

Autonomous Warfare Systems in Undersea Warfare: Operational Utility, Strategic Implications and Future Challenges

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Abstract:

The rapid advancement of artificial intelligence (AI), autonomous systems, sensor technologies, and network-centric warfare capabilities has transformed the character of maritime conflict in the twenty-first century. Autonomous Warfare Systems (AWS) are increasingly being integrated into naval operations to improve persistence, operational reach, surveillance capability, and decision-making speed in contested maritime environments. Within the maritime domain, undersea warfare has emerged as one of the most technologically demanding and strategically significant dimensions of modern conflict due to the increasing proliferation of advanced submarines, underwater sensors, and autonomous underwater platforms. The inherent stealth, survivability, and strategic utility of submarines continue to make them central instruments of sea denial, intelligence gathering, strategic deterrence, and power projection.

This paper examines the role of Autonomous Warfare Systems in undersea warfare, particularly in anti-submarine warfare (ASW), mine countermeasure operations, maritime surveillance, and network-centric naval operations. It analyses the operational utility of airborne, surface, and underwater autonomous platforms and evaluates how AI-enabled systems are reshaping contemporary naval doctrine. The study further explores lessons from recent conflicts, especially the Russia-Ukraine conflict, which has demonstrated the growing relevance of low-cost unmanned maritime systems in asymmetric warfare. In addition, the paper assesses the technological, strategic, ethical, and legal challenges associated with the deployment of autonomous systems in undersea operations.

The study concludes that while AWS significantly enhance operational effectiveness through persistent surveillance, force multiplication, and reduced risk to human operators, they are unlikely to replace human decision-making in high-intensity naval warfare. Instead, future undersea warfare will increasingly depend upon integrated human-machine teaming, robust command-and-control architectures, and internationally accepted legal and ethical frameworks governing the use of autonomous lethal systems.

Keywords: Autonomous Warfare Systems, Undersea Warfare, Anti-Submarine Warfare, Unmanned Underwater Vehicles, Artificial Intelligence, Maritime Surveillance, Human-Machine Teaming, Naval Doctrine, Asymmetric Warfare, Strategic Deterrence

Introduction

Naval power has historically remained one of the principal determinants of military and geopolitical influence. The twentieth century witnessed the emergence of sea power as a decisive factor in shaping the outcomes of both World War I and World War II. During these conflicts, maritime control enabled strategic mobility, protected sea lines of communication, and supported expeditionary operations across multiple theatres. The post-Second World War bipolar international order further accelerated the strategic significance of naval forces, particularly submarines and aircraft carriers, which emerged as critical instruments of deterrence and power projection.

The Cold War period saw unprecedented technological developments in naval warfare. Nuclear propulsion enabled submarines to operate underwater for prolonged durations, thereby increasing their survivability and strategic value. Simultaneously, advances in sonar systems, radar technologies, electronic warfare, and guided missile systems transformed the operational environment at sea. Modern naval warfare subsequently evolved into a highly networked battlespace where information superiority and rapid decision-making became critical to operational success.

The emergence of Artificial Intelligence (AI), machine learning, robotics, quantum technologies, and advanced communication networks in the twenty-first century has introduced a new phase in military transformation. Autonomous Warfare Systems are increasingly being employed across land, air, maritime, cyber, and space domains to enhance operational efficiency, reduce human exposure to danger, and improve the speed and accuracy of tactical responses. Within the maritime domain, autonomous systems have become particularly relevant for undersea warfare due to the unique challenges associated with operating in the underwater environment.

Undersea warfare remains one of the most complex dimensions of modern military operations. The underwater environment is inherently opaque, acoustically variable, and operationally demanding. Unlike air or surface warfare, where radar and electro-optical systems provide relatively long detection ranges, underwater detection primarily depends on acoustic systems whose effectiveness is constrained by oceanographic conditions such as salinity, temperature gradients, underwater currents, and seabed topography. These factors provide submarines with a significant tactical advantage by enhancing their stealth and survivability.

Modern anti-submarine warfare consequently requires the integration of multiple sensors, platforms, and communication systems operating simultaneously across vast maritime areas. Surface combatants equipped with hull-mounted and towed-array sonars, maritime patrol aircraft carrying sonobuoys and magnetic anomaly detectors, ASW helicopters using dipping sonars, and satellite-enabled surveillance networks all contribute to the detection and prosecution of underwater threats. However, maintaining persistent underwater surveillance using conventional manned platforms is operationally expensive, manpower-intensive, and logistically demanding.

Autonomous Warfare Systems offer potential solutions to many of these operational challenges. Unmanned aerial vehicles (UAVs), unmanned surface vessels (USVs), autonomous underwater vehicles (AUVs), and unmanned underwater vehicles (UUVs) can conduct surveillance, tracking, reconnaissance, mine countermeasure operations, and target acquisition with significantly reduced risk to human personnel. AI-enabled data fusion systems further enhance the ability to process large volumes of acoustic and sensor data in real time.

The growing proliferation of autonomous maritime technologies among major naval powers such as the United States, China, Russia, and NATO members demonstrates the increasing strategic relevance of AWS

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in future naval conflicts. Recent conflicts, particularly the Russia–Ukraine conflict, have further illustrated how low-cost unmanned systems can challenge conventional naval superiority and reshape maritime warfare.

This paper examines the operational utility, strategic implications, and future challenges associated with Autonomous Warfare Systems in undersea warfare. It analyses the evolution of AWS in maritime operations, assesses their role in anti-submarine warfare and mine countermeasure operations, and evaluates the ethical and legal concerns associated with increasing autonomy in naval combat systems. The paper argues that although autonomous systems will significantly augment future naval operations, human judgment and command responsibility will remain central to decision-making in high-intensity maritime conflict.

Literature Review

The growing integration of autonomous systems into military operations has generated substantial scholarly debate regarding the future of warfare, human-machine interaction, and strategic stability. Existing literature on Autonomous Warfare Systems (AWS) largely focuses upon artificial intelligence-enabled military technologies, lethal autonomous weapon systems, and the implications of autonomy for operational effectiveness and international security.

Scharre (2018) argues that autonomous systems are transforming the character of warfare by enabling faster decision-making cycles, distributed operations, and enhanced operational persistence. However, Scharre also emphasizes that fully autonomous lethal systems continue to face technological and ethical limitations, particularly in complex combat environments requiring contextual judgment.

Naval scholars increasingly highlight the relevance of autonomous systems within maritime and undersea warfare. Clark, Walton, and Eaglen (2020) observe that unmanned maritime systems provide significant advantages in anti-submarine warfare, mine countermeasure operations, and maritime surveillance due to their endurance and lower operational costs. Similarly, Kraska and Pedrozo (2023) contend that autonomous maritime systems are reshaping naval doctrine by enabling distributed maritime operations and persistent undersea surveillance.

Research conducted by the RAND Corporation and the Center for Strategic and International Studies (CSIS) indicates that artificial intelligence and autonomous technologies are likely to become central components of future naval competition, particularly in the Indo-Pacific region. These studies emphasize that autonomous systems may enhance maritime domain awareness while simultaneously introducing escalation risks associated with machine-speed operations and reduced decision-making time.

Recent scholarship examining the Russia–Ukraine conflict further demonstrates the operational relevance of low-cost autonomous maritime systems in asymmetric warfare. Rickli and Mantellassi (2023) argue that maritime drones and unmanned surface vessels have significantly altered the tactical environment in the Black Sea by challenging traditional assumptions regarding naval superiority.

Within the field of undersea warfare, existing literature also highlights persistent technological constraints associated with underwater communication, acoustic variability, navigation limitations, and cyber vulnerabilities. Sutton (2022) notes that underwater autonomous systems remain constrained by low-bandwidth acoustic communication systems and limited underwater positioning capabilities.

Although substantial research exists regarding autonomous systems in general warfare contexts, relatively limited scholarly attention has focused specifically upon the strategic implications of AWS in undersea

warfare. This paper therefore seeks to contribute to the growing body of literature by examining the operational utility, strategic significance, and future challenges associated with autonomous systems in maritime undersea operations.

Methodology and Analytical Framework

This study employs a qualitative analytical methodology based upon doctrinal analysis, case study examination, and comparative assessment of contemporary naval developments. The research relies primarily upon secondary sources, including peer-reviewed journal articles, strategic studies publications, defence reports, naval doctrine documents, and policy analyses related to autonomous warfare and maritime security.

The analytical framework of the study is structured around three principal dimensions. First, the paper examines the operational dimension of autonomous warfare systems by assessing their applications in anti-submarine warfare, mine countermeasure operations, maritime surveillance, and network-centric warfare. Second, the study evaluates the strategic dimension by analysing how autonomous systems influence deterrence, force structure, maritime competition, and asymmetric warfare. Third, the paper examines the legal and ethical dimension associated with increasing autonomy in naval combat operations.

Case study analysis forms an important component of the research framework. The Russia–Ukraine conflict, the DARPA Sea Hunter programme, and autonomous mine countermeasure operations in the Persian Gulf are examined to evaluate the practical employment of autonomous systems in contemporary maritime environments.

The study further adopts a comparative approach by examining how major naval powers, including the United States, China, NATO members, and regional Indo-Pacific actors, are integrating autonomous technologies into future maritime doctrine. This analytical approach allows the paper to assess both current operational realities and emerging trends likely to shape the future of undersea warfare.

Nature of Undersea Warfare

Undersea warfare constitutes one of the most technologically sophisticated and strategically sensitive aspects of maritime operations. The domain encompasses anti-submarine warfare, underwater surveillance, mine warfare, seabed operations, underwater reconnaissance, and strategic deterrence missions conducted by submarines and underwater platforms.

Submarines continue to remain among the most survivable and lethal instruments of modern warfare. Their ability to operate covertly beneath the sea surface allows them to conduct intelligence collection, strategic deterrence patrols, sea denial operations, and precision strike missions with minimal detection risk. Nuclear-powered ballistic missile submarines form a critical component of the nuclear triad for several major powers, thereby reinforcing the strategic importance of undersea warfare.

The primary challenge in anti-submarine warfare lies in the difficulty of detecting underwater targets in an environment characterized by acoustic distortion and limited visibility. Sound propagation underwater is influenced by temperature, salinity, depth, and seabed characteristics. Thermoclines and varying sound velocity profiles can significantly affect sonar performance, enabling submarines to exploit acoustic shadows and concealment zones.

Unlike aerial or surface warfare, where targets can often be detected at long ranges through radar systems, underwater detection ranges are comparatively limited. Active sonar systems may reveal the position of

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the prosecuting platform, while passive sonar systems depend upon detecting noise signatures emitted by submarines. Modern submarines employ advanced noise reduction technologies, anechoic coatings, pump-jet propulsion, and acoustic isolation systems to minimize detectability.

Consequently, anti-submarine warfare requires extensive coordination between multiple platforms and sensors. Surface combatants equipped with towed-array sonars operate alongside maritime patrol aircraft deploying sonobuoys across large search areas. ASW helicopters equipped with dipping sonars provide rapid localization capabilities, while submarines themselves often conduct hunter-killer operations against adversary submarines.

Undersea warfare also extends beyond traditional submarine hunting. Naval mines remain highly effective asymmetric weapons capable of restricting maritime movement and threatening naval forces. Mine countermeasure operations therefore represent an essential component of undersea warfare. Historically, mine clearance operations exposed sailors and divers to significant risks. Autonomous systems now increasingly perform these dangerous tasks.

The strategic relevance of undersea warfare has further increased due to contemporary geopolitical competition in maritime regions such as the Indo-Pacific, South China Sea, Arctic Ocean, and Indian Ocean Region. Growing submarine inventories among regional powers have intensified investments in ASW technologies and autonomous surveillance systems.

In the Indo-Pacific region, the increasing deployment of nuclear-powered submarines by China, India, Australia, and the United States reflects the growing strategic competition beneath the seas. The ability to monitor maritime chokepoints, secure sea lines of communication, and maintain undersea domain awareness has consequently become essential for naval planners.

Undersea warfare therefore represents a domain where persistence, stealth, endurance, and information superiority determine operational success. Autonomous systems are particularly well suited to this environment because they can operate for extended durations without the physiological limitations associated with human crews. As technological developments continue to improve AI-enabled sensor fusion, underwater navigation, and autonomous decision-making, AWS are expected to assume increasingly significant roles in future undersea operations.

Autonomous Warfare Systems: Concepts and Classification

Autonomous Warfare Systems refer to military platforms capable of performing tasks with varying degrees of human intervention. These systems rely upon combinations of artificial intelligence, machine learning algorithms, advanced sensors, communication networks, and automated decision-making processes to execute operational functions.

The degree of autonomy within military systems can generally be categorized into three levels. Human-in-the-loop systems require human authorization before employing lethal force. Human-on-the-loop systems can operate autonomously while remaining under human supervision, allowing operators to intervene if necessary. Human-out-of-the-loop systems possess the capability to independently identify, select, and engage targets without direct human control.

Most contemporary military autonomous systems continue to operate within human-in-the-loop or human-on-the-loop frameworks, particularly in lethal applications. However, increasing advances in AI and machine learning are gradually expanding the operational autonomy of these systems.

Within the maritime domain, AWS may be classified into several categories.

Figure 1
Classification of Autonomous Warfare Systems in Maritime Operations

System Type	Primary Role	Operational Domain	Example Platforms
UAVs	Surveillance, ISR, sonobuoy deployment	Air	MQ-9 Reaper, MQ-8 Fire Scout
USVs	ASW, mine warfare, patrol	Surface	Sea Hunter, MARLIN
AUVs/UUVs	Mine detection, seabed warfare	Underwater	K-STER, A18-M
AI Sensor Fusion Systems	Data integration and target recognition	Multi-domain	AI-enabled combat systems

Note. Adapted from Scharre (2018), RAND Corporation (2021), and NATO Maritime Strategy (2022).

Unmanned Aerial Vehicles

Unmanned aerial vehicles perform surveillance, reconnaissance, target acquisition, communication relay, and electronic warfare functions. In anti-submarine warfare, UAVs support sonobuoy deployment, wide-area maritime surveillance, and real-time data transmission.

Unmanned Surface Vessels

USVs are autonomous or remotely operated surface platforms capable of conducting surveillance, mine countermeasure operations, electronic warfare, anti-submarine warfare, and maritime security missions. These platforms may operate independently or alongside manned vessels as force multipliers.

Autonomous Underwater Vehicles and Unmanned Underwater Vehicles

AUVs and UUVs perform underwater surveillance, seabed mapping, mine detection, intelligence gathering, and undersea reconnaissance. Certain advanced systems are being designed for offensive operations, including autonomous torpedo deployment and undersea strike capabilities.

AI-Enabled Sensor Fusion Systems

Modern autonomous systems increasingly depend upon AI-enabled sensor fusion technologies capable of processing data from multiple sources simultaneously. Acoustic signatures, sonar returns, radar feeds, satellite imagery, and electronic intelligence can be integrated to improve situational awareness and target identification.

The effectiveness of AWS is enabled by several emerging technologies.

Artificial Intelligence and machine learning algorithms improve pattern recognition, acoustic analysis, anomaly detection, and autonomous navigation. Edge computing allows onboard data processing without

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requiring constant communication with centralized command centres. Satellite communication systems and secure data links facilitate real-time connectivity between distributed platforms.

Autonomous maritime systems also increasingly rely upon advanced navigation technologies. Since GPS signals cannot penetrate underwater environments, underwater autonomous systems depend upon inertial navigation systems, acoustic positioning, seabed mapping, and emerging quantum navigation technologies.

The integration of autonomous systems into naval operations supports the broader concept of network-centric warfare. In this operational model, multiple sensors and platforms share data through interconnected networks to generate a common operational picture. Distributed autonomous systems thereby contribute to maritime domain awareness and increase the effectiveness of naval task forces.

The military utility of AWS lies not merely in replacing manned platforms, but in augmenting operational capability. Autonomous systems can perform high-risk, repetitive, and endurance-intensive tasks while allowing human operators to focus upon strategic decision-making and mission command.

Applications of Autonomous Warfare Systems in Undersea Warfare

Airborne Autonomous Anti-Submarine Warfare

Airborne anti-submarine warfare has traditionally depended upon maritime patrol aircraft and shipborne helicopters equipped with specialized sensors and weapons. Aircraft such as the P-8 Poseidon and helicopters such as the MH-60R Seahawk utilize sonobuoys, dipping sonars, radar systems, electro-optical sensors, and magnetic anomaly detectors to locate and track submarines.

However, maintaining persistent airborne ASW coverage using manned aircraft is costly and operationally demanding. Autonomous aerial systems therefore offer significant advantages in terms of endurance, persistence, and reduced operational risk.

Medium Altitude Long Endurance (MALE) and High Altitude Long Endurance (HALE) UAVs can conduct wide-area maritime surveillance across vast oceanic regions. Platforms such as the MQ-9 Reaper possess the capability to relay sensor information to naval task groups and support long-range target tracking operations.

Autonomous rotary-wing systems are increasingly being developed for shipborne ASW roles. These platforms can operate from smaller warships without requiring large aviation facilities. Their ability to autonomously take off and land aboard moving ships significantly enhances operational flexibility.

The development of autonomous systems capable of deploying sonobuoys represents an important advancement in anti-submarine warfare. Sonobuoys remain essential for underwater acoustic detection, particularly in open-ocean environments where submarines may exploit acoustic concealment zones.

The SKELDAR V-200 unmanned aerial system represents an example of emerging autonomous ASW capability. Developed for maritime operations, the system is being evaluated for sonobuoy deployment and underwater target tracking missions. Such platforms can extend the sensor range of naval task groups while reducing dependence upon manned helicopters.

Similarly, the Schiebel Camcopter S-100 has demonstrated the ability to relay data from deployed sonobuoys to command centres ashore. This capability significantly enhances distributed anti-submarine operations by enabling remote processing and analysis of acoustic information.

Autonomous airborne systems also contribute to maritime domain awareness through persistent surveillance. Electro-optical sensors, maritime radar systems, and electronic intelligence payloads allow UAVs to monitor surface traffic, identify anomalous behaviour, and support naval interdiction operations.

The Northrop Grumman MQ-8 Fire Scout further demonstrates the growing integration of autonomous systems into naval operations.

Table 1
Comparative Roles of Autonomous Maritime Platforms

Platform Type	Operational Advantages	Operational Limitations	Representative Systems
UAVs	Long-endurance surveillance	Vulnerable to air defence	MQ-9 Reaper
USVs	Persistent ASW operations	Cyber vulnerabilities	Sea Hunter
AUVs/UUVs	Stealth and mine warfare	Communication limitations	A18-M
AI-enabled Systems	Rapid data processing	Ethical concerns	Sensor fusion systems

Note. Data compiled from CSIS Maritime Security Program (2022), DARPA ACTUV Program, and Naval War College Review studies.

Its ability to autonomously operate from warships, combined with onboard radar and electro optical sensors, enables extended surveillance and targeting support. By functioning as communication relay nodes, such UAVs contribute to network-centric naval warfare.

The operational significance of autonomous airborne systems lies not merely in their surveillance capabilities but in their ability to support manned-unmanned teaming. Human operators aboard warships can receive real-time information from multiple autonomous platforms operating simultaneously across wide maritime areas.

In future conflicts, AI-enabled airborne systems may increasingly support autonomous target recognition, acoustic classification, and predictive threat analysis. Machine learning algorithms could improve the detection of subtle acoustic signatures associated with modern quiet submarines.

Nevertheless, airborne autonomous systems continue to face several operational challenges. Electronic warfare, communication disruption, adverse weather conditions, and cyber vulnerabilities may affect mission effectiveness. Moreover, autonomous systems operating in contested airspace remain vulnerable to air defence systems.

Despite these limitations, airborne AWS are expected to become integral components of future anti-submarine warfare architectures due to their persistence, operational reach, and force multiplication potential.

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Shipborne Autonomous Systems

Unmanned surface vessels represent one of the most significant developments in maritime autonomous warfare. These systems can perform surveillance, reconnaissance, anti-submarine warfare, mine countermeasure operations, and maritime security missions without exposing human crews to operational risks.

One of the most prominent examples of autonomous surface warfare capability is the United States Defense Advanced Research Projects Agency (DARPA) Anti-Submarine Warfare Continuous Trail Unmanned Vessel program. The program sought to develop an autonomous vessel capable of persistently tracking quiet diesel-electric submarines across long distances.

The Sea Hunter autonomous vessel emerged from this initiative as a demonstration of long-endurance unmanned maritime operations. Designed using a trimaran hull configuration, the vessel can operate autonomously for extended durations while maintaining continuous surveillance.

The operational utility of platforms such as Sea Hunter lies in their persistence and affordability. Conventional anti-submarine operations require highly trained crews and expensive warships to maintain continuous submarine tracking. Autonomous surface vessels can perform similar surveillance functions at significantly lower operational costs.

Sea Hunter utilizes advanced sonar systems, electro-optical sensors, radar systems, and autonomous navigation technologies to track underwater threats. Its ability to comply with maritime navigation rules while operating autonomously demonstrates significant progress in autonomous maritime navigation.

Persistent submarine tracking represents one of the most difficult tasks in undersea warfare. Diesel-electric submarines operating on battery power can become exceptionally quiet, making them difficult to detect. Autonomous surface vessels equipped with active and passive sonar systems can maintain prolonged contact with such targets without exhausting human crews.

The integration of USVs into multinational naval exercises further demonstrates their growing operational relevance. During the Rim of the Pacific (RIMPAC) exercises, autonomous surface vessels participated alongside conventional naval platforms in coordinated operations. These exercises highlighted the potential of autonomous systems to extend the tactical reach of manned warships.

Several other countries are also investing heavily in autonomous surface warfare technologies. Türkiye has developed systems such as the MARLIN and MİR unmanned surface vessels for anti-submarine warfare and maritime security operations. These systems integrate sonar technologies, autonomous navigation, and communication systems capable of supporting coordinated operations with UAVs and underwater vehicles.

The operational value of USVs extends beyond anti-submarine warfare. Autonomous surface vessels can conduct intelligence collection, maritime interdiction, electronic warfare, and infrastructure protection missions. Their relatively low cost and modular payload capacity make them adaptable to multiple operational roles.

Mine warfare represents another area where autonomous surface systems offer significant advantages. Historically, mine countermeasure operations exposed sailors to considerable danger. Autonomous surface platforms can now tow sonar arrays, deploy remotely operated vehicles, and support mine detection missions without risking human lives.

The INSPECTOR 125 unmanned surface vehicle exemplifies the growing role of autonomous systems in mine warfare. Designed for maritime security and mine countermeasure operations, the platform can deploy underwater vehicles and tow side-scan sonar systems for seabed mapping and mine detection.

Autonomous surface systems are also increasingly integrated into distributed maritime operations concepts. Rather than concentrating combat power within a few large warships, distributed operations rely upon multiple interconnected platforms operating across wide maritime areas. USVs can support this operational model by acting as sensor nodes, communication relays, and forward surveillance assets.

However, autonomous surface systems remain vulnerable to cyber attacks, electronic warfare, and physical interdiction. Communication reliability remains particularly important because autonomous vessels often require periodic updates from command centres. Ensuring secure and resilient communication networks will therefore remain critical for future autonomous naval operations.

Autonomous Underwater Systems

Autonomous underwater systems represent perhaps the most transformative development in future undersea warfare. These platforms possess the potential to fundamentally alter the balance between offensive and defensive undersea operations.

Autonomous underwater vehicles are increasingly used for mine countermeasure operations, seabed mapping, underwater surveillance, intelligence collection, and infrastructure inspection. Their ability to operate covertly for extended durations makes them particularly valuable in contested maritime environments.

Mine warfare has historically represented one of the most dangerous aspects of naval operations. Naval mines remain inexpensive yet highly effective weapons capable of threatening commercial shipping and naval task groups alike. Autonomous systems now allow mine detection and disposal operations to be conducted remotely.

The K-STER mine disposal system demonstrates how remotely operated underwater vehicles can neutralize underwater mines while keeping operators outside danger zones. Such systems significantly improve operational safety and efficiency.

Similarly, autonomous underwater vehicles such as the A18-M and A9-M are designed for advanced mine countermeasure missions. These systems can autonomously detect, classify, and map underwater hazards while operating in proximity to sophisticated naval mines.

Autonomous underwater systems also support seabed warfare operations. Increasing global dependence upon undersea communication cables, offshore energy infrastructure, and maritime economic zones has elevated the strategic importance of seabed security.

Future conflicts may increasingly involve underwater infrastructure sabotage, cable disruption, and covert seabed operations. Autonomous underwater systems capable of surveillance, inspection, and intervention will therefore become strategically significant.

The development of extra-large unmanned underwater vehicles (XLUUVs) by major naval powers further illustrates the growing militarization of autonomous undersea systems. China, the United States, and Russia are all investing in long-endurance underwater platforms capable of conducting surveillance and potentially offensive operations.

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AI-enabled underwater systems could eventually perform autonomous patrol missions across strategic chokepoints. Such systems may remain submerged for prolonged durations while monitoring submarine activity, collecting intelligence, and supporting maritime domain awareness.

Autonomous torpedoes and loitering underwater munitions represent another emerging dimension of undersea warfare. Future systems may possess the capability to independently search for targets using acoustic and sensor data.

However, underwater autonomy remains technologically challenging due to communication limitations. Radio signals do not propagate effectively underwater, forcing underwater systems to rely upon acoustic communication methods characterized by low bandwidth and latency constraints.

Navigation also remains difficult in underwater environments lacking GPS connectivity. Autonomous systems therefore depend upon inertial navigation systems, terrain contour matching, and underwater acoustic positioning technologies.

Despite these limitations, autonomous underwater systems are expected to play increasingly important roles in future naval strategy due to their stealth, endurance, and operational flexibility.

Network-Centric and Multi-Domain Operations

Modern naval warfare increasingly depends upon network-centric operational concepts where information superiority determines combat effectiveness. Autonomous systems contribute significantly to this framework by acting as distributed sensors and communication nodes.

Network-centric warfare involves integrating data from multiple platforms into a unified operational picture. Surface ships, submarines, UAVs, satellites, and underwater sensors collectively contribute to maritime domain awareness.

Autonomous systems enhance this operational model by expanding surveillance coverage and improving persistence. Distributed networks of autonomous sensors can monitor large maritime regions continuously while reducing dependence upon manned platforms.

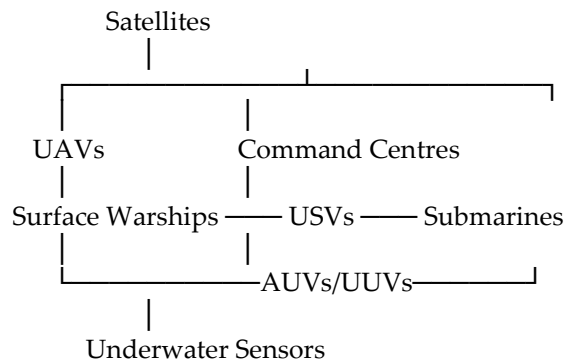
Artificial intelligence further enhances the effectiveness of network-centric operations by processing vast volumes of sensor data in real time. Machine learning algorithms can identify patterns, classify acoustic signatures, and support predictive threat analysis.

The concept of manned-unmanned teaming is particularly relevant in undersea warfare. Rather than replacing conventional platforms, autonomous systems augment human decision-making and extend operational reach.

For example, autonomous surface vessels may conduct forward surveillance while manned destroyers remain outside adversary threat envelopes. UAVs can relay targeting data to submarines or surface combatants. Underwater autonomous systems can monitor chokepoints while transmitting intelligence to command centres.

Future naval operations are likely to involve highly integrated multi-domain operations combining cyber, space, air, surface, and undersea assets.

Figure 2
Operational Architecture of Network-Centric Undersea Warfare



Note. Adapted from United States Navy (2020), NATO Maritime Strategy (2022), and Tangredi (2021).

Autonomous systems will therefore play central roles in enabling distributed and resilient maritime operations.

Case Studies in Autonomous Undersea Warfare

Recent operational developments and technological demonstrations provide important insights into the growing role of autonomous systems in maritime and undersea warfare. Contemporary case studies illustrate how autonomous platforms are increasingly shaping naval doctrine, anti-submarine warfare, mine countermeasure operations, and asymmetric maritime conflict.

Ukraine's Use of Maritime Drones in the Black Sea Conflict

The Russia–Ukraine conflict has emerged as one of the most significant contemporary demonstrations of autonomous and unmanned maritime warfare. Following the degradation of much of Ukraine's conventional naval capability after 2014, Ukraine increasingly adopted asymmetric maritime strategies utilizing unmanned surface vessels (USVs) and maritime drones against the Russian Black Sea Fleet.

Ukrainian systems such as the MAGURA V5, Sea Baby, and Mamai unmanned surface platforms were employed to conduct attacks against Russian warships, naval infrastructure, and logistical assets in the Black Sea. These low-cost autonomous and remotely operated systems demonstrated the ability to penetrate defended maritime zones and threaten significantly larger conventional naval platforms.

One of the most notable incidents occurred in October 2022, when Ukrainian maritime drones targeted Russian naval vessels near Sevastopol. The attacks highlighted the growing vulnerability of traditional naval assets to distributed unmanned maritime systems. Subsequently, repeated Ukrainian drone attacks compelled elements of the Russian Black Sea Fleet to relocate from Crimea, thereby affecting Russian maritime operational posture in the region.

The conflict demonstrated several important operational lessons for future naval warfare. First, autonomous and remotely operated maritime systems provide smaller powers with cost-effective asymmetric capabilities against technologically superior adversaries. Second, distributed autonomous attacks complicate defensive coordination and increase pressure upon naval command-and-control systems. Third, maritime drones significantly enhance operational reach without exposing personnel to direct combat risks.

The Ukraine conflict further illustrated the strategic impact of persistent unmanned maritime operations. Even limited tactical attacks generated disproportionate psychological and operational effects upon the

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Russian Navy. Consequently, the conflict reinforced the growing relevance of autonomous systems in future maritime and undersea warfare environments.

DARPA Sea Hunter and Autonomous Anti-Submarine Warfare

The United States Defense Advanced Research Projects Agency (DARPA) developed the Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) program to address the growing challenge posed by increasingly quiet diesel-electric submarines. The program led to the development of the Sea Hunter autonomous surface vessel, one of the most advanced examples of autonomous anti-submarine warfare technology.

Sea Hunter was specifically designed to autonomously track submarines over long durations while operating with minimal human intervention. The vessel incorporates autonomous navigation systems, sonar technologies, radar sensors, and artificial intelligence-enabled decision-support systems. Its trimaran hull design provides enhanced stability and endurance for prolonged maritime operations.

The operational significance of Sea Hunter lies primarily in its persistence and affordability. Traditional anti-submarine warfare missions require expensive destroyers, frigates, and maritime patrol aircraft supported by highly trained personnel. In contrast, autonomous systems such as Sea Hunter can conduct persistent submarine tracking at significantly reduced operational costs.

Sea Hunter has participated in several United States Navy exercises and experimentation programs, demonstrating the feasibility of autonomous maritime operations integrated with conventional naval task forces. The platform's ability to comply with international maritime navigation regulations while autonomously navigating congested waters represents an important advancement in autonomous naval technology.

The case demonstrates how autonomous systems can augment conventional anti-submarine warfare by extending surveillance coverage, reducing operational costs, and enabling persistent maritime monitoring. It further highlights the growing transition toward manned-unmanned teaming concepts within modern naval doctrine.

Autonomous Mine Countermeasure Operations in the Persian Gulf

The Persian Gulf remains one of the world's most strategically sensitive maritime regions due to its concentration of energy infrastructure and critical sea lines of communication. Naval mines have historically posed major threats to maritime security in the region, particularly during the Iran-Iraq War and subsequent regional tensions.

To address these threats, the United States Navy and allied forces increasingly integrated autonomous mine countermeasure systems into maritime security operations. Autonomous underwater vehicles (AUVs) and unmanned surface vessels equipped with side-scan sonar systems, mine-detection sensors, and remotely operated disposal systems were deployed to improve mine warfare capability.

Systems such as the K-STER mine disposal vehicle and autonomous underwater platforms developed by ECA Group demonstrated the ability to conduct mine detection, classification, and neutralization operations without exposing naval personnel to high-risk environments. These autonomous systems significantly improved operational safety while increasing the speed and efficiency of mine clearance operations.

The operational experience in the Persian Gulf highlighted several advantages of autonomous mine warfare systems. Autonomous platforms could operate continuously in hazardous waters, conduct detailed seabed mapping, and reduce dependence upon specialized manned minehunter vessels. Furthermore, modular autonomous systems provided greater operational flexibility and rapid deployment capability.

The Persian Gulf experience demonstrated that autonomous mine countermeasure systems are becoming essential components of modern naval operations. As naval mines continue to represent highly effective asymmetric weapons, autonomous mine warfare technologies are expected to play increasingly important roles in future maritime security operations.

Lessons from Contemporary Conflicts

Recent conflicts have demonstrated the increasing relevance of autonomous systems in modern warfare. The Russia–Ukraine conflict, in particular, has highlighted how low-cost unmanned maritime systems can challenge conventional naval superiority.

Following the Russian annexation of Crimea in 2014, Ukraine lost a substantial portion of its naval capability. Faced with an overwhelmingly superior Russian Black Sea Fleet, Ukraine increasingly relied upon asymmetric warfare strategies.

Unmanned surface vessels equipped with explosives emerged as highly effective tools for targeting Russian naval assets. Ukrainian maritime drones such as MAGURA, Sea Baby, and Mamai demonstrated the ability to strike warships, damage infrastructure, and disrupt Russian naval operations.

These attacks illustrated several important lessons for future naval warfare.

Table

2

Lessons from Contemporary Maritime Drone Warfare

Conflict/Region	Autonomous System Used	Operational Impact	Strategic Lesson
Russia–Ukraine War	MAGURA V5, Sea Baby	Damage to Black Sea Fleet	Asymmetric warfare effectiveness
Persian Gulf	K-STER, AUV mine systems	Improved mine clearance	Reduced personnel risk
Red Sea Security Threats	Maritime drones and USVs	Threats to commercial shipping	Proliferation of low-cost threats
Indo-Pacific Competition	Sea Hunter, XLUUVs	Enhanced maritime surveillance	Persistent undersea awareness

Note. Compiled from Rickli and Mantellassi (2023), CSIS Maritime Security Program (2022), and IISS Military Balance (2024).

First, autonomous and remotely operated systems significantly reduce the cost of maritime strike operations. Conventional warships and submarines are expensive platforms requiring extensive training and logistical support. Low-cost unmanned systems can impose disproportionate operational and economic burdens upon larger naval forces.

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Second, unmanned maritime systems enhance operational surprise. Small autonomous vessels operating at low profiles are difficult to detect using conventional radar systems, particularly in congested maritime environments.

Third, autonomous systems support distributed and decentralized warfare. Multiple unmanned platforms can simultaneously attack targets from different directions, complicating defensive responses.

The Ukraine conflict has also demonstrated the psychological impact of autonomous maritime systems. Persistent drone attacks forced the Russian Navy to relocate elements of the Black Sea Fleet and invest heavily in defensive measures.

Beyond the Black Sea, maritime drone warfare has also emerged in the Red Sea and Middle East. Non-state actors increasingly employ low-cost drones and autonomous systems against naval and commercial targets.

These developments indicate that autonomous maritime technologies are likely to proliferate rapidly among both state and non-state actors. The accessibility of commercial technologies such as satellite navigation, AI software, and unmanned platforms further accelerates this trend.

For naval planners, the primary lesson is that future maritime warfare will increasingly involve asymmetric threats from autonomous systems operating across surface and undersea domains.

Strategic, Legal and Ethical Challenges

Despite their operational advantages, Autonomous Warfare Systems present several strategic, legal, and ethical challenges.

Figure

3

Key Challenges Associated with Autonomous Undersea Warfare

Strategic Challenges	Legal Challenges	Ethical Challenges
Cyber attacks	Accountability gaps	Machine decision-making
Communication disruption	UNCLOS applicability	Civilian casualty concerns
Escalation risks	Compliance with LOAC	Human control debates
AI reliability	Target discrimination	Environmental impact

Note. Adapted from CNAS (2020), Kraska and Pedrozo (2023), and NATO (2022).

Strategic Challenges

Autonomous systems remain vulnerable to cyber attacks and electronic warfare. Adversaries may attempt to disrupt communication networks, manipulate sensor data, or hijack autonomous platforms.

Communication reliability is particularly problematic in underwater environments where radio-frequency communication is ineffective. Acoustic communication systems suffer from latency and bandwidth limitations, potentially affecting coordination between autonomous systems and command centres.

Autonomous systems also raise escalation concerns. AI-enabled systems operating at machine speed may reduce human decision-making time during crises. Misidentification or system malfunction could inadvertently trigger escalation.

Furthermore, autonomous systems may alter naval force structures and deterrence dynamics. The proliferation of low-cost autonomous platforms could reduce the survivability advantage traditionally enjoyed by large capital ships.

Legal Challenges

The deployment of autonomous lethal systems raises important legal questions under international law.

The United Nations Convention on the Law of the Sea (UNCLOS) governs many aspects of maritime operations, but existing frameworks were developed before the emergence of highly autonomous military systems.

Questions arise regarding accountability when autonomous systems cause unintended damage or civilian casualties. Determining responsibility becomes complex when decision-making is partially delegated to algorithms.

The Law of Armed Conflict requires distinction, proportionality, and military necessity during combat operations. Ensuring that autonomous systems can reliably distinguish between military and civilian targets remains a major challenge.

Maritime operations further complicate identification because commercial shipping traffic often operates within contested regions. Autonomous systems may struggle to interpret ambiguous tactical situations.

Ethical Challenges

Ethical concerns surrounding lethal autonomous weapon systems have generated significant international debate. Critics argue that machines should not possess the authority to make life-and-death decisions.

Organizations such as the Campaign to Stop Killer Robots advocate international restrictions upon autonomous lethal systems. Ethical concerns focus upon the absence of human judgment, empathy, and accountability in algorithmic decision-making.

Underwater warfare introduces additional ethical concerns due to the potential impact upon marine ecosystems. Increased deployment of autonomous underwater systems may affect marine mammals and underwater habitats through acoustic emissions and physical interference.

The possibility of autonomous underwater systems operating for extended periods without human supervision also raises concerns regarding unintended engagements and accidental escalation.

Despite these concerns, many military planners argue that autonomous systems may eventually reduce civilian casualties by improving precision and situational awareness. AI-enabled systems capable of rapidly processing sensor information could potentially reduce human error in high-pressure combat situations.

The challenge therefore lies in developing regulatory frameworks that balance military effectiveness with ethical and humanitarian considerations.

Future of Autonomous Undersea Warfare

The future of undersea warfare will likely be characterized by increasing integration between manned and unmanned systems operating across interconnected maritime networks.

Advances in artificial intelligence, machine learning, underwater communications, and energy storage technologies are expected to significantly improve the capabilities of autonomous undersea systems.

Figure
Future Trends in Autonomous Undersea Warfare

Emerging Technology	Expected Operational Impact
AI-enabled sensor fusion	Faster target identification
Quantum navigation	Improved underwater positioning
Swarm autonomous systems	Distributed maritime operations
XLUUVs	Persistent strategic surveillance
Human-machine teaming	Enhanced operational decision-making

Note. Adapted from RAND Corporation (2021), Tangredi (2021), and United States Navy (2020).

Extra-large unmanned underwater vehicles capable of long-duration autonomous operations may eventually perform strategic surveillance missions across critical maritime chokepoints. Swarms of smaller autonomous underwater systems could conduct coordinated reconnaissance, mine warfare, and electronic warfare operations.

Quantum sensing technologies may further improve underwater navigation and target detection capabilities. Enhanced underwater communication systems could allow more reliable coordination between distributed autonomous platforms.

The strategic competition in the Indo-Pacific region is also likely to accelerate investments in autonomous maritime warfare technologies. Nations seeking to secure maritime interests and counter growing submarine fleets will increasingly adopt autonomous surveillance and anti-submarine warfare systems.

For India, autonomous maritime systems offer important opportunities to enhance maritime domain awareness across the Indian Ocean Region. Persistent surveillance using autonomous systems could support monitoring of critical sea lanes, chokepoints, and underwater infrastructure.

However, the future operational effectiveness of AWS will depend upon several factors. Reliable AI-enabled target recognition remains technologically challenging, particularly in complex underwater environments. Cyber resilience and secure communication networks will remain essential.

Human decision-making is also likely to remain central to future naval operations. While autonomous systems can improve operational efficiency, strategic judgment and accountability cannot be fully delegated to machines.

Future naval doctrine will therefore increasingly emphasize human-machine teaming rather than complete autonomy.

Conclusion

Autonomous Warfare Systems are transforming the conduct of undersea warfare by expanding operational reach, persistence, surveillance capability, and force multiplication potential. Advances in artificial intelligence, autonomous navigation, sensor fusion, and network-centric warfare have enabled unmanned systems to perform increasingly sophisticated maritime missions.

In anti-submarine warfare, autonomous aerial, surface, and underwater systems provide persistent surveillance and enhance maritime domain awareness across large operational areas. In mine countermeasure operations, autonomous systems significantly reduce risks to human personnel while improving operational efficiency. Recent conflicts such as the Russia–Ukraine war have further demonstrated the disruptive potential of low-cost unmanned maritime systems in asymmetric warfare.

At the same time, the increasing militarization of autonomous systems presents important strategic, legal, and ethical challenges. Communication vulnerabilities, cyber threats, target identification limitations, and accountability concerns continue to constrain the deployment of fully autonomous lethal systems.

The underwater environment itself remains highly complex and technologically demanding. Acoustic variability, communication limitations, and incomplete seabed mapping create operational uncertainties that autonomous systems must overcome.

While AI-enabled autonomous systems will continue to expand their role in future maritime operations, they are unlikely to completely replace human command and decision-making in high-intensity warfare. Instead, future undersea warfare will increasingly depend upon integrated human-machine teaming, resilient communication networks, and internationally accepted legal frameworks governing the use of autonomous weapons.

Ultimately, Autonomous Warfare Systems should be viewed not as substitutes for human judgment, but as force multipliers capable of enhancing operational effectiveness in increasingly contested maritime environments. The challenge for future naval powers will lie in balancing technological innovation with strategic stability, ethical responsibility, and effective command oversight.

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