** The Royal Navy created several hundred Q-ships, armed merchant vessels designed to masquerade as helpless cargo ships until engaged by a submarine. Operating a Q-ship was particularly dangerous, since the captain had to bait the opposing U-boat into surfacing by pretending to be a panicked merchantman, and often had to take several torpedo hits before the submarine would resort to using its deck gun. Nevertheless, Q-ships were relatively low-cost ASW platforms and scored several notable kills against German U-boats.

Ultimately, Germany's unrestricted submarine warfare campaign backfired when it began to attack US-flagged ships. The German military, by drawing the United States into the war as it attempted to isolate Britain, simply traded one high-population and resource-rich adversary for another with even greater industrial capacity.[38] The US Navy contributed destroyers and escorts to protect Allied shipping and deployed five of its battleships to the Grand Fleet.

Nevertheless, the First World War prompted several new developments in undersea warfare: the independent deployment of submarines as commerce raiders, the use of depth charges and sonar technology in ASW, and the development of convoy tactics and ASW escort practices. These advances, along with the operational experience British, American, and German commanders gained, would drive the submarine and ASW tactics of the Second World War.

Technological Proliferation and Doctrinal Development: 1919–1945

Undersea warfare became a higher priority and more sophisticated during the interwar period, aided in part by the 1922 Washington Treaty, which regulated the displacement and construction rates of battleships and battlecruisers but did not address submarines.[39] While submarine development advanced, the US and British navies deployed surface ships with ASDIC active sonars, and the US and Japanese fleets developed new torpedoes and mines.

Budgetary constraints prevented widespread production and testing of new undersea technologies. As a result, the greatest interwar undersea warfare advances were doctrinal. Prominent officers in the US Navy, German Reichsmarine, and Imperial Japanese Navy (IJN) recognized the efficacy of submarines and pushed their staffs to develop concepts and to experiment using the limited submarine forces at their disposal. Hence, each navy began the Second World War with a specific conception of undersea warfare that supported its grand strategy.

Undersea Warfare and German Strategy

Like its imperial predecessor, the German Reich faced a potential US-supported Anglo-Franco-Russian coalition whose formation Germany needed to delay until one or more members could be eliminated. The German army planned to neutralize France using blitzkrieg operations that integrated armored units and airpower into a unified force able to exploit weaknesses in enemy defensive lines.[40]

German naval planners understood that knocking Britain out of the war would require Germany either to credibly threaten a land invasion or to grind Britain into economic or political submission. This required two distinct fleets—a raiding fleet to destroy British shipping and a battle fleet to defeat the Royal Navy. Although the Versailles Treaty prevented Germany from constructing battleships and aircraft carriers, the Kriegsmarine's surface officers argued that cruisers, destroyers, and other small combatants could support the strategy.

The surface fleet lost the argument to German submariners, led by U-boat commander Karl Dönitz, who articulated an alternative maritime strategy incorporating lessons learned from First World War maritime engagements.[41] Dönitz doubted the Kriegsmarine's ability to win a fleet action and was skeptical of surface raiders. In contrast, he believed that a major submarine campaign targeting Allied shipping could starve Britain into submission.

To overcome convoy tactics the Allies were likely to employ, Dönitz implemented the "wolf pack" concept.[42] Through Enigma-encrypted orders sent from occupied France, Dönitz would mass U-boats in the path of convoys that had been located by German decryption of convoy orders or by direction-finding of convoy radio transmissions. Wolf packs would be able to cut off convoys' escape and enable more torpedo attacks than individual submarines. The wolf pack allowed Dönitz to maximize the impact of what was a small U-boat fleet at the start of the Second World War.[43]

Undersea Warfare and Japanese Strategy

Despite its military strength, Japan lacked resources such as oil, rubber, and iron to fuel its military-industrial complex and ensure its economy was not subject to external control. Japanese leaders assessed they could address this shortfall by invading either mainland China or resource-rich island nations in Southeast Asia. Given China's proximity, the Japanese government initially opted for the former strategy, invading Manchuria in 1931 and the rest of China in 1937.[44]

China's size made subjugating it extremely difficult and risked war with Russia, as demonstrated by the 1939 Soviet-Japanese border conflict.[45] The Japanese military shifted priorities, and after early 1940, adopted the "Southern expansion strategy."[46] This approach called for the conquest of Western colonies in French Indochina, Malaya, the Dutch East Indies, New Guinea, and the Philippines. This wide-reaching strategy relied substantially on the IJN's ability to control the seas and support projection of ground forces.

The United States, however, posed an overwhelming threat to Japan's Pacific ambitions. Not only did the US military operate from Philippine and Pacific island military bases; the economic and industrial capacity of the United States dwarfed that of Japan. In 1939, even with high US unemployment and slow economic growth, America had double Japan's population, seventeen times its gross national income, five times its steel production, seven times its coal production, and eighty times its automobile production.[47]

Japanese military planners, like their German counterparts, attempted to neutralize or isolate potential opponents who could block Japan's establishment of a sphere of control and access to resources. Preemptive strikes were planned against European and American colonies and bases in the Western Pacific and the US military base at Pearl Harbor. By crippling the US fleet, Japanese military leaders hoped to prompt a political crisis in the United States and force a negotiated settlement that would partition the Pacific into US and Japanese zones of control.[48] If the United States chose to fight, Japan would expand its control as far as possible. Ideally, by the time US industrial capacity had recouped American losses, Japan's military would have constructed a maritime defense-in-depth of island bases. The IJN could then fight the US counteroffensive on its own terms.[49]

This strategy had distinct implications for force structure. Japan integrated its capital ships into a combined fleet of six to eight carriers that would pursue decisive engagements with the US fleet. Japan produced the most-effective torpedoes of the Second World War, which became the primary anti-ship weapons of Japanese aircraft and destroyers.

The IJN's strategy called for submarines to harass advancing US fleet groups and even the odds before decisive engagements by sinking or damaging US warships. To support this approach, Japan fielded one of the most advanced submarines of the Second World War, the Type-B cruiser, and produced a greater variety of submarines than any other combatant.

Allied Submarine and ASW Strategies

To win the Second World War, the United States developed tailored undersea warfare strategies in the Atlantic and Pacific, which in turn furthered each theater's maritime and grand strategic goals. In the Atlantic, the United States adopted a strategically defensive undersea approach to facilitate the transport of men and materiel to Britain, North Africa, and continental Europe. In the Pacific, the United States took the strategic offensive, using submarines to target Japan's war economy.

Atlantic Undersea Operations

The Allies' Atlantic ASW approach incorporated lessons from the First World War, using small combatant ships and patrol aircraft to protect merchant vessels organized into convoys. The World War II German submarine fleet, however, was much larger and more capable than its World War I predecessor. Although the Kriegsmarine began the war with only 26 ocean-going U-boats, by December 1941, it was deploying 80 submarines per day in the Atlantic, peaking at 160 in March 1943 and remaining between 80 and 120 until August 1944.[50] Moreover, newer U-boats could operate in the mid-Atlantic, where they could exploit the gap in Allied patrol aircraft coverage between Canada, Ireland, and Greenland.[51]

The impact of numerous capable U-boats was significant. During 1942, the first full year of US involvement in the war, German U-boats sank 6.23 million tons of Allied shipping, partly because unprotected merchant ships along the US East Coast suddenly became acceptable targets.[52] The crisis reached a head in early 1943, when the allies lost 627,377 tons of shipping during March alone.[53] The British War Cabinet feared economic collapse and considered cancelling convoys to conserve fuel for domestic operations.

However, a combination of new technologies bolstered Allied ASW, leading to functional victory in the Battle of the Atlantic by June 1943. These innovations can be grouped into four major categories, detailed below: detection and tracking technologies; weapons advancements; improved air cover; and increased escort presence.

Detection and Tracking Technologies

Diesel-powered submarines of the Second World War spent most of their time on the surface to run generators and exchange air because the snorkel was not yet perfected and in wide use. Most

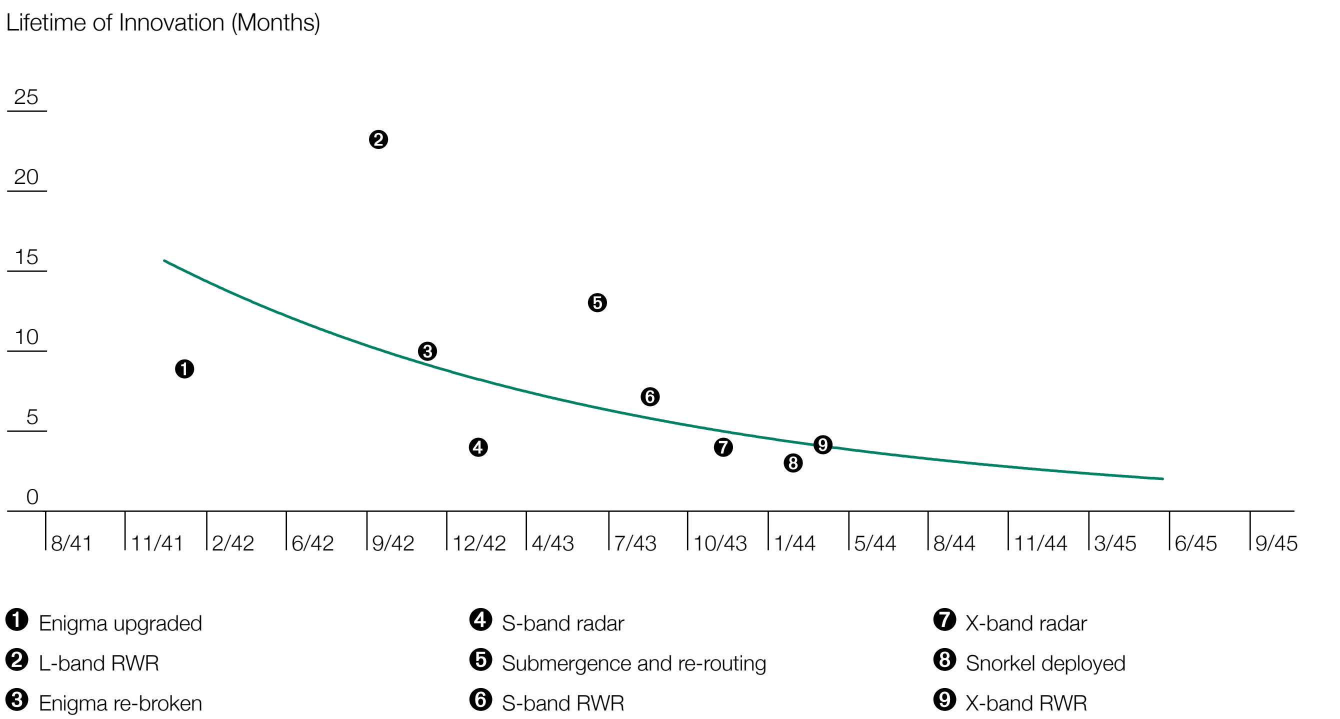
ASW detection and tracking technologies therefore relied on the electromagnetic spectrum (EMS), including airborne and shipboard radar, intercepts of submarine radio and radar transmissions, and decryption of submarine radio communications.

The concentration of ASW techniques on the EMS led to a move-countermove dynamic that accelerated throughout the Battle of the Atlantic. As shown in figure 3, radars on ASW ships and aircraft were countered by submarine radar warning receivers in successively higher frequencies from L to S to X bands. Decryption of convoy and submarine orders was countered by new encryption techniques, which were in turn decrypted. Despite the German Navy's advanced technology at the start of the war, it eventually lagged in the ASW competition because it was unable to transition new countermeasures into operational use as quickly as the Allies could field new sensors.[54]

The five most important detection and tracking innovations are detailed below:

- **Signals intelligence and cryptology:** During the critical engagements of 1943, British code-breakers cracked Enigma's latest iteration while the Admiralty secured its own encryptions. This allowed the Allies to provide early warning to targeted convoys and better direct ASW patrol aircraft.[55]
- **HF/DF:** High-Frequency Direction-Finding, known as HF/DF or "Huff-Duff," could fix U-boat locations by detecting the bearing of radio or radar transmissions. German wolf pack tactics made U-boats more vulnerable to HF/DF because they relied on radar to detect approaching convoys and on frequent communications to coordinate maneuvers. Initially, HF/DF technology could not be deployed on ships, but the Royal

Figure 3: Introduction of ASW sensing advancements and countermeasures that the Battle of the Atlantic accelerated throughout the conflict



Navy constructed coastal HF/DF facilities that were effective in parts of the Eastern Atlantic. By 1943, HF/DF equipment was small enough to deploy on convoy escorts, which proved decisive in the convoy battles of March and April 1943.[56]

- **Aerial radar:** British and American engineers developed ground-based military radar by the mid-1930s and used it to great effect during the Battle of Britain. By mid-1942, the Royal Navy was able to equip long-range maritime patrol aircraft with radars. This enabled both convoy defense in the Eastern Atlantic and offensive ASW operations against U-boats transiting the Bay of Biscay toward their patrol areas.[57]

- **Leigh Lights:** Because submarines surfaced to recharge batteries, refresh air, or run faster using diesel propulsion, they often transited to patrol areas and repositioned on the surface at night, when patrol aircraft and surface combatants would be less able to detect them. To deny U-boats this sanctuary, British patrol aircraft began carrying the Leigh Light in 1941 to confirm and localize potential submarine contacts initially detected by moonlight, or later, by radar.[58]

- **Sonar/ASDIC:** Signals intelligence provided early warning on submarine patrol areas, and HF/DF or radar could locate U-boats as they approached a convoy. Neither, however, could detect a submarine once it stopped transmitting and submerged. Sonar, or ASDIC, improved throughout the war, particularly in 1942 and 1943, and was the only technology to track submerged submarines. Its short range, however, made it ineffective for search. As a result, ASDIC was employed most often to chase a U-boat detected by other means, or after the submarine had attacked.

Weapons Advancements

Weapons were less important in the ASW competition than sensors because submarines generally disengaged and attempted to evade once they were being prosecuted. Because U-boats generally lacked the speed to catch up with a convoy after evasion, an ASW operation usually had the effect of taking the submarine out of the fight even if it was unharmed. Weapons did, however, need to be lethal enough for the threat to compel submarine commanders to evade once detected. Better weapons also enabled Allied hunter-killer ASW groups in the late war to destroy submarines. Four major advancements helped in this effort:

- **Forward-firing weapons:** In 1939, the depth charge was the sole ASW weapon. Depth charges were inaccurate, since sonar-equipped warships could not detect targets directly beneath them, and depth charges could be deployed only from directly above a target. Thus, the attacking ship would lose sonar or ASDIC contact before it could launch an attack. Forward-firing weapons like the Hedgehog and Squid launched projectiles approximately 100 yards ahead of the attacking warship, allowing the ship to approach its target head-on and maintain sonar contact. Additionally, Hedgehog munitions only exploded on contact, providing confirmation of a hit. The US and Royal Navies were fielding Hedgehogs widely by 1943.[59]

- **Depth charge projectors:** The US Navy's development of "K-gun" depth charge projectors allowed small surface combatants to project depth charges off to either side of the ship, allowing sonar tracking of the target throughout the engagement.[60]

- **ASW homing torpedoes:** Torpedoes increased in range, accuracy, and reliability throughout the Second World War. However, most Allied variants were unguided weapons aimed by pointing the launcher at the target. The Mk 24 FIDO torpedo-mine integrated a passive acoustic homing system and a mobile torpedo into a single weapon. Deployed from patrol aircraft like the PBY Catalina, the Mk 24 FIDO would search a pre-set area and depth, using a hydrophone to locate the target by sound. The Mk 24 FIDO was first deployed in March 1943 and gained its initial kills in May; it proved so accurate that the US Navy reduced its order request from 10,000 to 4,000.[61]

- **Rockets:** While rockets were developed for use against armored vehicles, their applicability to ASW was quickly realized. By 1943, smaller patrol aircraft were using rocket salvos to attack surfaced submarines.

Improved Air Cover

Patrol aircraft were a necessary complement to convoy escort vessels because they could scout ahead and break off from the convoy to operate offensively against submarines. Due to the limited range of patrol aircraft, U-boats were able to exploit a coverage gap in the central Atlantic. Two main developments closed the "mid-Atlantic gap:"

- **Escort carriers:** Escort aircraft carriers were instrumental in extending US and Allied air cover. While slower and smaller than fleet carriers in the Pacific, escort carriers' torpedo bombers could search hundreds of square miles and enable hunter-killer operations in suspected U-boat patrol areas. By July 1943, the US and Royal navies were operating dozens of escort carriers, enabling continuous air cover for convoys. American production expanded escort carrier air wings from six Fairey Swordfish in 1942 to a full squadron of F4F Wildcat fighters and TBF Avenger torpedo bombers in 1944.[62]

- **Improved patrol aircraft and basing:** Once RAF Bomber Command adopted four-engine heavy bombers, twin-engine bombers were transferred to Coastal Command. These aircraft, along with the older Vickers Wellington, were large enough to deploy radars, torpedoes, and Leigh Lights without sacrificing range, and their lack of speed and heavy armament were not significant shortcomings against submarines.[63] By early 1943, the United States was also fielding maritime-optimized B-24s in large enough numbers to provide continuous air cover over the western North Atlantic from new US and Canadian airfields in Nova Scotia.[64]

Increased Escort Vessel Presence

Reduced shipping losses during 1940 and 1941 coincided with increases in the number and capability of transatlantic convoy escorts—many provided by the US Navy. However, when the United States entered the war in December 1941, its extensive coastal shipping lanes became vulnerable to U-boat attack. With most potential ASW escorts already in convoy service or supporting Operation Torch, the allied invasion of North Africa, the Allies suffered significant losses during 1942. Following Operation Torch, the US and Royal Navies began transferring destroyers, increasing ASW capacity by March 1943. They were joined by new classes of light surface combatants, not fast enough to operate with a major fleet, but heavily armed enough to defend convoys against submarine attack. These ships, known as frigates or destroyer escorts, came into widespread use by May 1943.

Allied Pacific Undersea Strategy

The Pacific theater presented an entirely different challenge. US strategy assumed the Japanese government would not surrender unless its home islands were subjugated. This required absolute sea control, which could only be gained by capturing Imperial Japan's island strongholds and destroying the IJN. Thus, the Pacific war was truly maritime; nearly all land campaigns were amphibious and pursued the objective of improving Allied sea and air control.

The US military used an island-hopping campaign to pursue sea control throughout the Western Pacific.[65] US fleet groups would support amphibious assaults on critical strategic points, constructing a maritime corridor from California and Hawaii to the Japanese homeland. To support the strategy, US admirals balanced their doctrine's emphasis on fleet actions, such as at Midway or Leyte Gulf, with the need to also support amphibious operations, like Guadalcanal or Iwo Jima.

The US undersea campaign during the Pacific War remains less well known, but it formed a critical component of US maritime strategy. Before the war, US doctrine called for submarines to support the fleet.[66] This changed following Pearl Harbor, when Chief of Naval Operations Admiral Harold Stark ordered US submarines to undertake an unrestricted campaign against Japanese shipping.[67] Like the US carrier force, the Navy's submarines were not damaged during the Pearl Harbor attacks and represented one of the few tools available for retaliation against Japan.

US war patrols began the week of the Pearl Harbor attack.[68] However, the US submarine fleet had not planned for an unrestricted maritime campaign, and its commanders trained to act as scouts or snipers against warships on the periphery of conflict. Thus, for the first months of the war, US submarines focused on interdicting IJN warships rather than defensive minelaying or patrolling merchant shipping routes. Technology also hampered American efficacy, as the US Mark 14 torpedo was notoriously unreliable, and US submarines were generally outdated.

The IJN's strategy of using submarines against warships rather than merchant ships produced several successes. Japanese submarines sank the USS Yorktown at Midway and USS Wasp off Guadalcanal. Until 1943, Japanese submarines regularly targeted independent US surface combatants. Even later in the war, Japanese submarines scored kills, most notably against the USS *Indianapolis* in 1945.

However, two factors allowed the US Navy to mitigate the threat from Japanese submarines. First, by mid-1943, US forces had achieved air supremacy outside of the Pacific Island chains and had concentrated enough air forces around their Western Pacific lodgments to prevent Japanese submarine attacks. Second, technological and tactical advances gained from the Battle of the Atlantic were applied to ASW in the Pacific, which could be concentrated on defending fleet groups rather than US shipping.

The US submarine force also became an effective warfighting tool. Although the US Navy started the Second World War with older submarines, American engineers were accustomed to designing long-range, fast, heavily-armed cruiser submarines capable of operating alongside surface fleets. These attributes, applied to new Gato- and Balao-class submarines, enabled them to also be effective at interdicting merchant shipping in the Far East.[69] After two years of bureaucratic blame-shifting, US engineers also eventually addressed the Mark 14 torpedo's accuracy, reliability, and lethality shortcomings.[70]

The Japanese government contributed to American submarine success by failing to implement merchant convoys, leaving isolated ships vulnerable to attack. This decision was largely the result of insufficient Japanese shipping capacity. Because ships had to wait for the convoy to assemble and then wait to offload at the destination, convoys were up to 30 percent less efficient than deploying ships as they were ready.[71]

Thanks to improved submarines and weapons as well as a target-rich environment, US submarine crews gained proficiency and confidence. They were also able to get more time on station as the Allied island-hopping campaign established forward fleet bases, providing air cover for submarines and cutting the transit time to patrol areas.

With these improvements, the US submarine force conducted a comprehensive anti-shipping campaign that crippled the Japanese war economy. Government planners estimated that Japan required around six million tons of shipping capacity to meet wartime needs.[72] In 1942, US and allied submarines sank less than 100,000 tons of shipping capacity,[73] but by 1943, they destroyed more than one million tons.[74] Japanese shipping losses peaked in 1944 at two million tons, then declined due to a reduction in shipping as the Japanese Empire contracted toward the Home Islands.[75] Arguably, US submarines did more damage to the Japanese military-industrial complex than strategic bombardment did.

US submarines also sank numerous Japanese warships or transports, including the fleet carriers *Shokaku* and *Taiho*, during the 1944 Battle of the Philippine Sea, giving the US decisive air superiority and killing Japan's remaining experienced pilots. Submarines also sank the battleship Kongo, the converted carrier *Shinano*, and three heavy cruisers during the Battle of Leyte Gulf.

American undersea warfare was clearly critical to the US victory in the Pacific theater, mostly because it crippled the Japanese economy. Like the US Atlantic undersea strategy, it evolved from a distinct set of conditions and objectives. In each case, Allied navies adapted their submarine and ASW approaches to the challenges and opportunities they faced.

The Cold War: 1947–1991

The Cold War between the US and Soviet Union never spiraled into a Third World War, but the US Navy still mounted a coherent and distinct undersea warfare strategy. As in the First and Second World Wars, the US approach was shaped by geopolitical conditions, the nature of the Soviet threat, and capabilities and opportunities available to US and allied navies.

Soviet Military and Undersea Strategy

The Soviet Union commanded an empire stretching from the Pacific, through Asia, and into Central Europe, but its maritime inferiority matched its continental dominance. Geography restricted Soviet access to the sea, while post–Second World War America fielded a navy with fifty-three fleet carriers. Developing alliance structures crystallized this balance of power. The communist world occupied the Eurasian heartland, while its capitalist opponents formed a global ring containing communist expansion.

Nuclear weapons introduced in the decade following the Second World War complicated the correlation of forces. Nuclear deterrence became central to both the US and Soviet militaries, and each superpower engaged in a series of moves and countermoves, attempting to gain an escalatory advantage by improving delivery systems and defensive countermeasures.[76]

While the nuclear balance forestalled major power war on several occasions, it did not eliminate the role of conventional conflict in Soviet strategy. Soviet leaders hoped to create a massive land army that could rapidly conquer Europe.[77] By reaching the Rhine in under a week, the Soviets could force the United States to choose between initiating a global thermonuclear apocalypse or accepting Soviet Eurasian hegemony.[78]

Sea power became increasingly relevant to the Soviet strategy as the Cold War intensified and US nuclear and aerospace capabilities, coupled with NATO's armies, made a Soviet ground offensive risky. Naval forces, combined with support for left-wing revolutionaries and military-economic incentives to postcolonial states, allowed the Soviet Union to pressure NATO at multiple points, diverting attention and resources from the central front to other regions.

Soviet maritime strategy had three goals: ensuring nuclear deterrence, bolstering Soviet warfighting in a European conflict, and pressuring the Western powers globally. To support these lines of effort, Soviet naval chief and deputy defense minister Admiral Sergei Gorshkov constructed a fleet incorporating Mahanian and Corbettian strategic themes, the Jeune École's insights, and the lessons learned from Germany's world war naval campaigns.

Submarines contributed to each goal of Soviet maritime strategy.[79] Ballistic missile submarines ensured Soviet nuclear second-strike capabilities starting in the early 1960s. Heavy bombers, air-launched nuclear missiles, and ICBMs are vulnerable to air defenses and overwhelming first strikes.[80] By contrast, nuclear-armed submarines designed for long-range cruises could remain at sea for weeks or months, avoid enemy detection, and guarantee that a nuclear state would retain strike capabilities even after enduring a devastating initial attack.

Soviet intelligence indicated that US naval capabilities could detect Soviet ballistic missile submarines on patrol. Thus, beginning in the 1970s, the Soviet Navy developed the "bastion" concept, in which Soviet surface forces and land-based aircraft would ensure sea control of a sheltered body of water, like the Barents Sea or Sea of Okhotsk.[81] Soviet submarines could shelter in these bastions until they sortied to be within range of US targets. The Soviets fielded submarine-launched ballistic missiles with increasing ranges on the Delta-class SSBNs and later the Borei- and Typhoon-class SSBNs, which did not have to sortie and could conduct strategic deterrent patrols in the Arctic.

To bolster Soviet warfighting in Europe and pressure Western powers, the Soviet Navy steadily advanced its attack submarine fleet. Initially it reverse-engineered Type-XXI U-boats; later, Soviet engineers developed a wide variety of new nuclear and diesel attack submarines. These included fast, deep-diving SSNs like the Alfa class that were designed to sortie into the North Atlantic and attack European-bound US reinforcements during a conventional war.[82] Slower, quieter SSNs, such as the Victor and Sierra classes, were designed to hunt US SSBNs on deterrent patrol and interdict American naval forces.

Although the Soviet Navy fielded more than a dozen SSN classes, the Soviet attack submarine fleet was mostly diesel-electric. The relatively short submerged endurance of conventional submarines and the need to make long transits through geographic choke points such as the GIUK gap reduced the utility of the Soviet diesel submarine force. To counteract these vulnerabilities, the Soviets used SS in European waters and established multiple overseas bases and submarine resupply ports in Syria, South and Southeast Asia, Africa, and Cuba. During wartime, SS would harass American and allied shipping and attack other targets of opportunity.

American Strategy and Undersea Warfare Doctrine

The US Cold War strategy stemmed from the central strategic objective of denying any state or coalition Eurasian hegemony.[83] Naval power was central to this strategy, linking together a global alliance network and ensuring the free flow of supplies, reinforcements, and communications between North America, Europe, and Asia. Moreover, as the United States discovered in Korea and again in Vietnam, maritime power was a flexible contingency response tool that could execute targeted power-projection operations without overseas basing.

Undersea warfare was, in turn, central to US maritime strategy. The Soviet Union posed a qualitatively different maritime challenge than Imperial Germany and Nazi Germany. The USSR lacked the capital ships necessary to challenge the United States in a fleet action, but Soviet submarines threatened US carrier groups, SSBNs, and merchant shipping, as well as the US homeland, with nuclear weapons.

In response, the US Navy constructed a multi-layered ASW system that integrated land-based aircraft with carrier air wings. The US Sound Surveillance System (SOSUS) network formed the backbone of US continental ASW defense and was eventually able to use improved hydrophones, favorable acoustic conditions, and maritime geography to cover most of the Atlantic and Pacific Oceans.[84] SOSUS was complemented by maritime patrol aircraft deploying sonobuoys and submarines with towed sonar arrays. Later, surveillance towed array (SURTASS) ships used active and passive sonar to monitor adversary submarine movements, as SOSUS became less effective due to Soviet submarine quieting in the wake of information provided the Soviets by the John Walker spy ring in the 1980s.[85]

US Cold War ASW efforts could be considered in terms of offensive operations against Soviet submarines in and near their home ports, and bastions and defensive operations around US and allied naval forces and territory. On offense, US ASW operations focused on choke points and constrained waters that Soviet submarines would need to pass through when leaving their local operating areas, such as the GIUK gap and Strait of Gibraltar. Offensive ASW tactics used SOSUS arrays, SURTASS ships, and US SSNs to detect submarines at choke points or in bastions. Submarine contacts were then tracked by maritime patrol aircraft and turned over to an SSN for long-term surveillance and intelligence gathering.

The US Navy's defensive ASW efforts centered on the carrier battle group (CVBG) and its Grumman AF *Guardian*, S-2 *Tracker*, and S-3 *Viking* fixed-wing aircraft. The CVBG would deploy S-2s or S-3s with sonobuoys more than 100 nm from the carrier, beyond the range of Soviet submarine-launched torpedoes and anti-ship missiles (ASMs). Surface combatants with towed arrays and shipborne SH-2, SH-3, and later SH-60 ASW helicopters with active dipping sonars would search inside the 100 nm search area. After detecting a submarine, S-2s or S-3s and ASW-capable helicopters would localize the target and attempt to destroy it with air-dropped torpedoes.

From the construction of the Thresher/Permit-class onwards, the US Navy also deployed SSNs with CVBGs, but their main role was to search ahead of the CVBG to sanitize areas in advance of the carrier's arrival.[86] US ASW operations were generally not conducted when a US submarine was in the area, in order to enable rapid attacks on enemy submarines and avoid fratricide.[87]

Beginning in 1959, the Navy converted several of its older Essex-class aircraft carriers (CVs) into ASW carriers, designated CVS.[88] The relatively light S-2 could deploy from the smaller deck of the Essex class and conduct long-range search patrols, while SH-34 and SH-3 helicopters would localize and attack enemy submarines. US allies also adopted the CVS concept.

Starting in the early 1970s, the "high-low" fleet plan of Elmo Zumwalt, then US Navy chief of naval operations, refined US ASW concepts. Zumwalt recognized that Soviet submarines were pressuring the US Navy in multiple regions, hoping to overstretch American resources and tip the European correlation of forces in their favor. In response, Zumwalt divided US naval force structure into "high" and "low" components. High-end capabilities like carriers, submarines, and large surface combatants would be concentrated on the Soviet threat and largely reserved for major confrontations. The Navy would then build smaller, cheaper surface combatants to cover secondary theaters, defend global shipping, and respond to contingencies.

Under the high-low fleet plan, new Ticonderoga-class Aegis cruisers were joined by Spruance- and Kidd-class destroyers in CVBGs, while new Oliver Hazard Perry–class frigates replaced destroyers on patrol elsewhere. The versatile 4,100-ton Perry class fielded diverse capabilities, including anti-air and anti-ship missiles, a towed sonar array, and two ASW-capable helicopters.

The 1980s US Maritime Strategy integrated ASW operations into an operationally and strategically offensive approach. US naval strategists posited that the United States could afford to be much more aggressive at sea than it had been throughout the 1970s.[89] Much as the Soviets hoped to peel off American units by creating distractions in the South Atlantic and Latin America, the United States could leverage its maritime power to pressure exposed Soviet flanks. Concentrated US naval forces could destroy Soviet fleet groups in the Mediterranean, the Pacific, and the Baltic, facilitating amphibious landings that would disrupt a Warsaw Pact offensive. Simultaneously, the United States could pressure Soviet submarine bastions in the Barents Sea and Sea of Okhotsk, jeopardizing Soviet second-strike capabilities and compelling front-line Soviet SSNs to return home in defense of SSBNs.

Undersea warfare capabilities were critical to this strategy. Los Angeles–class submarines could attack land targets with Tomahawk missiles and conduct ASW in contested areas, such as Soviet bastions where surface and air ASW forces would not be effective or survivable. The Perry-class frigates also entered service, allowing redeployment to CVBGs of more capable Kidd- and Spruance-class destroyers—the latter of which were designed for ASW. The US Navy also fielded the quiet Ohio-class SSBN during the 1980s to undermine Soviet maritime strategy by reducing the ability of Soviet SSNs to threaten US second-strike capabilities.

The US Navy's experience with ASW during the Cold War demonstrated the benefits of an offensively minded doctrine. By adopting the Maritime Strategy during the 1980s, the US military was able to erode the Soviet Union's confidence in its undersea fleet, which was in many ways the crown jewel of the Soviet military.

Pax Americana: US ASW until the 2000s

The Soviet Union's collapse in 1990 obviated the apparent need for robust ASW capabilities. The US military then expected its primary threats to come from so-called rogue states like Iraq, Libya, North Korea, and Iran, powers with limited conventional capabilities and selective WMD capabilities, rather than sophisticated, modern militaries. Operation Desert Storm in 1991 solidified an emphasis on airpower and precision targeting in US military planning and operations. Institutionally, the Navy was forced to adapt, investing in new fixed-wing aircraft like the F/A-18 E/F *Super Hornet* and guided ground-attack munitions while phasing out ASW aircraft such as the S-3 *Viking*.

Forward-deployed carriers were also integral to Middle Eastern wars following the terrorist attacks of September 11, 2001. The USS *Enterprise* deployed to the Northern Arabian Sea immediately after the attacks, where its aircraft supported special forces and other ground troops during the first weeks of Operation Enduring Freedom in Afghanistan. Multiple carriers provided strikes and close air support during Operation Iraqi Freedom in 2003. In both cases, carrier air wing (CVW) strike capacity reduced the US military's dependence on land basing, which several regional allies and partners were reticent to provide.

At the same time that CVWs decreased their ASW capabilities, surface combatants also refocused on ground attack and deemphasized ASW. While Arleigh Burke-class destroyers and Ticonderoga-class cruisers still fielded active and passive sonar arrays and helicopter-borne ASW systems, their primary roles became maritime security, missile defense, and strike.

Submarines retained a role in US defense strategy, particularly as the nuclear triad's most survivable leg. However, US SSNs shifted to mostly intelligence, surveillance, and reconnaissance (ISR) missions, their active warfighting duties largely restricted to launching Tomahawk missiles. Consistent with that role, the US Navy converted four of its oldest Ohio-class SSBNs during the mid-2000s into guided-missile submarines (SSGNs) capable of deploying sixty-six special operations personnel and carrying 154 Tomahawks.

ASW regained some prominence during the mid-2000s, as the RFN restored periodic SSN deployments and the PLAN fielded more advanced conventional submarines, including some with air-independent propulsion (AIP). The need for ASW capacity became more urgent with the retirement of the Perry-class frigates during the mid-to-late 2000s. The Navy intended to address ASW capacity shortfalls in part with the littoral combat ship (LCS), which incorporates surface warfare (SUW), ASW, or mine countermeasure (MCM) modules. As a result of delays in the program, the ship mostly deployed with SUW modules and conducted maritime security operations, but the MCM and ASW modules are expected to be fielded during the early 2020s.[90]

Undersea Warfare and Contemporary Strategic Competition

The People's Republic of China (PRC) poses the greatest threat among contemporary powers to US interests and global stability. Under Hu Jintao and Xi Jinping, the Chinese Communist Party (CCP) translated China's economic wealth into a military expansion aimed at achieving quantitative superiority and qualitative parity with US and allied forces in the Indo-Pacific. Moreover, unlike the Soviet Union and Imperial and Nazi Germany, China's coastline affords it maritime access that facilitates its naval power.

Through modernization, the PLA has fielded a force that could overwhelm US and allied forces in the opening stages of a conflict by saturating targets among the Western Pacific island chains with air-, land-, and sea-launched cruise and ballistic missiles and air-delivered bombs. Simultaneously, the PLA could hold US reinforcements at arm's length through longer-range capabilities, such as submarines that threaten US carrier groups and sealift. The result may force US leaders to choose between a brutal, potentially nuclear campaign to retake the Western Pacific, or surrender and acceptance of Chinese hegemony.[91]

Undersea capabilities play a specific role in China's military strategy. The majority of the PLAN submarine fleet is composed of diesel-electric or air-independent propulsion submarines that are largely unable to deploy overseas without snorkeling and potentially revealing their location.[92] Therefore, they will likely be used as part of the PLA's broader sensor and weapons network against US naval forces in the Western Pacific.[93]

Among nuclear submarines, Jin- and Xia-class SSBNs provide the PRC with a second-strike capability. The PRC currently lacks bastions in which to protect SSBN operations, although the PLA's efforts to militarize the South China Sea could eventually allow SSBN operations under the protection of PLA air, surface, and ASW defenses. The PLAN's nine SSNs are designed for longer-range patrols outside the Western Pacific, although they are reportedly noisy compared to their US or Russian counterparts.[94] The PLAN has invested in nuclear submarine construction capacity, which may presage an improvement in acoustic performance and growth in the size of the nuclear submarine fleet.[95]

The PLA's modernization focused initially on anti-air and anti-surface sensors and missiles as part of its broader counter-intervention strategy against US and allied forces. The lower priority of ASW in PLA modernization gave US leaders the impression that the US Navy's undersea advantage would be decisive during a US-China conflict.[96] Since the 2000s, however, the PRC has invested heavily in a growing network of undersea sensors like SOSUS to better monitor the South and East China Seas. When combined with maritime patrol aircraft and ASW frigates operating from the PRC mainland, this sensor network may enable PLA forces to detect and threaten US submarines, particularly if submarines reveal their presence by launching missile or torpedo attacks. PLA ASW efforts may harass US submarines sufficiently to reduce their effectiveness inside the First Island Chain.[97]

As for Russia, Putin's kleptocratic oligarchy wields far less power than its Soviet predecessor, but targeted technological investment and robust Soviet engineering sustained elements of Russian military power into the twenty-first century. Rather than overwhelming NATO forces along the central front, Russia likely hopes to "crack" the NATO alliance through a series of political victories, culminating in a decisive military campaign against a vulnerable Eastern European state.

Geography makes land and air power central to this strategy. Russian naval power, however, remains relevant, as it allows the Kremlin to pressure European allies from Russian bases in friendly Syria, and to even the odds against NATO in the Baltic's constrained operational environment.

For Russia, much like the Soviet Union before it, undersea capabilities constitute the core of its offensive maritime forces.[98] Its force of fifty-six attack and missile submarines is divided between eleven SSBNs on deterrence patrol, thirty-six SSNs and SSs, and nine SSGNs.

The most capable RFN submarines are the Yasen- or Severodvinsk-class SSGNs. Although the Yasen is formally an SSGN, its payload of thirty-two missiles is between that of US Virginia-class SSNs and Ohio-class SSGNs, and it would be on par with the Virginia Payload Module planned for inclusion in the Block V Virginia-class submarines now under construction.[99]

The Yasen SSGNs are also acoustically comparable to the Virginia class and have similar, if not better, weapons and sensors. Fortunately for the US Navy, only two ships of the class are now deployed.[100]

In addition to the Yasen class, other newer Russian SSNs are comparable to US Los Angeles–class submarines in terms of acoustic and sensor performance. The majority of active boats are Sierra IIs and Victor IIIs, both fielded during the 1980s to hunt American SSBNs. They are joined by more capable Akula IIs developed at the end of the Cold War. Russian SSs have a similar range of capability, with Cold War–era Romeos still in the fleet, alongside Kilo and improved Kilo SS.

The RFN adopted a force distribution similar to that of its Soviet predecessor, deploying its SSNs predominantly with the North Sea Fleet so they can interdict NATO and US shipping or naval forces in the Atlantic. Basing in the Northern Fleet also enables Russian SSNs and SSGNs to threaten cruise missile attacks against the US East Coast or hold US SSBNs at risk, providing the Russian government escalation options in the event of a conflict. The RFN deploys its SSs with the Northern Fleet and Black Sea Fleet for operations against NATO navies in the Mediterranean's shallower and more constrained waters.

Iran, although not a great power adversary, still poses an undersea threat to US naval forces. The Iranian regime's wartime strategy may involve denying the United States access to the Persian Gulf and crippling international shipping to damage the global economy and force a settlement on favorable terms. The Islamic Republic of Iran Navy (IRIN), which generally operates outside the Persian Gulf, has several SSs, including three improved Kilos. IRIN Kilos experience poor battery performance due to high ocean temperatures in the region, which limits their submerged endurance and ability to deploy outside the region. The *Ghadir* mini-submarines (SSMs) of the Islamic Revolutionary Guard Corps Navy (IRGCN), based on the North Korean Yono class, could threaten US naval forces inside the Persian Gulf, particularly when coupled with the IRGCN's fleet of fast attack craft.[101]

North Korea's submarine force presents a more significant challenge to US naval forces than Iran's. North Korean submarines have more freedom of action, and they are closer to major powers and regional powers whose economies and naval forces would be vulnerable to even a small or relatively ineffective submarine warfare campaign. Pyongyang's submarine fleet is also among the largest in the world, with more than eighty boats, including at least one diesel-electric ballistic missile submarine (SSB).[102] The North Korean SSB force does not present a more dangerous threat than the regime's road-mobile ballistic missiles, but it would add a new consideration for US and allied ASW efforts.

ASW will therefore be one of the most important missions for US naval forces in a confrontation with North Korea. Although many of the North Korean Navy's forty coastal submarines (SCCs) and twenty Cold War–era Romeo SSs are in relatively poor condition or unable to deploy, its more than twenty Yono SSMs may be difficult to find and destroy.[103] Because mini-submarines have a low acoustic signature and operate in noisy shallow waters, they are likely to be hard to locate using passive sonar; their small size also makes them difficult to discern using active sonar. And when they are found, many modern torpedoes will not home on them due to their low acoustic signature and target strength.[104]

The North Korean military is likely to use SSCs and SSMs to attack US and allied naval forces early in any conflict, given the submarines' short endurance and range. As evidenced by the attack of a North Korean SSM on *Cheonan*, a Republic of Korea Navy ship, these small submarines can carry effective weapons and slow down US and allied efforts to cut off North Korea from the sea or to land troops along the North Korean coast during wartime.[105]

Implications for New ASW Concepts

The wide variety and growing sophistication of undersea threats faced by US and allied forces demands new ASW approaches that are scalable and affordable. Today's ASW concepts, relying on manned platforms and capable platform-based sensors, may work well against a small number of modern submarines, such as those operated by the RFN. The US approach would be inordinately expensive, however, against a regional competitor like Iran or North Korea, and would be unable to scale to address the number of quiet conventional submarines the PLAN could deploy.

Unmanned vehicles, sensors, and engagement platforms offer a way to achieve scalability and reduce costs for ASW operations. Concepts for unmanned ASW operations, however, should exploit lessons from past ASW campaigns to improve their efficiency and effectiveness. For example, past experience suggests submarine operations can be suppressed through frequent or continuous overt tracking and attacks, which could be more affordably conducted by unmanned than manned platforms. These implications will be discussed in the next chapter.

Unmanned systems are unlikely during the next decade to achieve the autonomy necessary to conduct ASW on their own, but today's level of technology can enable them to do many of the ASW tasks manned platforms currently perform. Combining unmanned vehicles, vessels, sensors, and control systems with human command would provide US and allied navies a way to efficiently counter the submarine threat that frees up manned multi-mission platforms for other pressing missions.

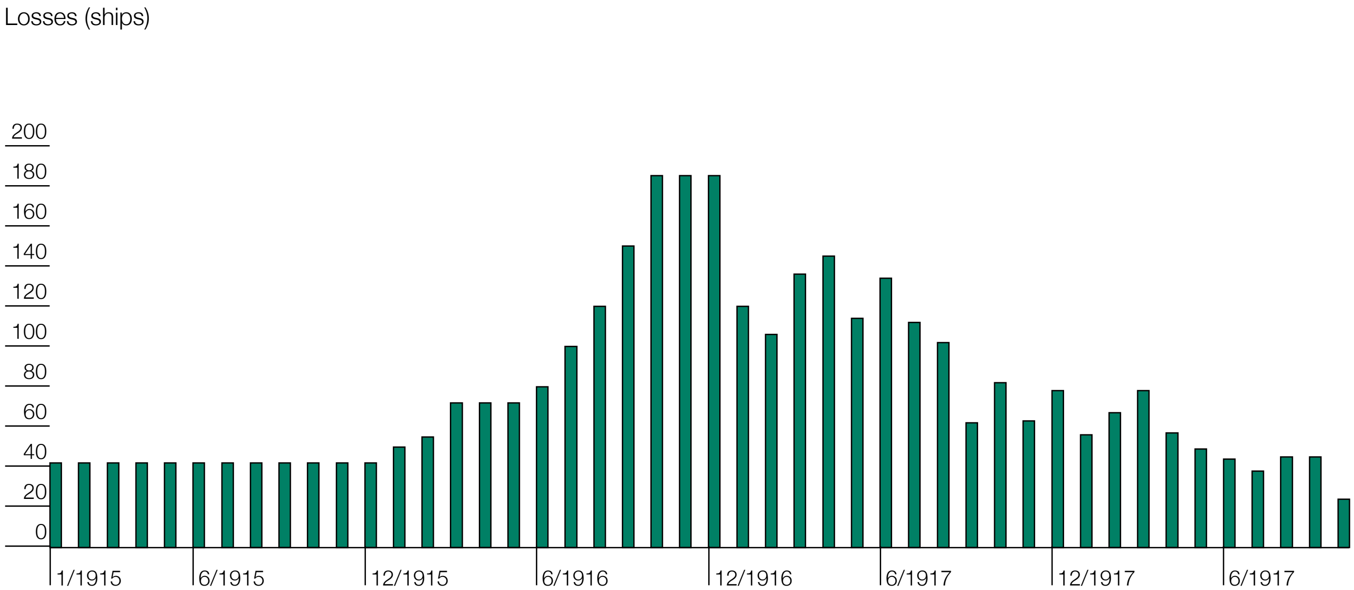
CHAPTER 3. IMPLICATIONS OF HISTORICAL CAMPAIGNS FOR FUTURE ASW OPERATIONS

Although submarines, their targets, and ASW platforms have all changed during the decades since the world wars and Cold War, the fundamental relationships between them are still largely the same. Submarines, if they are traveling slowly enough to avoid detection by sonar, have an approximately 2-to-1 speed disadvantage compared to surface warships or commercial vessels.[106] Submarines generally lack self-defense systems, relying primarily on acoustic countermeasures to confuse or distract incoming weapons. And submarine sonar is unable to quickly provide precise assessments of whether incoming attacks are likely to be successful.

Unlike surface warships or aircraft, submarines face challenges standing and fighting, rapidly assessing the likely effectiveness of an attack, or out-maneuvering incoming weapons. Stealth is a submarine's most important defensive capability. Submarine commanders therefore tend to promptly evade when attacked, or they exit the operating area when counter-detected. Successful ASW campaigns, such as the Battle of the Atlantic, exploited these disadvantages to suppress or drive away submarines, rather than engaging in protracted prosecutions to sink them.

Photo Caption: Russian President Dmitry Medvedev delivers a speech in the northern Russian town of Severomorsk on June 15, 2010 at the Sevmash shipyard launching of a K-329 Severodvinsksk, a Russian nuclear multipurpose attack submarine class. The submarine is based on the Akula-class submarine and the Alfa-class submarines and are projected to replace Russia's older Soviet-era class attack submarines both Akula class and Oscar class. (Vladimir Rodionov/ AFP via Getty Images)

Figure 4: Shipping losses in the Atlantic Ocean during the First World War[108]



First World War

Although submarines were used in previous conflicts, World War I marked their first large-scale employment in wartime. It was also the first opportunity for ASW forces to exercise their entire detect-to-engage kill chain at scale. As previously noted, submarines were an important element of German military strategy, which depended on shipping interdiction to reduce US support for forces of the Grand Alliance.

German naval leaders focused their submarine operations outside departure and arrival ports because the slow speed of First World War submarines prevented them from intercepting shipping in the open ocean. Although the British and US navies patrolled their coasts, submarines would submerge when ASW forces approached and could remain under for one to two days, until their batteries or air ran out. This was usually sufficient to evade ASW forces which, until 1917, lacked effective sonar systems or depth charges that would enable continued prosecution of submarines and, potentially, their destruction.[107]

Although submarines were unable to execute attacks when being pursued by ASW forces, coastal patrols were not able to continuously monitor all the shipping lanes to and from allied ports. Arriving or departing merchant ships still faced a substantial likelihood that a submarine was in position to attack. This led to rising and increasingly problematic shipping losses during the war (shown in figure 4), and these grew dramatically in 1916 as the United States began shipping large amounts of supplies and equipment to Europe.

The lack of synchronization between ASW patrols and merchant shipping, which gave German submarines opportunities to attack, changed in 1917 with the introduction of convoy tactics. Although less efficient than allowing ships to transit as soon as they were loaded and ready, convoys enabled ASW patrols to be deployed in concert with merchant ships and compressed potential targets in time and space. Surfaced submarines could not travel faster than merchant ships, requiring them to position ahead of convoys and attack during a short window before convoys passed out of range.[109]

The introduction of portable hydrophones and effective depth charges in 1917 added to the challenge for submarines. Although primitive by today's standards, these capabilities enabled patrols to sustain ASW prosecutions until a submarine was forced to surface, was damaged or destroyed, or was driven far enough away to be out of the fight for several days.

Figure 4 shows that convoys and improved ASW capabilities reduced shipping losses, even as the amount of shipping increased with the US entry into the war in April 1917. German reports and the gradual decline in shipping losses, however, suggest ASW operations were not destroying submarines. Given the small German submarine fleet during the First World War, significant numbers of submarine sinkings would likely have reduced allied shipping losses more dramatically.

Second World War

The basic structure of the Atlantic submarine-ASW competition during the Second World War was similar to that of the First World War. Axis submarines from Germany and Italy interdicted

Figure 5: Convoy routes and U-boat patrol areas during the Battle of the Atlantic[110]

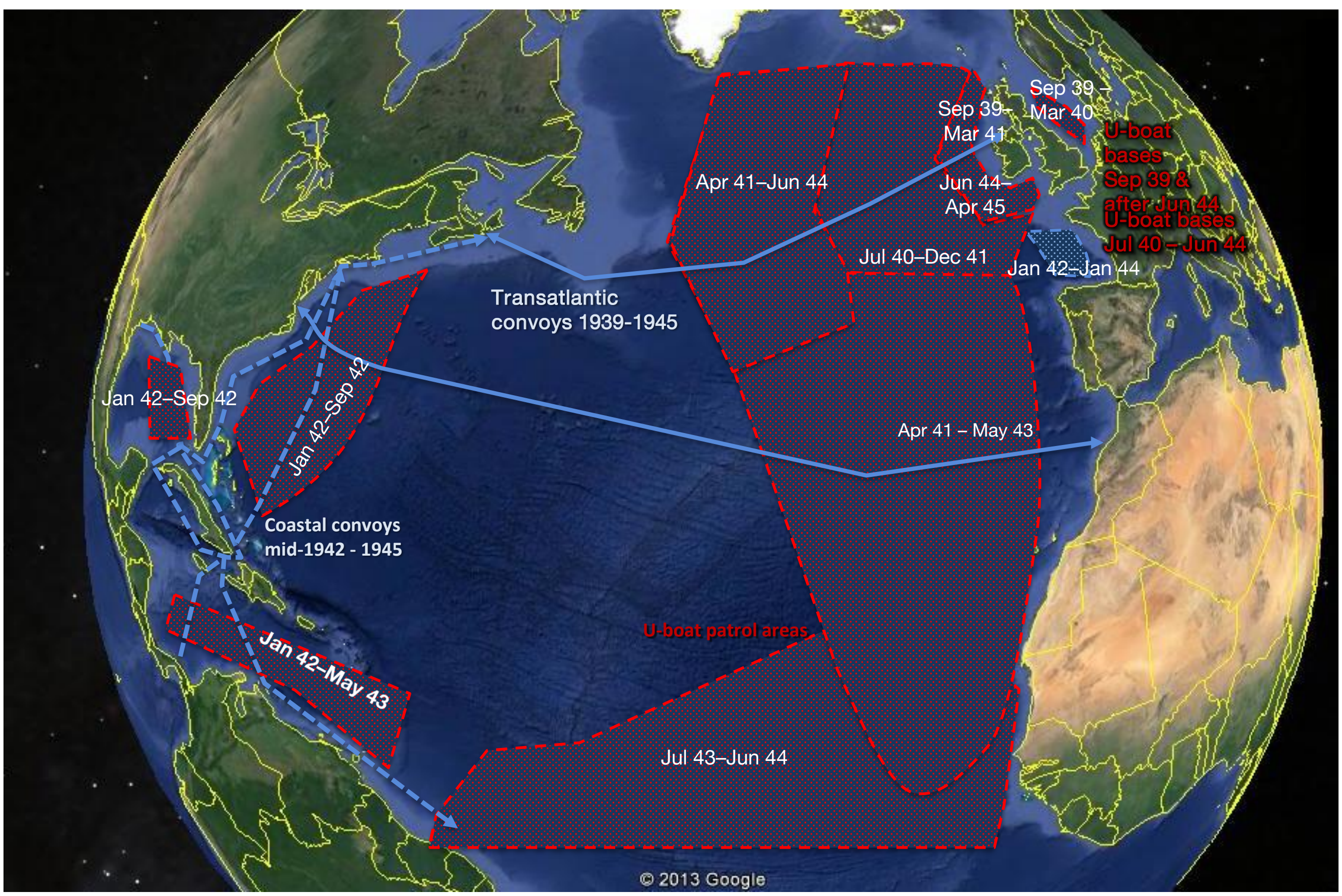
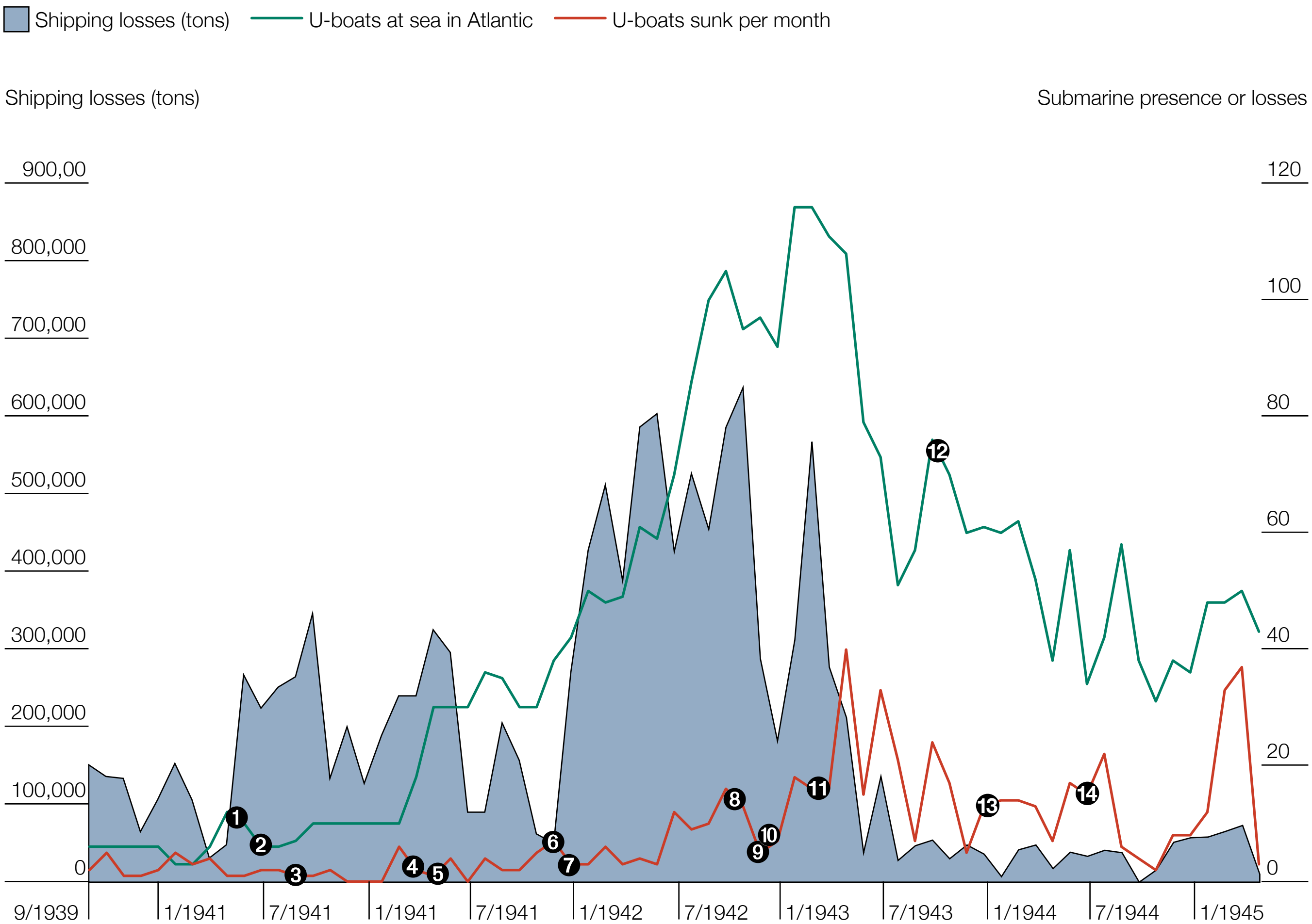


Figure 6: Allied shipping losses and Axis submarine presence and losses during the Battle of the Atlantic[112]



❶ U-boats shift to surfaced night attack due to sonar threat

❷ Wolf pack tactics start

❸ Leigh Light & L-band radar on a/c

❹ HF/DF, radar on escort

❺ Enigma decrypted

❻ New Enigma codes

❼ Hedgehog begins fielding

❽ L-band GSR deployed

❾ Hedgehog fully fielded

❿ New Enigma decrypted

⓫ S-band radar

⓬ S-band GSR deployed

⓭ X-band radar deployed

⓮ X-band GSR deployed

convoys between the United States and its European allies. The Battle of the Atlantic, however, featured faster submarines with longer endurance that enabled Axis forces to interdict shipping in the open ocean and shift patrol stations to avoid ASW operations and follow convoy routes.

The submarine-ASW competition in the Pacific campaign is less useful analytically than the Battle of the Atlantic. As noted above, the IJN did not mount a sustained ASW effort against US submarines that attacked Japanese shipping in the Western Pacific. Japanese submarines, for their part, did not make a significant impact on US shipping or naval forces because of their small numbers and focus on operating with the combined IJN fleet rather than independently.

Applying lessons from the First World War, Allied naval forces operated shipping in convoys from the start. Allied leaders accepted the resulting 30 percent reduction in shipping efficiency and escorted convoys with ASW patrols of improving capability and proficiency, which reduced the number of combatants available for other operations.[111] Both costs were deemed necessary to sustain Britain and enable preparations for the invasion of continental Europe.

Submarine forces also made improvements, however. Axis U-boats, instead of operating near ports as in the First World War, could use their greater speed and endurance to operate in open ocean. Using information gained from decrypting Allied convoy communications and detecting convoy radio transmissions and radar with HFDF, German commanders ashore radioed orders to position submarines astride the routes of upcoming convoys. These advancements enabled each submarine to be highly productive early in the war, as shown in figure 6; Allied shipping suffered significant losses, even though only about a dozen U-boats were deployed in the Atlantic on any given day until 1941. These losses were aided by wolf pack tactics that exploited the use of convoys by positioning multiple submarines along shipping routes, allowing more engagements against convoys before they passed out of range or the submarines were engaged by ASW escorts.

The Axis submarine warfare approach began to falter, however, in 1941. Despite the increased presence of submarines in the Atlantic as the fleet grew and Axis forces gained access to bases in newly occupied France, shipping losses dropped sharply in mid-1941. As in the First World War, the reason was not that submarines were being destroyed. Instead, submarines were being driven away from convoys by ASW forces using a combination of new capabilities. ASW patrol aircraft began carrying lights and radar to detect U-boats at longer ranges and at night; ASW ships deployed DF equipment to detect submarine radars and radio transmissions; and more escorts were available to pursue submarines and prevent re-attacks until the convoy had cleared the area.

Shipping losses also deceased during 1941 after Britain captured a U-boat, *U-110*, along with its Enigma machine, enabling the Allies to break the Enigma code used to encrypt German submarine orders. By intercepting orders to German wolf packs, British and American naval leaders were able to route convoys away from submarine patrol areas, achieving an effect similar to that of escorts driving U-boats away from convoys. By early 1942, however, the German Navy recognized its submarine communications were compromised and introduced a new Enigma code and encryption gear. [113]

The impact of improving Allied ASW capability was masked during early 1942 by the return of encrypted submarine messages and the US entry into the war. German submarines that had been patrolling the US East Coast were free, starting in December 1941, to attack coastal shipping that was moving material to convoy departure ports or allies in the Caribbean and South America. With most US ASW forces in the Northern Atlantic protecting convoys, Axis submarines were able to impose losses that doubled those from earlier in the war.

The substantial shipping losses of 1942 dropped precipitously, however, by mid-1943. Although submarine presence was higher than earlier in the war, shipping losses fell by about 90 percent between spring and summer of 1943. As in 1941, submarines were not being destroyed in sufficient numbers to lower their presence, suggesting that again they were being suppressed and that convoys were able to evade attack.

As noted above, several technical advancements contributed to the suppression of Axis submarines from 1943 through the war's end. During 1942, Allied ASW forces fielded a growing fleet of ships equipped with active sonar and escort aircraft carrying more accurate S-band radars, which were numerous enough to leave escorts to prosecute submarines while the convoy continued to its destination. The Allies were also able to break the new Enigma code by early 1943 and attempt to route convoys around U-boat patrols, although this effort was less successful than earlier in the war due to the larger German submarine fleet and more disciplined communications practices.[114]

German efforts to counter Allies' use of radar may have unwittingly contributed to the effectiveness of submarine suppression. Starting in 1942, U-boats began carrying warning receivers that could detect L-band radars. As a result, submarine commanders often submerged and evaded when Allied radars were detected, reducing or eliminating their ability to attack Allied convoys even when the likelihood of radar detection may have been low. This dynamic continued as the Allies fielded higher-frequency S- and X-band radars later in the war, and submarines deployed corresponding warning receivers.

Role of Weapons Placement

In many cases, sensing alone was sufficient to drive away Axis submarines. To effectively suppress U-boats, however, required the credible threat of a successful ASW attack. Until 1942, ASW forces relied on depth charges, which were not very accurate, because when the ship passed above the submarine to drop charges, it would lose track of the submarine. During 1942, the Allies fielded the Hedgehog rocket-propelled depth bomb, which could be aimed at submarines as they were being tracked on sonar. This improved accuracy compared to depth charges. Although the smaller warheads on weapons like the rocket-propelled Hedgehog, Mousetrap, or Squid were less likely to sink a submarine, their greater accuracy made damage more likely than with a depth charge.

The importance of weapons placement to successful ASW engagements suggests that future ASW concepts should either use inexpensive, relatively inaccurate weapons to drive off submarines or employ small, sophisticated torpedoes that aircraft or risk-worthy ships can deploy directly on the submarine's projected location.

Importance of Disaggregated ASW Concepts

New sensors and weapons improved the ability of Allied forces to communicate to a U-boat crew that their submarine had been detected and was being prosecuted. ASW escorts, however, were often unable to sustain pursuit because they had to return to their convoys. By 1943, Allied navies had built up enough capacity to begin complementing dedicated convoy escorts with hunter-killer ASW groups that could prosecute submarines while convoys continued on their transit.

Hunter-killer groups helped reveal the value of multiple platforms to successful ASW prosecutions. A submarine can evade a single ship or aircraft by bottoming, radically changing course and speed, or releasing flotsam and

Table 2: Likelihood of weapons achieving a submarine hit during the Battle of the Atlantic[115]

WEAPON	LETHAL RADIUS (FT)	# OF CHARGES / BARRAGE	PROBABILITY OF HIT PER BARRAGE (%)				
			1ST HALF 1943	2ND HALF 1943	1ST HALF 1944	2ND HALF 1944	1ST QTR 1945
Depth Charge	21	9	5.4	4	6.4	5.1	7
Mousetrap	0	24		7.5	15.4	28.1	23
Squid	0	16				33.3	62

jetsam to convince ASW forces that it was destroyed. If the ASW platform attempts to sustain or regain contact as the submarine maneuvers, this may place it in a poor position to subsequently engage the target. If multiple platforms conduct the prosecution, one can maintain track on the submarine while the others position themselves to conduct an engagement or regain contact, if lost. As shown in table 3, multiple platform prosecutions during the Battle of the Atlantic were more likely to sink submarines or regain track after the submarine evaded.

Figure 7: Forward-fired weapons like the hedgehog achieved higher lethality than unaimed depth charges dropped on possible submarines

Depth Charge (1939)

Hedgehog (1941)

Table 3: Probability of successful ASW prosecutions during the Battle of the Atlantic[116]

(U) LOCATION OF ATTACKS	(U) SINGLE PLATFORM	(U) MULTI-PLATFORM
(U) US attacks, Atlantic and Mediterranean; Jan 1943–Feb 1944		
(U) Number of incidents	176	18
(U) Number assessed as sunk or probably sunk	9	3
(U) Percent successful	5	17
(U) US attacks, Atlantic and Mediterranean; March 1944–May 1945		
(U) Number of incidents	41	38
(U) Number assessed as sunk or probably sunk	5	21
(U) Percent successful	12	55
(U) Probability of regaining contact		
Jan 1943–July 1943	0.54	0.8
Aug 1943–Feb 1944	0.68	0.9

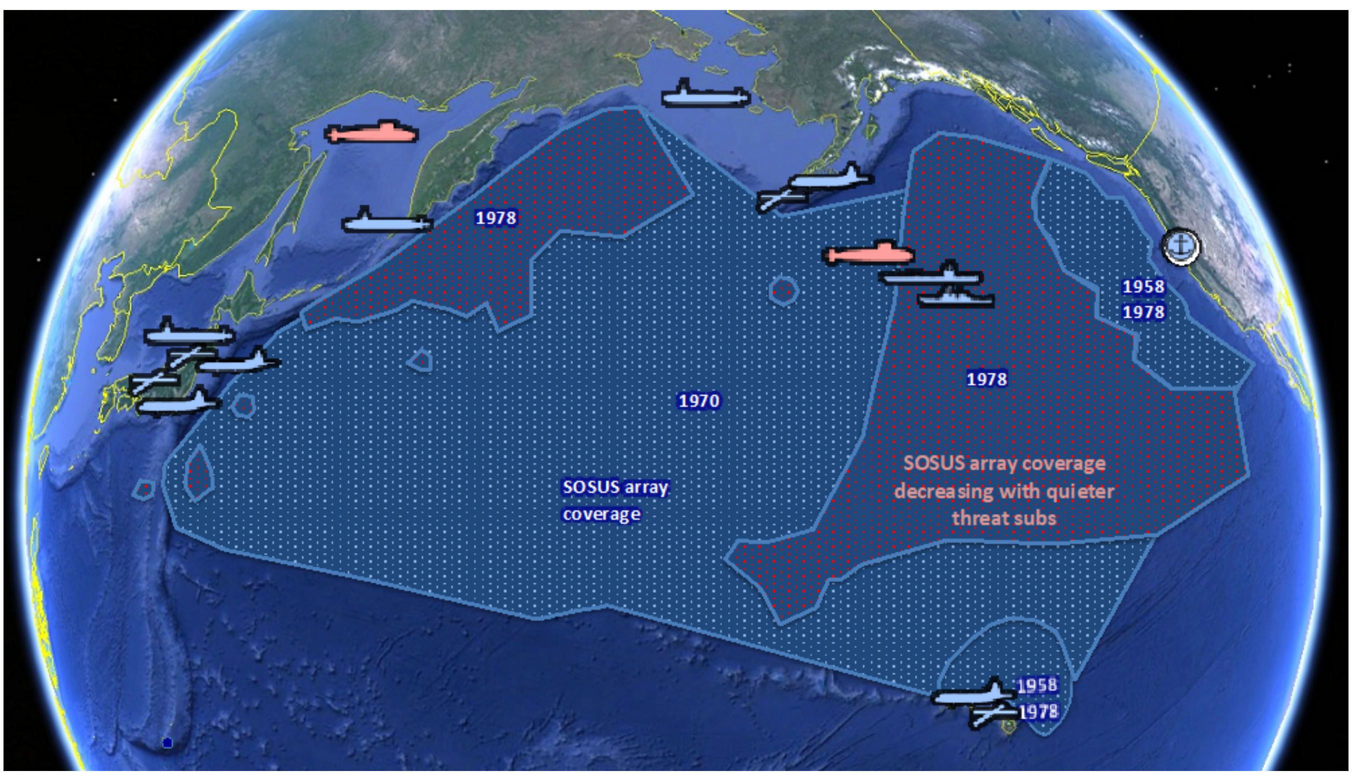
The results of multiple platform engagements may be difficult to leverage with today's US and allied ASW forces, due to a lack of ASW platforms. If the submarine's likely location is not known, as when a naval or maritime force is being defended in open ocean, the resulting large search area could make it impossible for a small number of ASW units to be rapidly repositioned for a coordinated prosecution, once a submarine is detected. Unmanned systems may aid in having enough ASW platforms to enable multiple platform engagements.

The Cold War

Although Cold War ASW strategy and operations did not include the whole ASW kill chain as in the First and Second World Wars, they do offer insights for the conduct of future ASW campaigns. The advent of nuclear submarines during the 1950s posed a challenge for radar and electronic intelligence, the predominant ASW search sensors during the world wars. In contrast to diesel submarines, which spent most of their time on the surface, nuclear submarines could remain submerged indefinitely and not use their radars or radios.

Nuclear submarines, however, did present an opportunity for the nascent technology of sonar, which the US and British navies continued to improve following the Second World War. Whereas diesel submarines are quiet when submerged and sound like other ships when operating their engines on the surface, nuclear submarines continuously emit sound from rotating machinery, such as pumps that are needed to support the propulsion plant. The US Navy exploited this insight—discovered during testing of the first nuclear submarine, USS *Nautilus*—to implement

Figure 8: Changing Cold War SOSUS coverage as sensors and submarine quieting efforts improved[119]



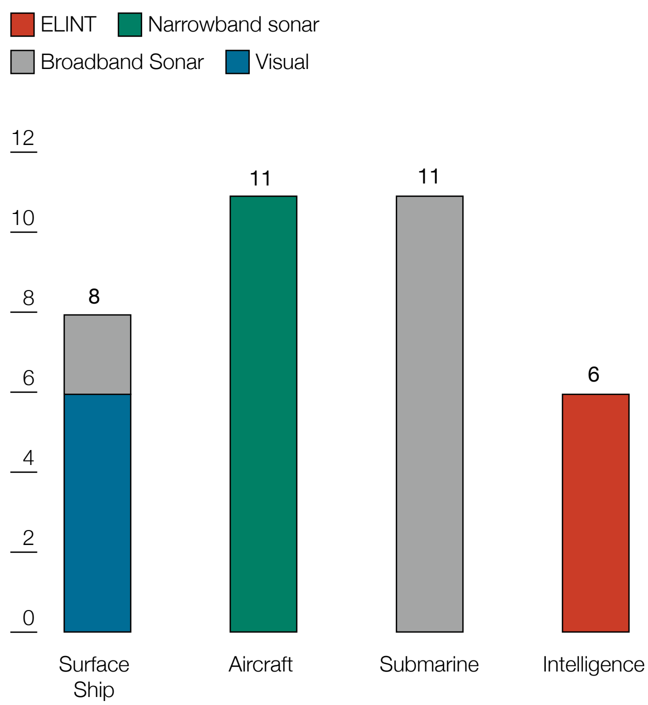
an ASW strategy and operational concepts focused on using passive sonar.[117]

Under the new ASW concept, US naval forces would use SOSUS to detect Soviet submarines, which would then be tracked using sonobuoys deployed by P-3C maritime patrol aircraft and eventually turned over to US SSNs for surveillance. This approach enabled the US Navy to gain intelligence on Soviet submarine characteristics and operations, and to position ASW forces to promptly engage submarines if a conflict started. As shown in figure 8, the coverage provided by the SOSUS system grew as it was expanded and improved with new hydrophones.[118]

By the late 1970s, however, Soviet Navy leaders learned of their submarines' vulnerability to passive sonar and began an aggressive effort at submarine quieting. This reduced the coverage provided by SOSUS and the detection ranges possible with US sonobuoys and SSN sonars. By the 1980s, the US Navy lacked the SOSUS coverage and P-3C and SSN capacity to find and track growing numbers of quiet Soviet submarines. These submarines would pose a threat to US CVBGs or convoys resupplying European allies during a conflict with the Warsaw Pact.[120]

To address the challenge posed by the Soviet submarine fleet, the US Navy mounted a new ASW strategy that focused on threatening Soviet nuclear SSBNs in their patrol areas across the Arctic Ocean, Barents Sea, and Sea of Okhotsk. The strategy was based on the assumption that Soviet Navy leaders would send their best SSNs to protect the SSBNs, reducing the number that US patrol aircraft and SSNs would need to track and engage in open ocean. This offensively oriented ASW approach enabled US submarine forces to exploit their larger number of quiet SSNs to offset the Soviets' growing parity in their small number of most-advanced SSNs. This same approach could be employed today to address the challenges posed by the Yasen and Sierra II classes.

Figure 9: Sources for US detections of Soviet SSNs during 1967 Arab-Israeli War[122]



To complement the US Navy's offensive ASW efforts, its surface combatants and shipboard helicopters carried active sonars to conduct defensive ASW against Soviet SSNs. As shown in figure 9, Cold War nuclear submarine detections resulted from narrowband and broadband passive sonar, visual sensors, or ELINT sensors. Although helicopters also carried a small number of passive sonobuoys, the surface fleet's reliance on hull-mounted and dipping active sonars suggests that the goal of defensive ASW operations was to drive Soviet SSNs away rather than prosecute and sink them.[121]

Conclusion

Submarines are effective platforms for penetrating enemy defenses and conducting missions, from intelligence gathering to strike warfare. They do, however, have several limitations that

ASW forces can exploit. In terms of their missions, submarines' relatively slow speed when in quiet mode affords them short windows to engage transiting surface ships with torpedoes before the ships are out of range. It also constrains submarines' ability to reposition for a successful attack if target ships change their transit path. Although ASMs enable much larger windows for submarines to attack ships, modern merchant ships are ten or more times as large as their predecessors from the world wars and may not be as susceptible to ASMs.

In addition to their slow speed, submarines depend on sonar when they are submerged, which is less precise than the radars used by surface ships or aircraft and would not enable a submarine to promptly determine if an attack is likely to be successful. Moreover, submarines generally do not have self-defense systems like the Aegis Combat System and surface-to-air missiles carried by a surface combatant. Together, their slow speed and limitations in sensors and self-defense compel submarine crews to promptly evade when they are attacked.

The experience of US and Allied forces through both world wars and the Cold War suggests that effective ASW campaigns should focus on suppressing submarine operations rather than sinking submarines. ASW strategies and concepts kept submarines from completing their missions by attacking them, convincing crews their submarine has been counter-detected, or creating challenges that required submarines to return to home waters. These same approaches, described in the next chapter, could be applied to future ASW operations, enabling them to be more affordable and sustainable than is possible with today's concepts and capabilities.

CHAPTER 4: NEW ASW CONCEPTS

The US Navy's current approaches to ASW are largely unchanged from those of the early Cold War, in part because they address a similar set of circumstances. Although submarines are now deployed by several adversaries rather than only the Soviet Union, US naval forces again face relatively large fleets of conventional submarines and a small number of quiet nuclear submarines. And as in the Cold War, contemporary ASW missions are mainly for intelligence-gathering and surveillance rather than combat.

The ASW concepts employed by the US Navy today are expensive and manpower intensive, and they take multi-mission DDGs and SSNs away from potentially more important missions such as air defense or strike warfare. These approaches, though they made sense during the intensifying Cold War, may be unaffordable in a period of flat or declining defense budgets, and they would likely be unsustainable during confrontation or conflict with a capable submarine force. New concepts are needed that reduce costs and free up multi-mission platforms for higher-priority missions.

New concepts would also need to be more effective than today's ASW tactics. In addition to being costly, current air and surface ASW tactics are optimized around the goal of sinking or destroying submarines. Unfortunately, because lightweight air- and surface-launched torpedoes have low lethality, resource-intensive ASW prosecutions will rarely result in a "kill" unless a submarine executes the attack with a heavyweight Mk-48 torpedo.[123] As a result, US forces will continue expending fuel, sonobuoys, and weapons with a low probability of destroying the enemy submarine.

Photo Caption: A Sea Hunter autonomous unmanned surface vehicle gets underway on the Willamette River following a christening ceremony in Portland, Oregon in April 2016. (US Navy)

The resource- and manpower-intensive nature of US and allied navies' current ASW concepts drives them toward defensive ASW strategies. As manned platforms and sonobuoys run out or are needed elsewhere, ASW operations will necessarily collapse to protect high-value targets, instead of suppressing enemy submarine operations closer to the adversary's waters. New unmanned-centric ASW concepts can help US and allied navies regain the offensive.

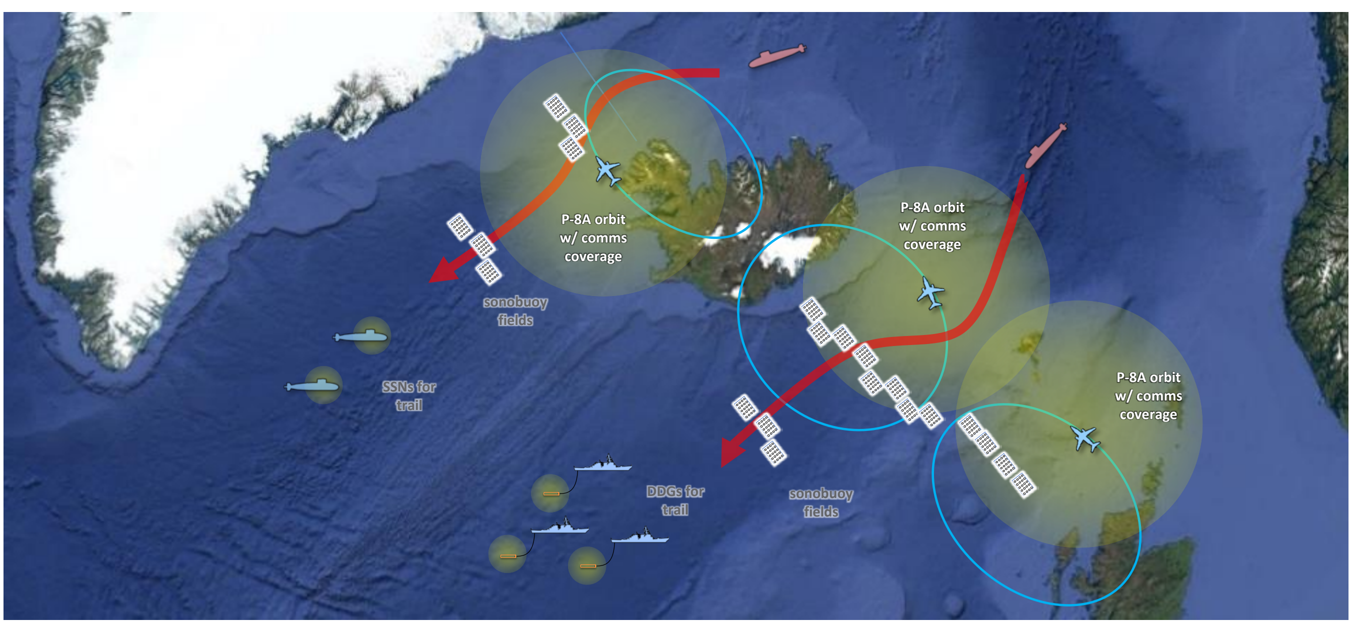
ASW Operations Today

In general, the Navy's updated version of Cold War ASW tactics, often called "full-spectrum ASW," uses airborne and space-based ELINT sensors, stationary acoustic sonars such as SOSUS, and manned SURTASS vessels to initially detect submarines. Contacts are then passed for tracking to maritime patrol aircraft like the P-8A, which use successive fields of sonobuoys to track submarines. Beyond P-8A operating areas, SSNs and surface combatants equipped with helicopters and passive multi-function towed arrays (MFTAs) surveil and track adversary submarines. An example of such an operation is shown in figure 10 for Russian SSNs passing through the GIUK gap, although similar tactics would apply in the Pacific theater against PLAN submarines.[124]

For the notional scenario depicted in figure 10, cueing provided by SURTASS ships, SOSUS, or ELINT sensors indicates Russian SSNs are heading south into the GIUK gap. To track the Russian submarines, P-8A maritime patrol aircraft deploy fields of passive or active sonobuoys across potential submarine transit lanes.[125]

Older, passive Directional Frequency Analysis and Recording (DIFAR) sonobuoys and Directional Command Active Sonobuoy System (DICASS) sonobuoys, have detection ranges of 2–3 nm, requiring about twenty sonobuoys to create a field capable of monitoring approximately 10–13 nm on a side.[126] Newer MAC active sonobuoy systems could achieve 5–8 nm detection ranges and therefore require half as many sonobuoys to cover the same area.[127] To cover all the likely submarine transit routes

Figure 10: Notional example of today's ASW approach in GIUK gap



between Greenland and Iceland would require about three fields; surveilling the potential transit lanes between Iceland and the United Kingdom would require about twelve. The number and size of sonobuoy fields could be reduced if intelligence from other sensors suggested that the transiting submarine could use a specific route.

If the transiting submarine's potential path is unknown, three P-8As would be needed to deploy the up-to-fifteen sonobuoy fields in figure 10 and continuously monitor the sonobuoys from an altitude of about 20,000 feet. US SSNs and surface combatants would take station to track Russian submarines beyond the choke points.

Although the approach described in figure 10 provides an effective search barrier, more than a dozen P-8As would be needed to provide continuous aircraft rotation on three stations, and several surface combatants or SSNs would be needed to maintain track on exiting Russian SSNs. As shown in table 4, procurement costs for these platforms would be nearly $20 billion. Although they can conduct other missions and have service lives of twenty-five years or more, they represent a sizable up-front cost to create the capability for peacetime ASW surveillance. This places the US Navy on the wrong side of the cost curve with Russia, which spends about $1.6 billion on a single Yasen SSN.[128]

Perhaps more concerning are the O&S costs associated with this approach, shown in table 5. Once a Russian submarine is suspected of transiting toward the GIUK gap, ASW ships and aircraft need to be moved into position and operate until the submarine arrives. Sonobuoy fields, with operational lives

Table 4: Procurement costs for the ASW operation depicted in figure 10[129]

	UNIT COST	NUMBER REQUIRED	TOTAL COST ($M FY 2020)
P-8As	$184,807,300	14	$2,587
Sonobuoys	Varies	14,648	$55
DDG-51 Flt III	$1,869,000,000	4	$7,476
MH-60R (2 per DDG)	$34,660,440	8	$277
SSN-774	$3,100,000,000	3	$9,300
		TOTAL	**$19,695**

Table 5: O&S costs of ASW operation depicted in figure 7[130]

	UNIT O&S COSTS PER HOUR	NUMBER REQUIRED	TOTAL COST OVER 1 MONTH ($M FY2020)
P-8As	$9,111	14	$72.79
DDG-51 Flt III	$8,562	4	$24.66
MH-60R (2 per DDG)	$5,479	8	$8.27
SSN-774	$8,447	3	$18.25
		TOTAL	**$123.96**

of up to eight hours, need to be reseeded regularly while awaiting the submarine's transit, and when ocean currents or the submarine's movement take the field away from the target. Depending on the submarine's speed, initial tracking could take several days, after which a US SSN might remain on the trail of the Russian submarine for weeks.

As was planned during the early Cold War, naval forces would likely apply this peacetime ASW concept to defeat enemy submarines during a conflict. US naval forces, by maintaining track of submarines that pose the greatest potential threat—such as RFN SSNs approaching the continental United States, or PLAN AIP submarines nearing CVNs—would rapidly transition to attack submarines and protect high-value targets.

This approach has several potential flaws. Most prominently, the US ASW approach does not scale well. If the Chinese or Russian governments were planning an act of aggression, they would likely seek to overwhelm US ASW capacity by surging submarine deployments during a period of heightened tensions or gray-zone operations when US rules of engagement would preclude attacks. US commanders, faced with potentially dozens of unlocated enemy submarines when conflict started, might need to divert forces to ASW or restrict naval operations to avoid potential submarine threats.

A secondary, but not insignificant, problem with the current US ASW approach is closing the kill chain to destroy enemy submarines. World War II revealed that weapon placement accuracy significantly impacts an ASW attack's lethality. US SSNs conducting ASW can exploit their ability to close with a target, and the Mk-48 heavyweight torpedo's speed, maneuverability, and sensors, to achieve effective placement and high probabilities of destroying an enemy submarine. P-8As and MH-60R helicopters may not be able to gain proximity to an enemy submarine due to air defense threats, and their lightweight torpedoes may lack the speed and range to make up the distance between their entry point into the water and the target. The challenges for air-launched ASW weapons are exemplified by the Mk-54 torpedo's low lethality compared to heavyweight torpedoes like the MK-48.[131]

A third, strategic flaw with US ASW concepts is their focus on two main areas: choke points where detection and tracking can be efficiently conducted; and the ocean area within realistic submarine-launched missile range of US and allied forces and targets. ASW operations are conducted infrequently between submarine home ports and choke points, where US forces could delay deployment of submarines or create threats that keep them in their local waters. Furthermore, adversary submarines could remain unlocated for days or weeks in between choke points and US and allied maritime forces at sea, requiring extensive ASW efforts to reacquire them when hostilities intensify and attacks are authorized.[132]

During the Cold War, US SSNs conducted track and trail operations on Soviet SSNs after they were initially detected by SOSUS, sonobuoys, or ELINT sensors. This approach faltered when the number of quiet, front-line Soviet SSNs exceeded the number of available US SSNs. Today, though the Chinese and Russian navies have a small number of very quiet submarines, US SSN capacity is half its Cold War average. Moreover, US SSNs are better employed for counter-SSBN operations, intelligence-gathering, and SUW than for trailing adversary submarines in open ocean.

A New Approach to ASW

US and allied militaries will need new ASW concepts and capabilities that are more affordable during peacetime and improve the effectiveness of ASW operations during combat. An approach that relies more on unmanned systems for sensing and suppression and on manned platforms for command and control (C2) and submarine destruction could achieve these objectives. By reducing the cost of ASW operations and enabling them to scale, an unmanned approach to ASW executes a classic business disruption strategy, whereby a cheaper and less sophisticated alternative displaces the incumbent as technologies improve and user needs stay the same.

US and allied experience from the world wars and Cold War demonstrates that ASW concepts should exploit fundamental constraints of submarines. When submarines are counter-detected or attacked, their slow speed, lack of self-defense, and sensor limitations compel their crews to promptly evade rather than staying on mission and attempting to fight off or elude attacks. At the same time, destroying submarines is difficult due to the limitations of undersea weapons. As a result, successful past ASW campaigns relied explicitly or implicitly on marginalizing submarines through suppression or avoidance, instead of destroying them.

Adopting the objective of suppressing submarine operations creates opportunities for unmanned capabilities to perform a larger share of ASW missions. Once an enemy submarine is being tracked, attacks with small, well-placed weapons may be sufficient to inflict damage or cause the submarine crew to evade. Although these attacks could be conducted by either manned or unmanned platforms, the short range of surface- and air-launched ASW torpedoes suggests a weapons platform must precisely position itself close to the target for an effective attack. To quickly achieve a favorable attack position, it may be necessary to deploy large numbers of weapons platforms or aircraft that can operate in contested areas at acceptable risk. Both requirements would be better met with relatively inexpensive unmanned platforms than manned ships or aircraft.

Unmanned ASW systems of systems would employ active and passive sonars, as well as non-acoustic sensors, with the sensor type aligned to specific times, geographies, and tasks in the overall ASW campaign. For example, active sonars can enable wide-area searches because their power level is controlled by the ASW platform. However, they have substantially lower detection ranges in shallow water and generally cannot classify underwater contacts. Passive sonars, because they can classify contacts based on their sound signature, are useful for investigating active sonar contacts, or as search sensors in choke points where search areas are already constrained. Non-acoustic ASW sensors, such as magnetic anomaly detection (MAD), generally have very short detection ranges and are mainly useful for verifying a target prior to engagement.

Human operators will still be needed to oversee the actions of unmanned ASW sensors and weapons platforms. Although tracking, identification, and engagement of possible submarines could be automated, human commanders should set priorities for ASW search, tracking, and engagement and authorize attacks on enemy submarines.

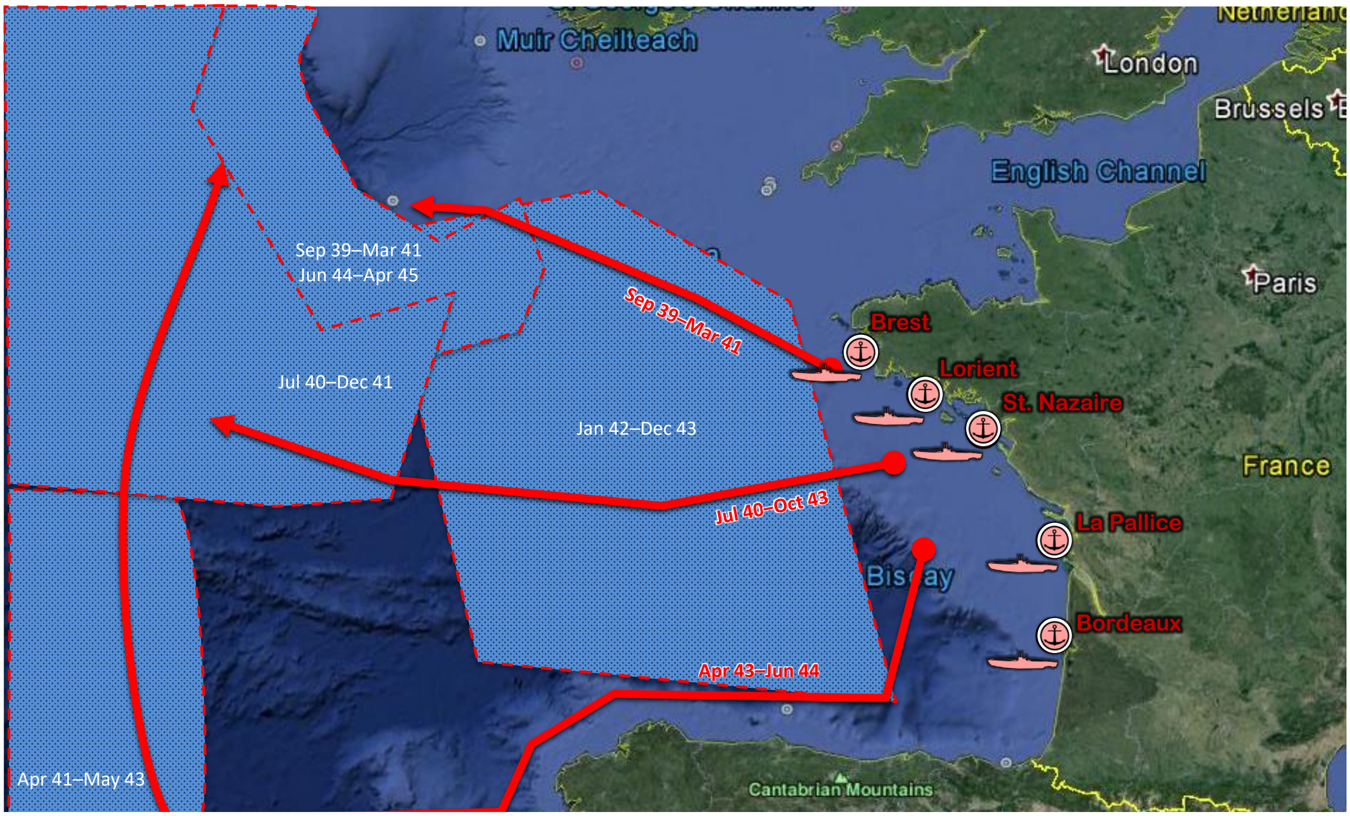
The combination of human command and machine control for ASW could be accomplished by deploying a P-8A in the ASW operational area, enabling it to communicate directly with ASW platforms and systems. This approach may be most appropriate in uncontested airspace like the North Atlantic, or during peacetime in potentially contested areas like the South China Sea. When airspace is likely to be contested, the P-8A's planning and communications capabilities could be placed on a ship or in a mobile ground-based shipping container, from which operators could coordinate ASW operations via aerial communication relays or satellites.

Shifting to an Offensive ASW Strategy

ASW is often considered a defensive activity because submarines are fundamentally an offensive weapon system. Even when submarines are protecting a target, as in coastal defense, they do so by attacking potential threats with torpedoes or cruise missiles, rather than shielding the target like an air defense destroyer. As a result, most ASW operations in the vicinity of friendly forces are defensive.

The increasing number and sophistication of adversary submarines will prevent a strictly defensive ASW approach from being successful. Submarine-launched anti-ship and

Figure 11: Airborne ASW operations in the Bay of Biscay (blue areas) compelled U-Boats to take increasingly longer and more circuitous routes (in red)[134]



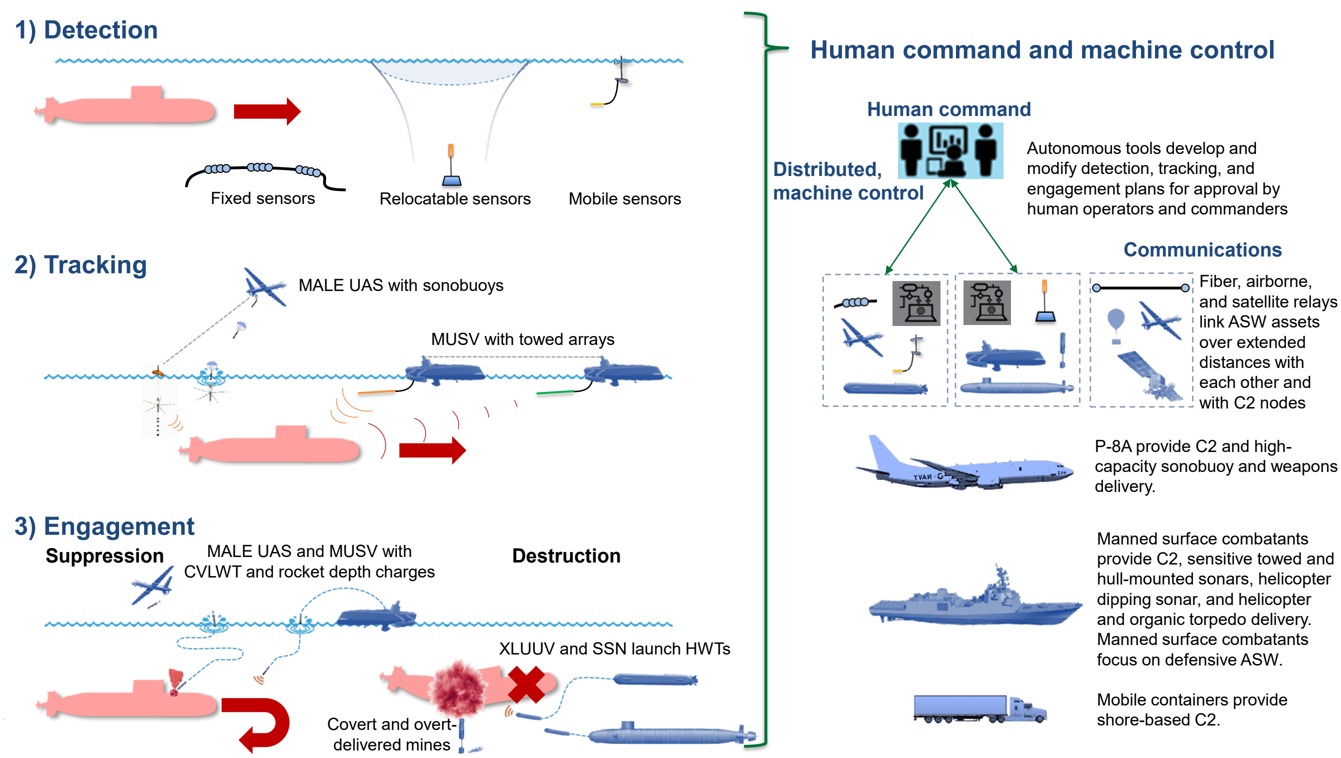
land-attack missiles, like the US Tomahawk and Russian Kalibr, have ranges of more than 1,000 nm. This makes search areas too large for a strictly defensive ASW approach to succeed, especially considering the quieting incorporated into modern Russian and Chinese submarines.[133]

US and allied ASW strategies, instead of attempting to clear submarines from increasingly large areas, should increase their emphasis on offensive ASW operations that prevent or delay enemy submarines from reaching their operational areas. For example, during the Second World War, Allied ASW forces reduced the German submarine presence in the North Atlantic by threatening U-boats transiting the Bay of Biscay from their bases in France. As shown in figure 11, Allied ASW efforts caused German submarine commanders to travel progressively longer routes to their patrol areas. U-boats also spent an increasing portion of their transit time submerged to avoid detection, further slowing their progress and reducing the number at sea in the Atlantic.

US counter-SSBN operations during the Cold War pursued a similar strategy of keeping attack submarines from reaching open ocean. In that case, ASW operations were designed to compel an opponent to keep SSNs at home for defensive purposes.

ASW concepts can be considered in terms of the effects chain needed to carry them out, including cueing, detection,

Figure 12: Proposed unmanned-centric offensive ASW approach



tracking, and engagement. An unmanned ASW system of systems, using human command and machine control, offers many advantages in executing these effects chains over today's approach, which relies primarily on manned platforms using organic sensors, such as towed arrays or sonobuoys. The proposed unmanned-centric offensive ASW approach is summarized in figure 12.

Cueing

Today, offensive ASW operations require cueing to prompt deployment of manned ASW platforms to the operational area to localize, track, and potentially attack submarines. The cost of sustaining allied maritime patrol aircraft, surface combatants, surveillance ships, or submarines precludes keeping sufficient numbers of them on station to support ASW prosecutions. The US and allied dependence on cueing creates an opportunity for adversary forces: if they can degrade or defeat US surveillance sensors, their submarines may be able to reach open ocean before substantial US ASW forces are in a position to respond. Similarly, if an adversary could "flood the zone" with a large number of deploying submarines, US ASW forces would likely be unable to track them all before they reached open ocean.

Cueing in the unmanned ASW approach would continue to use ELINT and EO/IR satellites and seabed sonar arrays like SOSUS. These systems would be complemented by unmanned platforms to reduce US vulnerability to adversary sensor countermeasures. The systems would include MUSVs using active or passive towed arrays like those employed by

Figure 13: MUSVs like the *Sea Hunter*, XLUUVs like the *Orca*, and MALE UAVs including the MQ-9B can carry ASW sensors and weapons.

SURTASS ships; XLUUVs, including the Navy's *Orca*, with towed passive sonar arrays; and MALE UAVs, such as the MQ-9B *SeaGuardian* or the Royal Air Force MQ-9B Protector, carrying radar, ELINT, and EO/IR sensors. These unmanned systems would be less expensive to operate forward than manned platforms, allowing more of them to be sustained on station as a backup to traditional cueing methods.[135]

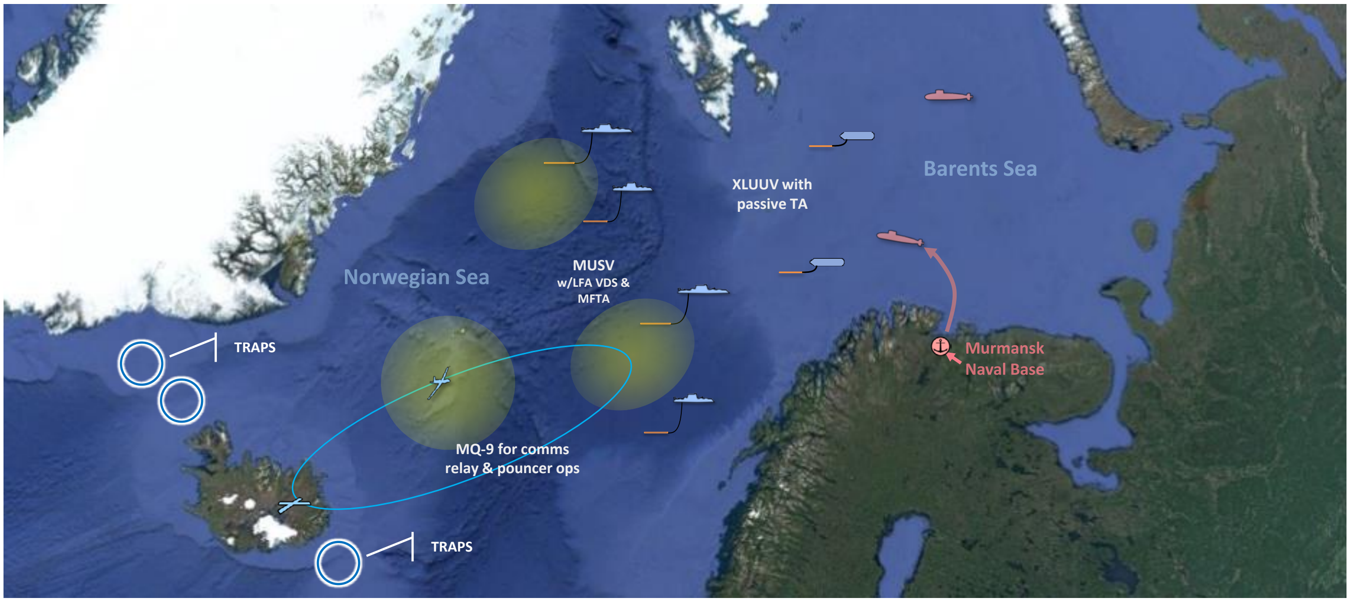
Unmanned platforms could supplement cueing sensors by continuously monitoring likely submarine transit lanes. They could also enable more rapid and scalable ASW operations when cueing is delayed due to adversary counter-ISR actions like sensor jamming, dazzling, or decoy deployments.

Choke Point and Home Waters ASW Operations

Choke points like the GIUK gap and Ryukyu Strait separate Russian and Chinese submarine bases, respectively, from the open ocean. Submarines need to transit these choke points to reach areas where they can attack US and allied forces, interdict shipping, or threaten strikes against military and civilian targets ashore. The exception is ballistic missile submarines, which carry weapons able to reach targets thousands of miles away.

Offensive ASW operations focus on choke points. This is because they narrow the area over which ASW forces need to search for deploying submarines and engage them, reducing the number

Figure 14: Home Waters ASW against Russian submarines in the Norwegian and Barents Seas could be conducted by unmanned platforms using passive or active sonar



of multi-mission ASW platforms required. Limited search areas are essential for ASW operations today, due to the operating and procurement cost of DDGs, SSNs, and P-8As and the demands for these platforms to conduct operations elsewhere.

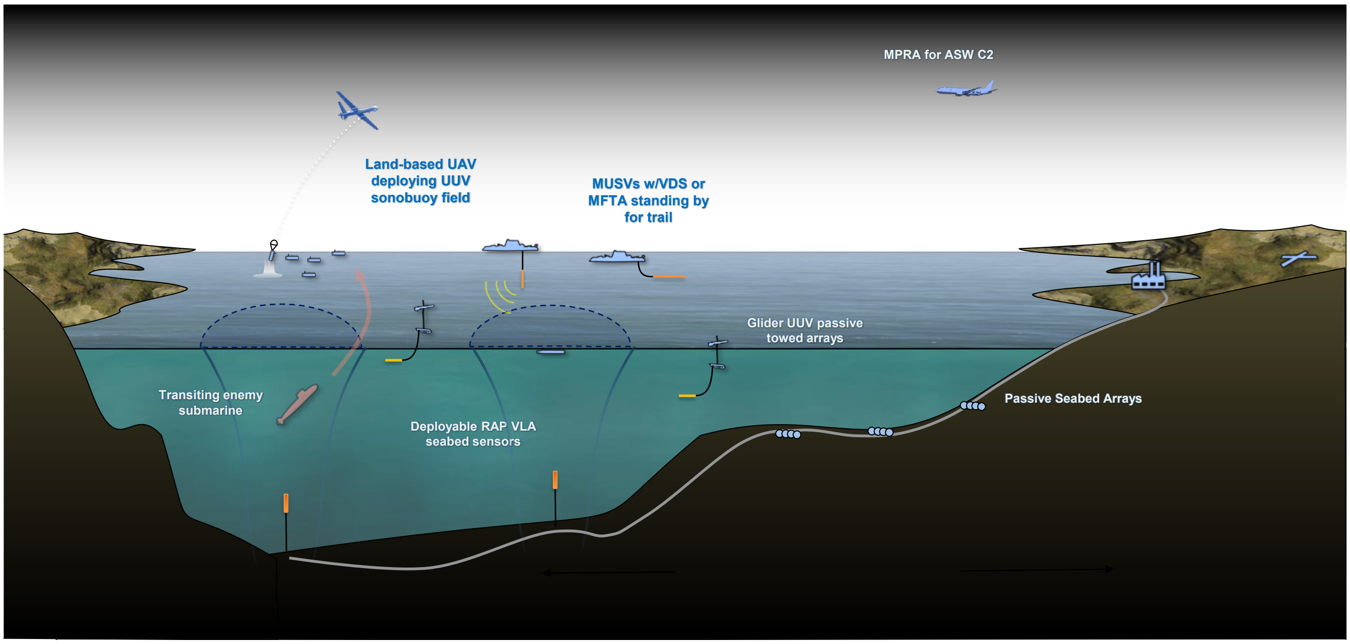
Constraints on the availability of manned ASW platforms also prevent them from conducting regular offensive ASW operations in an adversary's "home waters" between submarine home ports and choke points. In contrast, unmanned vehicles, such as MUSVs and MALE UAVs like the MQ-9B, are inexpensive to operate and could be fielded in larger numbers than manned multi-mission platforms, enabling regular ASW operations in forward areas such as the Barents or East China Seas. They also offer greater endurance than manned platforms, which would reduce the likelihood of lost contacts. For example, a fully equipped ASW variant of MQ-9B could operate for more than twenty-four hours, and MUSVs like Sea Hunter can operate for weeks at a time. During peacetime, these operations can yield valuable intelligence from an opponent's training and exercises; during conflict, far forward offensive ASW can slow or stop deployment of enemy submarines and reduce the number that US and allied naval forces would need to counter.

Figure 14: Home waters ASW against Russian submarines in the Norwegian and Barents Seas could be conducted by unmanned platforms using passive or active sonar.

Search and Track

Seabed sensors like SOSUS would be used to monitor straits and channels when power and communications are available. In choke points lacking utility connections ashore, or where anchoring could damage cables between sonar arrays and shore, ASW forces would deploy battery or solar-powered passive sonar arrays like the transformational reliable acoustic path sensor (TRAPS). Portable vertical line arrays (VLAs) such as TRAPS

Figure 15: Future choke point ASW search and tracking operation using unmanned systems



detect submarines in a cone above the array with a radius of about 10–20 nm, with the coverage area growing as depth increases, and communicate with ASW forces using a radio buoy.[136]

In shallow water or in areas where frequent dredging and fishing could disturb portable seabed arrays, MUSVs, XLUUVs, catamaran-style small USVs, or medium UUVs (MUUVs) towing passive sonar arrays would fill gaps in coverage. UUVs and USVs with passive sonar arrays would also be used to search an opponent's home waters inside choke points.

Unmanned passive sonars would use automated target recognition algorithms, increasingly augmented with machine learning, to identify specific submarine tonals from the overall ocean noise. These techniques are employed in TRAPS and SOSUS today, and they would enable sensors to process sonar information and send short contact messages to other ASW forces and commanders.[137]

The newest generation of RFN SSNs and PLAN SSPs may be too quiet to reliably track with only passive sonar. Active sonar could be used instead against these targets, although it reveals the location of ASW forces and does not provide sound signatures to enable identification of a submarine. To reduce the threat to search platforms, active sonar can be employed multi-statically, with a risk-worthy or expendable unmanned platform carrying the transmitter and passive sonar arrays towed by manned or unmanned platforms receiving the returns.

In choke point and ASW operations, MUSVs tow low frequency active (LFA) variable depth sonars (VDS) in areas between submarine home ports and open ocean, as shown in figure 14. LFA sound, operating between 100 and 1,000 Hz, can enable detection ranges of more than 100 nm in deep water and dozens of miles in shallow water.[138] A VDS enables the LFA transmitter to be placed vertically in the water column, where it can use the ocean's temperature profile to further improve sound transmission quality or range.[139] LFA sonar returns could be received by other MUSVs or surface combatants equipped with surface ship MFTAs, or XLUUVs and MUUVs with small versions of submarine towed arrays.

Today, active sonar operations often use multi-static active coherent (MAC) source sonobuoys and air-deployable active receiver (ADAR) sonobuoys deployed by P-8As. This is because they do not expose the host platform to counter-detection and can provide precise target locations to support attacks. Sonobuoys, however, have a short operating life and cannot move with the target submarine. The use of unmanned vehicles will help address this limitation, as described above. Future versions of sonobuoys should incorporate more UUV technology. Although 3-inch diameter UUVs that fit in sonobuoy launchers will not be able to keep up with a submarine, they could compensate for current, stay in contact longer by moving with the submarine, and then drive to a location where they could be recovered for reuse.

Unmanned platforms could employ non-acoustic sensors such as magnetic anomaly detection (MAD) or wake detectors as part of tracking operations. The short range of these technologies makes them difficult or potentially costly to use for search. However, they could provide a means of retaining track on a submarine contact that is attempting to evade by running quiet or using acoustic countermeasures. Unmanned platforms such as small UUVs or UAVs would be able to more closely approach the target, with less chance of alerting the submarine or placing manned tracking platforms at risk.

Command and Control (C2)

As noted in the introduction, unmanned ASW operations will employ a C2 approach combining human command with machine control. Unmanned search and track operations at choke points and in an adversary's home waters would be highly automated, with sensors following search plans developed and modified in real time by autonomous tools. Human operators deployed to the region would manage offensive ASW operations by reviewing search plans before and during an operation and providing direction and guidance to the autonomous control systems, including overriding them when necessary. Search plans would be approved by human commanders, who would also direct engagements when allowed.

In areas such as the GIUK gap, the EM environment should allow for over-the-horizon satellite and airborne line-of-sight communications with ASW forces throughout the North Atlantic, Norwegian Sea, and Barents Sea. Although C2 could be conducted from a control center on the ground in Iceland or from a surface combatant, placing C2 nodes on an airborne P-8A would enable the use of line-of-sight communications as a backup if satellite links were lost. The P-8A's complement of sonobuoys and weapons would enable it to augment the capacity of MALE UAVs in the region for submarine localization and engagement.

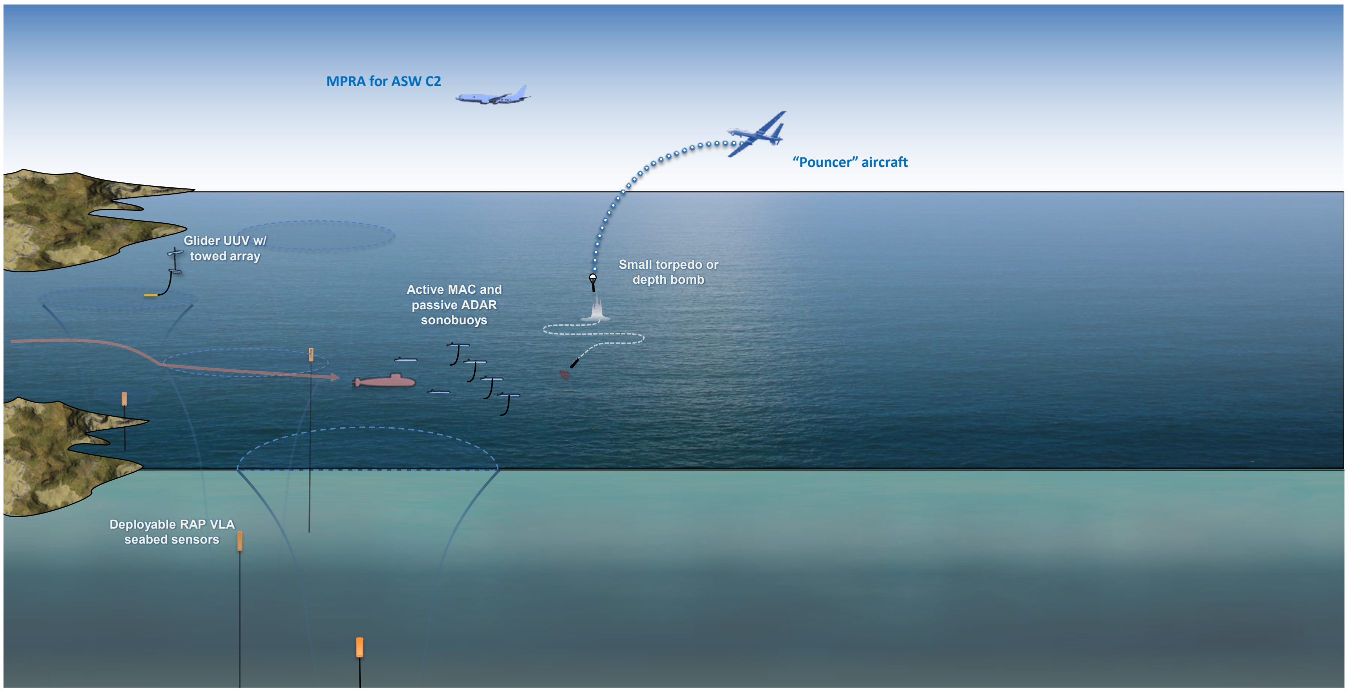
Choke Point Engagement

During peacetime, detection and tracking would be the normal extent of choke point and home waters ASW operations. During periods of heightened tension, US and allied commanders may want to deter adversary submarines from reaching open ocean. This they could do by making passive ASW efforts more overt, such as by using USVs instead of UUVs or using active, rather than passive, sonar.

In wartime, choke points would provide good locations for attacking transiting enemy submarines. As noted in the previous chapter, US and allied submarines equipped with heavyweight torpedoes are the most effective way to destroy an adversary submarine. This finding could be extended to other delivery mechanisms that can place a large warhead in close proximity to the target, such as the developmental Hammerhead mine or XLUUVs carrying heavyweight torpedoes.[140]

Unless enemy submarines pose an imminent threat, however, suppressing their operations as shown in figure 16 and driving

Figure 16: Choke point submarine suppression



them back toward port with air-launched ASW weapons would be a more efficient approach than attempting to destroy them. Also, as in the Cold War, friendly SSNs could conduct offensive ASW against enemy SSBNs to compel the enemy to bring attack submarines home to protect its strategic deterrent.

Land-based MALE UAVs would conduct submarine suppression attacks to alert enemy submarines that they have been detected and are being actively prosecuted. To do this they would use small, inexpensive, air-launched torpedoes such as the compact very-light-weight torpedo (CVLWT); depth bombs like the Hedgehog; or rocket depth charges like the Russian RPK-8. That might be sufficient to drive enemy submarines back through the choke point or away from US and allied forces. As in World War II, these weapons might damage the submarine so that it loses its acoustic stealth, must return to port for repairs, or is disabled like the Russian submarines *Losharik*, *Kursk*, or *Komsomolets* or Chinese submarine No. 361, all of which suffered peacetime material failures.[141]

Track and Trail

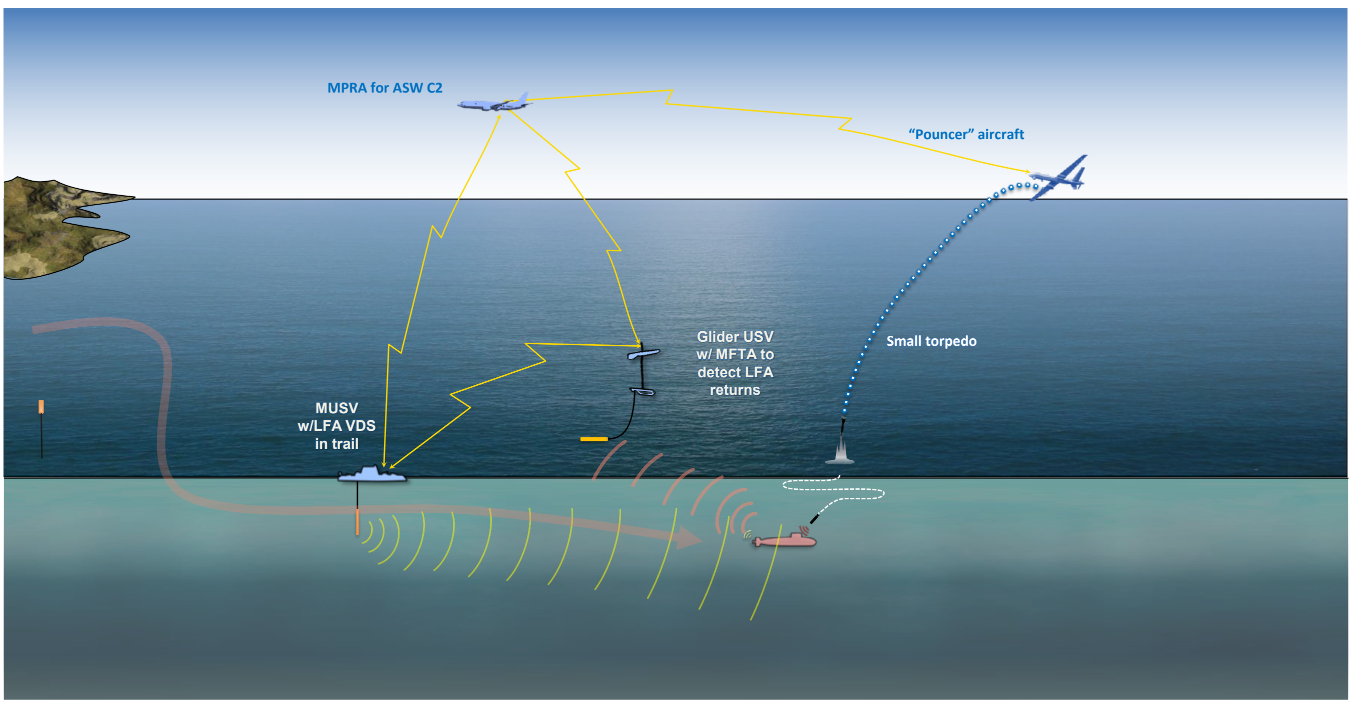
During peacetime or periods of heightened tension when engagements are not allowed, submarines passing through choke points could go unlocated, enabling them to attack US and allied naval forces when the enemy decides to initiate hostilities. Of greater concern, unlocated submarines could reposition to the waters off the US coast and threaten US SSBNs on patrol, or military bases and population centers.

Defensive ASW operations along the US coast are likely to be unsustainable. The increasing range of submarine-launched missiles continues to expand the areas to be searched; at the same time, the decreasing range of passive sensors against

Table 6: Significant ASW capacity would be needed to search 1,000 nm off the US West Coast (542,000 nm2) for a submarine moving at 15 kts.[142]

PLATFORM	NOMINAL SENSOR RADIUS (NM)	SEARCH AREA PER PLATFORM (NM2)	NUMBER NEEDED TO MONITOR EASTPAC
LCS or FFG w/ LFA VDS	30	28,274 nm2 per hour per LFA VDS	19 (of 20 planned FFG or 32 LCS)
P-8 with 126 MAC sonobuoys	5 (per receiver buoy)	6,597 nm2 per P-8A	82 (of 117 total)
TRAPS	20	1,257 nm2 per TRAPS	431 (of 45 potential units procured)

Figure 17: Notional unmanned submarine trail and attack



quieter Chinese and Russian submarines is raising the number of systems and platforms needed to search, as shown in table 6.

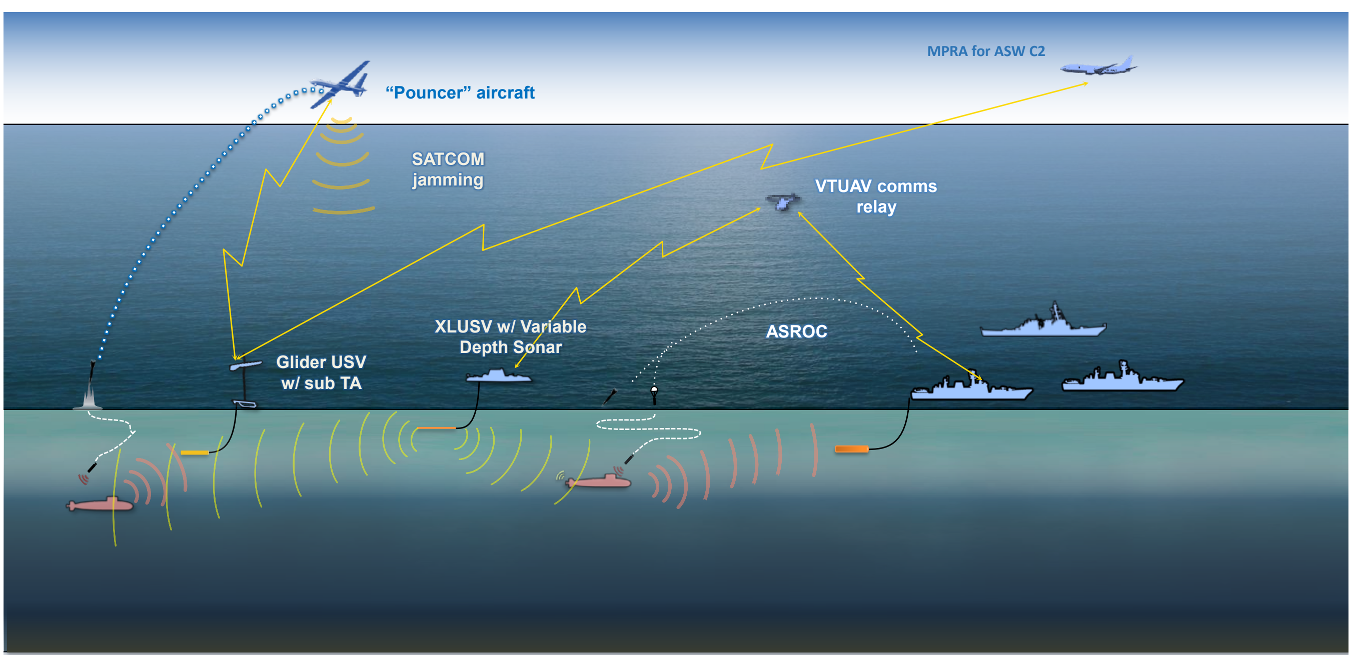
An alternative approach to counter submarines outside their local waters is to trail them, enabling engagement when conditions warrant and providing cueing to reduce the challenge for homeland ASW forces. Track and trail using manned platforms is costly and takes aircraft, ships, and submarines away from other missions. However, using unmanned vehicles and new sensors, an unmanned ASW system of systems would enable efficient track and trail. For overt trail, an MUSV towing an LFA VDS, and an MUSV or glider USV towing a passive array, could monitor adversary submarines from tens of miles away, passing periodic or continuous reports to commanders via satellite communications or aerial relays. Although the submarine would be aware it was being trailed, the standoff range of the MUSV would not suggest an imminent attack, which would reduce the likelihood of escalation.

For covert track and trail, schools of glider USVs or XLUUVs towing passive sonar arrays could trail adversary submarines from up to a dozen miles away, depending on the target's noisiness. They could be combined with land-based UAVs carrying SUUVs, or sonobuoys equipped with passive sonars, like today's DIFAR and ADAR sonobuoys, to regain contact if the submarine's signal begins to fade. For more aggressive action to regain contact, UAVs could also carry active DICASS or MAC-equipped SUUVs or sonobuoys.

If hostilities began and rules of engagement changed, track and trail forces would transition to engage submarines under the direction of ASW commanders operating forward in P-8As. Consistent with a suppression approach to ASW, MALE UAVs could pounce on enemy submarines trailed by MUSVs and attack them using precisely placed depth bombs or small short-range torpedoes. Alternatively, MUSVs in trail could close on the target submarine at acceptable risk and launch short-range standoff ASW weapons such as an anti-submarine rocket (ASROC) with a CVLWT or depth-bomb payload.

Another aspect of offensive ASW would be the covert and overt delivery of mines around choke points and enemy ports. Low observable aircraft and XLUUVs could be used to deploy mines into contested or highly contested areas, while other aircraft and MUSVs could be used to deploy mines into uncontested or moderately contested areas. Mines such as the developmental Hammerhead could be used offensively to target enemy submarines and surface contacts in enemy operating areas, and defensively to guard friendly waters from potentially approaching enemy threats.

Figure 18: Defensive ASW operations



Defensive ASW

The focus of US and allied ASW strategy should be offensive ASW operations like those described above, keeping adversary submarines bottled up in their local waters or busy evading tracking or attack. When offensive operations are unsuccessful or overcome by submarine numbers, however, military and civilian maritime formations need the ability to preemptively disrupt an enemy submarine's attack.

The most challenging aspect of defensive ASW operations is the range of adversary anti-ship cruise missiles, which are likely to reach 1,000 nm within the next decade, consistent with the range of the US Navy's Tomahawk missile. This range would enable submarines in protected bastions like the South China Sea or Barents Sea to attack naval or maritime forces well outside relevant choke points.

From a practical standpoint, submarines will need third-party targeting to attack surface ships from more than a few dozen miles away. Submarine radars and electronic sensors will generally not be able to detect a ship over the horizon. Although sonar can detect targets beyond the horizon, specific tonals needed to identify a specific ship or class of ship may not be detectable more than a few dozen miles away. Naval forces can therefore use a multi-domain approach to defensive ASW, combining airborne electronic warfare systems to jam communications to submarines with unmanned wide-area ASW operations to find and disrupt submarine attacks.

In the defensive ASW scheme depicted in figure 18, land-based MALE UAVs and shipboard UAVs conduct electronic warfare in suspected enemy submarine operating areas on common enemy SATCOM frequencies. This should reduce enemy submarines' ability to receive third-party targeting. Closer to protected naval and maritime forces, the defensive ASW concept will use MUSVs with LFA VDS to search for enemy submarines or deter their approach. MUSVs, FFGs, and DDGs with passive towed arrays will listen for returns from LFA sonars as well as tonals of approaching enemy submarines.

Defensive ASW operations would be managed by C2 cells on P-8As deployed with naval forces, or on a DDG or FFG in the naval formation. As with choke point ASW operations, placing commanders and operators in theater with unmanned ASW systems would mitigate the impact of enemy communications jamming. It would do so by enabling line-of-sight communications with a P-8A directly, or with a DDG or FFG via a shipboard vertical takeoff and landing UAV (VTUAV) relay, such as the MQ-8C.

When enemy submarines are detected, they would be engaged by land-based MALE UAV pouncers armed with small torpedoes and depth bombs or, if no MALE UAVs are available, P-8As or shipboard UAVs. If submarines are detected within about 50 nm of naval and maritime forces, they would also be attacked by FFGs and DDGs using improved ASROCs. Next-generation missiles, by using a smaller payload than the Mk-46 torpedo in today's ASROC, could achieve a longer range and be smaller, potentially allowing four ASROCs to be loaded in a VLS cell like the Evolved Sea Sparrow Missile (ESSM).

If defensive ASW operations are unsuccessful, surface combatants and other targets will need improved air defenses to defeat submarine-launched ASMs.[143] Naval forces, if engaged by torpedoes, could employ acoustic decoys and jammers as well as kinetic anti-torpedo defenses.

An unmanned approach to ASW can more effectively protect US and allied forces from submarine attack by expanding the areas and duration over which ASW can be conducted. Many of the unmanned systems described above use sensors and processing capabilities that are identical, or very similar, to those employed by manned platforms or SOSUS today. Perhaps more importantly, unmanned ASW concepts can lower the cost to buy and operate ASW systems over their lifetime. As DoD enters a period of likely fiscal constraints, costs for time and manpower-intensive ASW operations will be an increasing concern.

CHAPTER 5: ANALYSIS AND RECOMMENDATIONS

The benefits of unmanned concepts for ASW can be assessed in terms of cost as well as their ability to sustain operations over operationally relevant areas and durations. Today's US and allied approaches to ASW tend to rely on unmanned sensors, such as SOSUS sonar arrays or ELINT satellites, only for initial cueing. Tracking and potential prosecution of submarines is conducted by manned aircraft, ships, and submarines. Not only does this reliance on manned platforms take them away from higher-value uses where their integrated C2 capabilities and weapons are essential for tightly coordinated attacks; it also is less effective because of their inherent endurance and capacity limitations.

The limitations of today's approach to ASW are most problematic in the open ocean. Today's manned ASW platforms can conduct offensive ASW at choke points—albeit at great cost, financially and operationally—and defensive ASW near military and civilian maritime forces. They have almost no capacity for ASW operations between an opponent's home waters and potential targets, including US and allied homelands, commercial shipping, and naval forces. This shortcoming places a potentially insurmountable burden on defensive ASW operations to defeat attack submarines up to 1,000 nm away from potential targets.

An unmanned approach could address the need for more ASW capacity that is less expensive to buy and operate. It would also afford a wider range of escalation options: unmanned overt sensing to shape adversary behavior, suppression attacks by unmanned platforms to disrupt adversary submarine operations, or manned SSNs with heavyweight torpedoes to destroy enemy submarines such as SSBNs.

Photo Caption: An MQ-9 Reaper sits on the flight line at Creech Air Force Base, Nevada, Dec. 17, 2019. (US Air Force)

This chapter will assess the unmanned approach to ASW described in chapters 3 and 4, in two potential scenarios:

- a gray-zone confrontation between the PRC and Japan in the East China Sea that escalates into a protracted conflict in the Western Pacific; and
- a gray-zone confrontation between Russia and Latvia during which a front-line Russian submarine transits toward the US East Coast as an escalation management measure.

In each of these scenarios, today's notional theater ASW concept will be compared to the unmanned ASW approach advanced in the previous chapters.

A US-PRC Confrontation

In this scenario, the PRC and Japan remain engaged in a confrontation over control of the Senkaku Islands, which has now expanded to include the Sakishima Islands as well. Although PRC military or paramilitary forces have not landed on any of the islands, China Coast Guard and PLAN ships have loitered nearby, while PLAN aircraft routinely overfly the islands, including inside Japan's air defense identification zone.

During this time, cueing from intelligence sources suggests the PLAN is deploying submarines from the South Sea Fleet and East Sea Fleet to stand by for operations in the Western Pacific

Figure 19: A notional application of today's ASW approach using manned platforms and associated sensors to search for and track enemy submarines in defense of naval forces

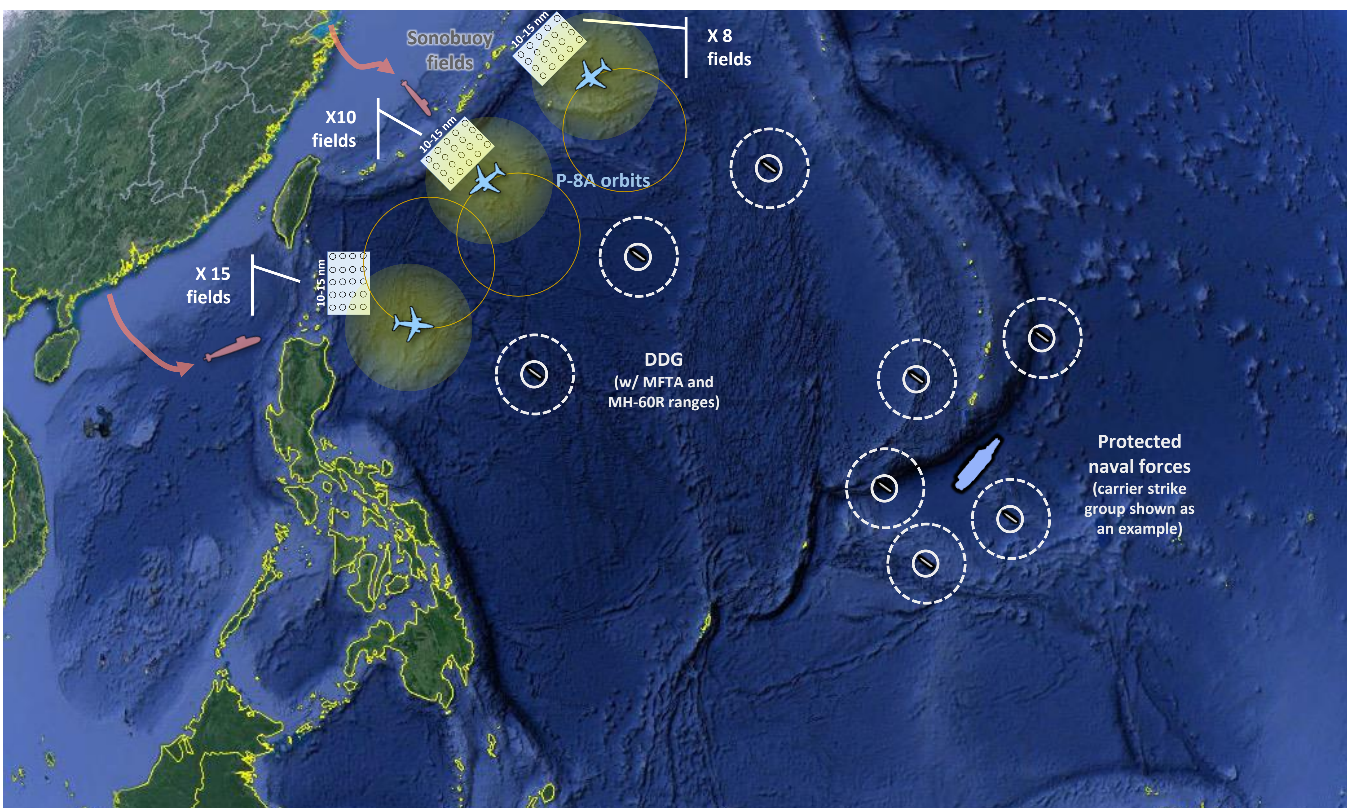


Table 7: Procurement costs associated with manned ASW approach, assuming a one-month operation with continuous employment of the platforms depicted in Figure 15

	UNIT COST	NUMBER REQUIRED	TOTAL COST ($M FY2020)
P-8As	$184,807,300	17	$3,141.72
Bathythermograph	$ 529	914	$0.48
ADAR Sonobuoy	$3,156	18,711	$59.05
MAC Sonobuoy	$4,999	12,474	$62.36
DDG-51 Flt III	$1,869,000,000	4	$7,476.00
MH-60R (2 per DDG)	$34,660,440	8	$277.28
SSN-774	$3,100,000,000	3	$9,300.00
		TOTAL	**$20,316.90**

Table 8: Operations and sustainment costs associated with manned ASW approach, assuming a one-month operation with continuous employment of the platforms depicted in Figure 15

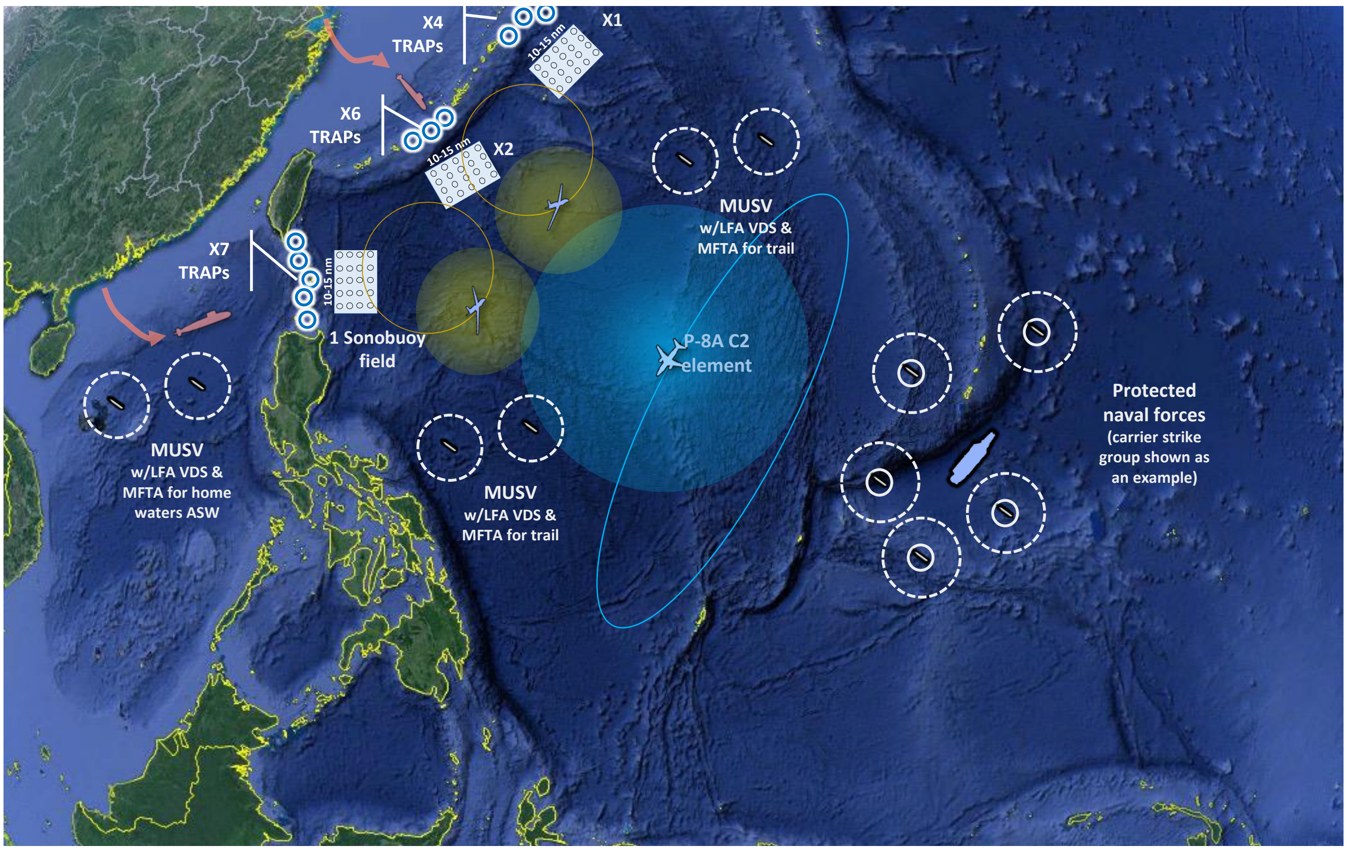
	UNIT O&S COSTS PER HOUR	NUMBER REQUIRED	TOTAL COST OVER 1 MONTH ($ M FY2020)
P-8As	$9,111	17	$97.36
DDG-51 Flt III	$8,562	4	$24.66
MH-60R (2 per DDG)	$5,479	8	$8.27
SSN-774	$8,447	3	$18.25
		Total	**$148.53**

and Philippine Sea. It is likely these submarines would threaten naval forces, shipping routes, and the more populated southern and eastern coasts of Japan.

In the traditional ASW approach using manned platforms, DDGs with MFTAs and P-8As with sonobuoys would search choke points through which submarines are likely to transit. Once submarines are detected, they would normally be tracked and trailed by US SSNs that would stand by to attack the enemy submarines when conflict begins. SSN track and trail will not be feasible, however, because the PLAN is deploying more than two dozen of their projected fleet of more than fifty modern submarines. As a result, several P-8As, DDGs, and submarines would be needed to monitor potential submarine transit routes to enable ASW attacks when rules of engagement allow.

The procurement costs to establish and sustain the search and track capabilities illustrated in figure 19 would be substantial. More importantly, the demands this approach would place on manned platforms might preclude other operations, such as missile defense of US or allied bases ashore in Japan or the

Figure 20: The unmanned ASW approach can efficiently counter submarines passing through chokepoints, trail submarines in open ocean, and conduct ASW in China's home waters.



Marianas, or attacks against PLAN surface combatants in the East or South China Seas.

Perhaps of greater concern are the operations and sustainment costs of maintaining this ASW force between the PLAN's home waters in the East and South China Seas and naval forces operating in the Philippine Sea.

The unmanned ASW approach would improve on this traditional concept by replacing sonobuoy search fields with stationary sonar systems like TRAPS. Sonobuoys will be deployed by MALE UAVs to track submarines only after they are initially detected by stationary sensors. This reduces the number of aircraft and sonobuoys needed and employs sophisticated sensors like MAC sonobuoys to fine-tune the targeting solution on the submarine.

After submarines leave active or passive sonobuoy fields, they are trailed by MUSVs equipped with LFA VDS or MFTA, which will maintain contact with passive or multi-static sonar, depending on whether overt or covert tracking is intended. MUSVs in trail on a submarine will enable ASW attacks when rules of engagement allow and are appropriate for the commander's plan.

The unmanned ASW concept will yield significant cost savings compared to today's approaches that center on manned platforms. Perhaps more importantly, the unmanned approach will be more scalable, allowing greater ASW capacity to be mobilized faster. It will also be more proportional, giving commanders more tools to counter submarines and signal resolve to adversaries.

Arguably, the procurement cost savings from the unmanned approach is a somewhat moot point, since the manned platforms used in today's ASW concepts are already built and fielded. This assessment, however, fails to account for the opportunity cost incurred by consuming the availability and service lives of manned platforms for ASW operations—only a set of the multiple roles DDGs, P-8As, and MH-60Rs are designed to fill. Although P-8As and MH-60Rs have ASW as a primary mission, they also conduct maritime surveillance and SUW missions that are likely to be in high demand during a confrontation with the PLAN.

In the scenario described above, SUW platforms like the MH-60R and DDG will be needed to counter the efforts of China's

Table 9: Procurement costs associated with unmanned ASW approach, assuming a one-month operation with continuous employment of the platforms depicted in Figure 16

	UNIT COST	NUMBER REQUIRED	TOTAL COST OVER 1 MONTH ($M FY 2020)
TRAPS	$2,000,000	17	$34.00
P-8A	$184,807,300	4	$739.23
MALE UAV (MQ-9B)	$29,000,000	13	$377.00
Bathythermograph	$529	37	$0.02
ADAR Sonobuoy	$3,156	662	$2.09
MAC Sonobuoy	$4,999	441	$2.20
MUSV	$50,000,000	12	$600.00
		TOTAL	**$1,754.54**

Table 10: O&S costs associated with unmanned ASW approach, assuming a one-month operation with continuous employment of the platforms depicted in figure 20

	UNIT O&S COSTS PER HOUR	NUMBER REQUIRED	TOTAL COST OVER 1 MONTH ($M FY2020)
TRAPS	$171	17	$2.10
P-8A	$9,111	4	$26.24
MALE UAV (MQ-9B)	$649	13	$6.07
MUSV	$1,142	12	$9.86
		TOTAL	**$42.18**

People's Armed Forces Maritime Militia and other paramilitary maritime forces, and to defeat PLAN combatant ships. If the Navy made a modest investment in unmanned systems to enable a new approach to ASW, this would not allow it to retire its P-8As or DDGs. However, it could allow reduced spending on recapitalizing these platforms at their end of service life.

The unmanned approach achieves further savings by lowering the ongoing O&S costs for ASW missions, as shown in table 10. The sustainment cost savings of about 70 percent over the cost of the traditional ASW approach could be applied to purchase the elements needed to implement the unmanned ASW concept.

In the example above, the unmanned concept costs about $100 million less per month than the traditional manned ASW approach. The force structure components needed for the unmanned concept (TRAPS, MALE UAV, and MUSV) cost about $1 billion. The unmanned ASW approach could therefore pay for itself within about nine-and-a-half months of focused Western Pacific ASW operations, which could take place over multiple years.

US-Russia Confrontation

In this scenario, the Russian government is orchestrating covert attacks against Latvian border outposts and infrastructure to destabilize the southeastern part of the country. To provide escalation options, the Russian military begins deploying a half-dozen modern SSNs—about all that are not undergoing significant maintenance on a given day. The SSNs are ordered to the US East Coast, where they will threaten to sink US SSBNs or to launch missile attacks against American population centers and military bases.

Figure 21: The unmanned ASW approach would enable more efficient choke point ASW operations that could extend into Russian home waters, such as the Barents Sea

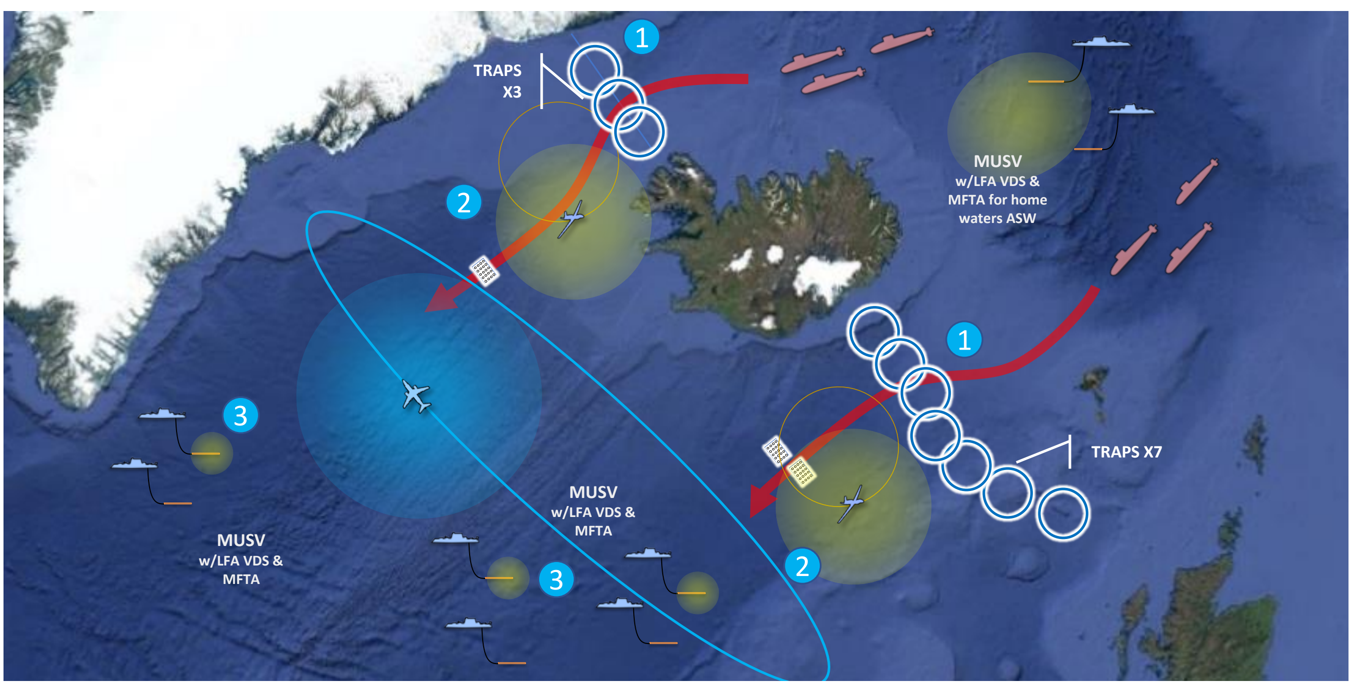


Table 11: Procurement costs for unmanned and manned approaches for ASW at the GIUK gap to surveil a Russian submarine deployment, as depicted in figure 17

	UNIT COST	NUMBER REQUIRED	TOTAL COST ($M FY 2020)
TRAPS	$2,000,000	10	$ 20.00
P-8A	$184,807,300	4	$739.23
MALE UAV (MQ-9B)	$29,000,000	9	$261.00
BT	$529	29	$0.02
ADAR	$3,155	529	$1.67
MAC	$4,999	353	$1.76
MUSV	$50,000,000	16	$800.00
		Total for Unmanned Concept	**$1,823.68**
		Total for Manned Concept (detailed in Chapter 4)	**$19,696.02**

Table 12: O&S costs for unmanned and manned approaches for ASW at the GIUK gap to surveil a Russian submarine deployment, as depicted in figure 17

	UNIT O&S COSTS PER HOUR	NUMBER REQUIRED	TOTAL COST OVER 1 MONTH ($M FY2020)
TRAPS	$171	10	$1.23
P-8A	$9,111	4	$22.91
MQ-9B	$649	9	$4.21
MUSV	$1,142	16	$13.15
		Total for Unmanned Concept	**$40.26**
		Total for Manned Concept (detailed in Chapter 4)	**$123.96**

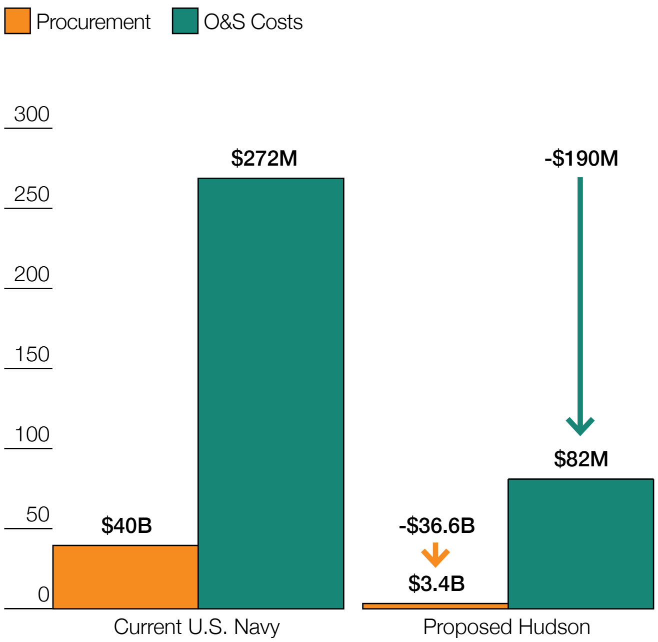
As described in chapter 4, today's ASW concepts using manned platforms and systems will require a significant investment in ships, aircraft, and sonobuoys. In the unmanned approach, shown in figure 21, relocatable sonars like TRAPS are positioned across the GIUK gap to detect submarines as they move south into the Northern Atlantic Ocean. Possible detections of Russian submarines are investigated using passive or active sonobuoys deployed by land-based MALE UAVs.

As deploying submarines leave the choke point, they are trailed by MUSVs using LFA VDS and by MFTAs conducting bi-static sonar operations. When ASW attacks are appropriate, they would be conducted either by MUSVs launching rocket-propelled depth bombs, or MALE UAVs using small torpedoes, such as the CVLWT, or depth bombs.

As in the Pacific scenario, the unmanned ASW approach generates substantial cost savings compared to today's

Figure 22: Procurement and O&S cost comparison between current US Navy and proposed Hudson ASW approaches

Procurement and O&S costs (billions and millions of dollars, respectively)



concepts that rely on manned multi-mission platforms. The savings generated by the lower O&S costs would pay for the unmanned concept's required procurement of TRAPS, MALE UAVs, and MUSVs after approximately thirteen months of focused ASW operations, which could take place over multiple years.

Figure 22 sums the costs to procure necessary assets and operate and sustain forces for one month in the China and Russia scenarios. The proposed, unmanned-centric ASW approach costs significantly less to procure and operate.

Recommendations

US and allied militaries should increase their investment during the next five to ten years in unmanned ASW sensors and platforms, as well as smaller weapons that can be carried in relevant numbers by manned or unmanned ships and aircraft. The technologies described in the preceding chapters are either mature and in use by US or allied navies, or they are rapidly reaching maturity.

Although unmanned systems will require additional spending within what are likely to be constrained defense budgets during the coming decade, existing manned platforms do not need to be retired or canceled to facilitate a shift to unmanned ASW. MUSVs, UAVs, and deployable sensors could reduce the amount of time manned ships and aircraft need to operate in support of ASW missions. As described above, the resulting O&S savings will more than cover the procurement cost of unmanned systems.

To enable a more rapid adoption of this approach, however, procurement funding could be shifted from a few manned platforms to buy an initial portfolio of unmanned ASW systems. For example, by reducing procurement over the next several years by one FFG, one DDG and one SSN, the Navy could field the ASW portfolio of unmanned sensors, platforms, and expendables shown in table 13. Aspects of this trade may not be desirable for industrial base or other reasons, but it illustrates the relatively modest change in investment needed to adopt what will be a more efficient and effective approach to ASW.

Some elements of this portfolio are already being procured, such as sonobuoys, MUSVs, and TRAPS; others, such as land-based MALE UAVs or depth bombs, are not. Some systems, including the CVLWT or LFA VDS, are being fielded but not in sufficient numbers to support the proposed new ASW concepts.

Although the unmanned ASW approach will require a modest increase in spending during the near-term, it is imperative the Navy adopt new ways to conduct this mission. The current

Table 13: Initial investment portfolio to support a US Navy unmanned ASW approach

SYSTEM	NUMBER	UNIT COST	TOTAL COST ($M FY2020)
"A" size ADAR sonobuoys	6,000	$3,156	$19
"A" size MAC sonobuoys	4,000	$4,999	$20
RAP VLA Sensors (e.g., TRAPS)	50	$2,000,000	$100
Small torpedoes like the CVLWT	2,250	$226,530	$510
Rocket-propelled depth bombs capable of being deployed by aircraft or shipboard trainable countermeasures launchers	2,250	$113,265	$255
Encapsulated torpedo mine	1,000	$1,812,240	$1,812
USV Glider with passive sensor	425	$800,000	$340
Land-based MALE UAVs equipped with sonobuoy launchers and ASW sensor processing	40	$29,000,000	$1,160
XLUUV	12	$80,000,000	$960
MUSVs equipped with trainable countermeasures launchers and LFA VDS or MFTA	12	$50,000,000	$600
LFA VDS or MFTA kits for vessels of convenience	12	$5,000,000	$60
		TOTAL	**$5,836**

approach will be too expensive to sustain during periods of heightened tension or conflict and lacks the scale to effectively protect US naval forces and civilian shipping or infrastructure from submarine attack.

CHAPTER 6: CONCLUSION

The United States and its allies face significant challenges to their national security and, in some cases, sovereignty. The strategies of great powers China and Russia effectively employ their military and paramilitary capabilities to gain territory and influence from their neighbors. Regional powers such as Iran and North Korea coerce US allies and partners with ballistic missiles and terrorism to gain concessions or diplomatic recognition.

Submarines are an increasingly important element of adversaries' weapons portfolios, delivering key capabilities needed for their strategies. For the Russian and North Korean militaries—though their undersea fleets are very different—submarines provide a tool to threaten unwarned strategic attacks against opponents to gain escalation dominance. For the Chinese and Iranian militaries, submarines contribute to networks of weapons and sensors designed to threaten US and allied access or freedom of action.

Despite their effectiveness, submarines have inherent limitations. They generally lack high-capacity self-defense systems and are not quiet or fast enough to evade without revealing their location. In addition, their sensor systems cannot usually provide rapid assessments of whether an incoming attack will be successful. As a result, submarines, unlike surface combatants, cannot stand and fight, and unlike aircraft, they cannot quickly evade attacks once an engagement is underway. These factors generally lead submarine commanders to promptly evade attacks or counter-detection once their presence is suspected.

US and allied ASW forces can exploit the inherent limitations of submarines by using overt sensing and suppression attacks to prevent them from conducting attacks and by driving them away from intended operational areas. Unmanned platforms, which generally have lower payload capacity than manned ships and aircraft, can be effective attack platforms using smaller ASW weapons that enable suppression of submarines rather than destruction.

Unmanned systems can also be more affordable and scalable across each segment of the ASW kill chain. Deployable stationary sonar sensors can provide continuous coverage of areas instead of sonobuoys, complementing SOSUS arrays and enabling tracking of submarines passing through choke points or approaching US and allied naval forces. Mobile sensors on, or deployed by, unmanned vehicles can track and trail submarines after they leave their protected waters, enabling them to be engaged before they can attack US or allied naval and maritime forces.

Today's approaches to conducting these missions in peacetime and conflict are expensive, and they take manned multi-mission platforms away from other, potentially higher-priority operations. To address the rising submarine threat, US and allied militaries need a new approach to ASW that is more sustainable and effective. Otherwise, adversaries will exploit their growing undersea advantage to permanently alter security relationships with US allies and partners.

GLOSSARY OF TERMS AND ACRONYMS

1. air independent propulsion (AIP)
2. aircraft carrier (CV)
3. air-deployable active receiver (ADAR)
4. air-independent propulsion submarine (SSP)
5. anti-ship missile (ASM)
6. anti-submarine rocket (ASROC)
7. anti-submarine warfare (ASW)
8. ASW carrier (CVS)
9. autonomous underwater vehicle (AUV)
10. ballistic missile submarine (SSBN)
11. carrier air wing (CVW)
12. carrier battle group (CVBG)
13. Chinese Communist Party (CCP)
14. coastal submarine (SCC)
15. command and control (C2)
16. compact very light-weight torpedo (CVLWT)
17. diesel-electric ballistic missile submarine (SSB)
18. directional command active sonobuoy system (DICASS)
19. directional frequency analysis and recording (DIFAR)
20. electromagnetic spectrum (EMS)
21. Evolved Sea Sparrow Missile (ESSM)
22. extra-large unmanned underwater vehicle (XLUUV)
23. Greenland, Iceland, United Kingdom (GIUK) gap
24. guided-missile submarine (SSGN)
25. Imperial Japanese Navy (IJN)
26. intelligence, surveillance, and reconnaissance (ISR)
27. Islamic Republic of Iran Navy (IRIN)
28. Islamic Revolutionary Guard Corps Navy (IRGCN)
29. littoral combat ship (LCS)
30. low frequency active (LFA)
31. magnetic anomaly detection (MAD)
32. medium USV (MUSV)
33. medium UUV (MUUV)
34. medium-altitude long endurance (MALE)
35. mine countermeasure (MCM)
36. mini-submarine (SSM)
37. multi-function towed array (MFTA)
38. multi-static active coherent (MAC)

39. nuclear-powered attack submarine (SSN)

40. operations and support (O&S)

41. patrol aircraft and destroyer (DDG)

42. People's Liberation Army (PLA)

43. People's Liberation Army Navy (PLAN)

44. People's Republic of China (PRC)

45. Russian Federation Navy (RFN)

46. sound surveillance system (SOSUS)

47. surface warfare (SUW)

48. surveillance towed array (SURTASS)

49. transformational reliable acoustic path sensor (TRAPS)

50. unmanned aerial vehicle (UAV)

51. unmanned surface vessel (USV)

52. variable depth sonar (VDS)

53. vertical line array (VLA)

54. vertical takeoff and landing UAV (VTUAV)Tectatecat aut et

ENDNOTES

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Notes

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Hudson Institute
1201 Pennsylvania Avenue, Fourth Floor, Washington, D.C. 20004
+1.202.974.2400 www.hudson.org