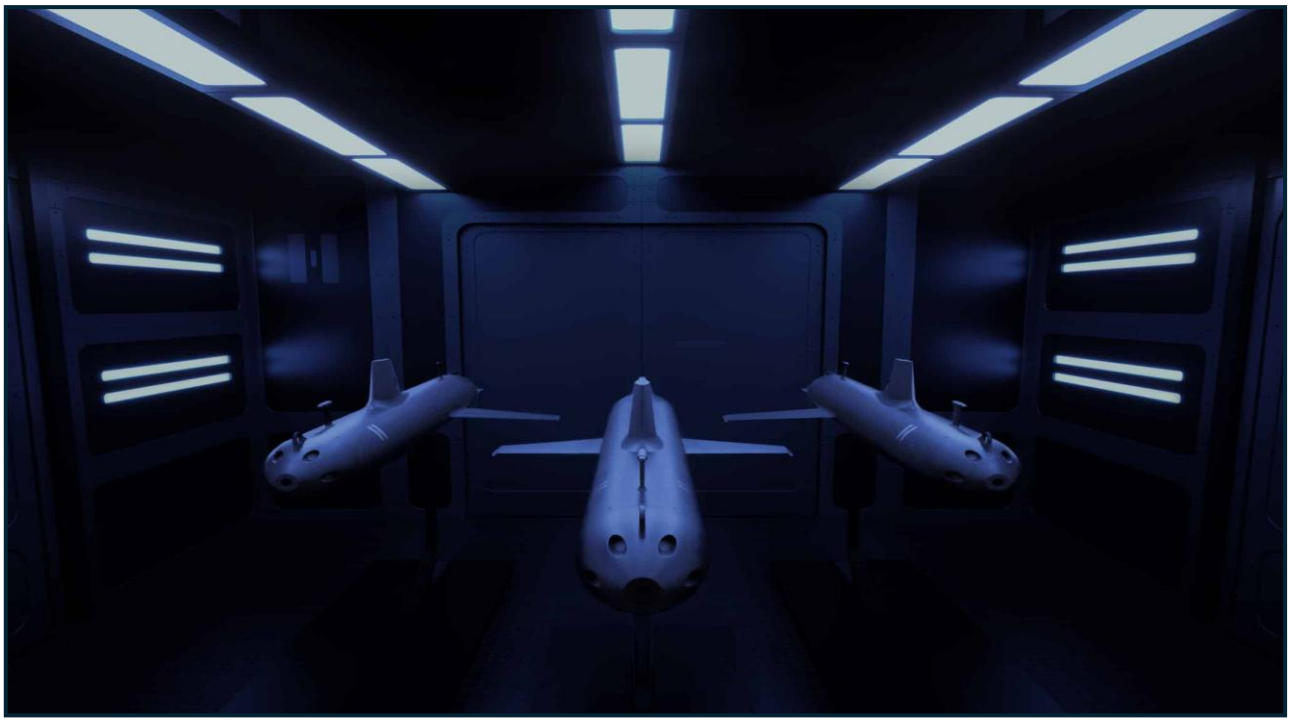
Disruptive Underwater Unmanned[1] Vehicle (UUV) Technologies in the Future Fleet



The Fathom/Lura combination provides a containerised, AI-enhanced, underwater sensing capability package designed to be affordable, deployable, scalable, and available. (Credit: Helsing)[2]

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[1] By definition, an unmanned system minimizes risk to personnel by removing them from a platform that is placed in harm's way. But until that platform is capable of functioning autonomously, it does little to reduce the demand on personnel acting as operators. To gain a real force multiplier advantage, commanders will need unmanned systems capable of operating autonomously, enabling scarce personnel resources to focus on other priorities.

[2] Naval News – Dr Lee Willett '' Helsing and Partners Prepare to Scale Up New AI-enhanced Underwater Surveillance Package'' https://www.navalnews.com/event-news/cne-2025/2025/05/helsing-and-partners-prepare-to-scale-up-new-ai-enhanced-underwater-surveillance-package/ 27 May 2025

[3] *The views, interpretations, and conclusions presented in this paper are entirely those of the author in a personal capacity. They do not represent official positions, policies, or endorsements of the North Atlantic Treaty Organization (NATO), any of its member states, or affiliated institutions. The content has been prepared solely for academic and professional discussion and should not be construed as reflecting officially released or classified NATO doctrine or guidance. All information contained herein is derived from open and unclassified sources, and no restricted or sensitive material has been used in its development.*

Abstract

Disruptive Underwater Unmanned Vehicle (UUV) Technologies for Seabed Defence and Deterrence NATO's undersea battlespace is increasingly contested, with seabed infrastructure such as cables and pipelines vulnerable to hostile interference. This project proposes advancing disruptive Underwater Unmanned Vehicle (UUV) technologies to strengthen seabed defence and enhance deterrence. Research will be focused on the existing NATO developments of autonomous UUV capabilities for persistent surveillance, anomaly detection, and rapid counteraction against potential threats. Focus areas include international cooperation (academia and industry) in defence on mission execution in complex seabed terrain to bridge the gaps of traditional naval platforms and cutting-edge unmanned systems. Existing sea trials and NATO exercises will validate for the research outcome. The outcomes will deliver qualitative themes, lessons learned and observations of UUVs platforms, and new operational concepts to safeguard critical seabed infrastructure, reinforcing maritime deterrence and undersea dominance in contested domains.

EXECUTIVE SUMMARY

In an era of intensifying great-power competition, NATO's maritime security paradigm is shifting dramatically. Increasingly, naval contests are not merely fought on the surface of the seas, they extend into the deep, hidden domains of the seabed. Critical infrastructure such as undersea cables, pipelines, and other seabed assets have become strategic vulnerabilities. These vulnerabilities expose the Alliance to coercion, sabotage, or hybrid warfare.[4] For over two decades NATO maritime forces enjoyed a near-monopoly in their associated battle networks.[5]

Against this backdrop, NATO is rapidly embracing disruptive technologies, especially UUVs essential enablers for seabed defence and deterrence. This essay explores how NATO is developing and integrating UUV capabilities, the institutional and technological frameworks supporting them, real-world experimentation, and the operational concepts and lessons learned. The ultimate goal: to strengthen undersea deterrence, protect critical seabed infrastructure, and maintain undersea dominance in increasingly contested domains.[6]

Undersea infrastructure is the invisible backbone of global connectivity and energy systems. More than 95.00 percent of global internet traffic travels through submarine cables, while pipelines transport energy across continents.[7] As NATO itself has acknowledged, these seabed networks are strategically critical and increasingly at risk. Disruptive technologies like UUVs are now central to NATO's doctrine of persistent surveillance, operational resilience, and deterrence.[8]

Recent incidents such as damage to undersea cables in the Baltic Sea underscore the growing threat. Such disruptions carry not just economic costs but can be deployed as tools of coercion or sabotage.[9]

DIGITAL OCEAN

To respond to these risks, NATO leaders endorsed the Digital Ocean Vision at the 2023 Vilnius Summit. This doctrine expands the Alliance's maritime domain awareness "from seabed to space," leveraging satellites, sensors, AI, and autonomous systems clouding UUVs to provide continuous coverage and rapid response.[10]

This vision is not symbolic: under it, NATO is investing in technological innovation, fostering interoperability, and reshaping force structure. A key outcome is the integration of unmanned systems into NATO's maritime task forces and that's where UUVs come in.

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[4] The Guardian - Miranda Bryant '' Undersea 'hybrid warfare' threatens security of 1bn, Nato commander warns'' `16 Apr 2024 https://www.theguardian.com/world/2024/apr/16/undersea-hybrid-warfare-threatens-security-of-1bn-nato-commander-warns?utm_source=chatgpt.com

[5] NATO Archive – Klaudia Maciata '' Fortifying the Baltic Sea - NATO's defence and deterrence strategy for hybrid threats'' 5 May 2025 https://archives.nato.int/uploads/r/nato-archivesonline/8/6/2/862abd3be6243146aba7e327ea1ab33d07b3d887735f4acc79944621678407de/2025-05-05_Fortifying_the_Baltic_Sea-NATO___s_defence_and_deterrence_strategy_for_hybrid_threats_ENG.pdf

[6] CSIS - Sean Monaghan, Otto Svendsen, Michael Darrah, and Ed Arnold ''NATO's Role in Protecting Critical Undersea Infrastructure'' 19 Dec 2023 https://www.csis.org/analysis/natos-role-protecting-critical-undersea-infrastructure

[7] NOAA ''Submarine Cables'' https://www.noaa.gov/submarine-cables

[8] US Naval Institute – Vice Admiral Robert Gaucher '' How New Technologies Are Making the Submarine Force More Lethal'' Oct 2025 https://www.usni.org/magazines/proceedings/2025/october/how-new-technologies-are-making-submarine-force-more-lethal

[9] Statista – Kathaarina Buchholz ''Baltic Sea Cable Incidents Pile Up'' 6 Feb 2025 https://www.statista.com/chart/33892/damage-to-underwater-cables-and-pipelines-in-the-baltic-sea/

[10] Unmanned Systems Technology – Joe Macey '' NATO Endorses Digital Ocean Vision Plan to Enhance Maritime Situational Awareness'' 23 Oct 2023 https://www.unmannedsystemstechnology.com/2023/10/nato-endorses-digital-ocean-vision-plan-to-enhance-maritime-situational-awareness/

NATO's Digital Ocean Vision is a foundational concept in this transformation. The Vision emphasizes continuous awareness "from seabed to space," leveraging advanced sensors, AI fusion, and autonomous platforms to build a real-time, persistent common operational picture. UUVs play a crucial role: they provide the stealth, endurance, and access to environments too dangerous or costly for crewed systems to monitor constantly.

Crucially, NATO is reinforcing its innovation ecosystem by bringing together industry, military, and academia. The NATO Digital Ocean Industry Symposium exemplifies this, providing a platform for companies to present long-endurance UUVs, sensor technology, and AI analytics directly aligned with Alliance needs. These dialogues ensure that NATO's future undersea architecture evolves in step with cutting-edge technology and academic research.[11]

NATO HQ/ACT TFX-MAINSAILS AND AUWB-MN

Part of making this vision operational is Task Force X, an initiative under NATO's Allied Command Transformation (ACT). Task Force X is tasked with accelerating the deployment of unmanned maritime systems (USVs, UUVs, UAVs) to generate persistent intelligence, surveillance, reconnaissance (ISR), and to protect critical undersea infrastructure. In June 2025, Task Force X Baltic, a pilot at-sea demonstration, showcased multi-domain integration using USVs, UUVs, and UAVs to create layered maritime presence.[12]

For example, four Saildrone Voyager uncrewed surface vehicles (USVs) operated during the Task Force X Baltic demonstration. These USVs conducted 24/7 surveillance over the Gulf of Finland and Western Baltic Sea, even in rough weather, detecting and tracking hundreds of vessels including so-called "dark" or unregistered vessels and integrating data into NATO's command picture. The Voyagers' long-range radar and persistent presence were complemented by faster uncrewed platforms, demonstrating a layered structure of autonomous systems.[13]

Task Force X's aim is not just experimental, but it seeks to establish a scalable, operational concept. The June exercise was described as the first live application of the Task Force X concept. The data collected was fed into a common operating picture (COP), standardizing across platforms via communication protocols and leveraging NATO's emerging command-and-control architecture for maritime robotics.[14]

But hardware isn't enough you also need data, connectivity, and analysis. That's where Mainsail comes in. This is NATO's data exploitation platform, which fuses inputs from satellites, underwater sensors, sonar, and other sources into a cloud-based environment for real-time analysis.

Mainsail uses AI and machine learning to perform pattern-of-life analysis, identify anomalies, and provide predictive insights. Through this, NATO gains a comprehensive "picture" of

[11] NAVY Leaders – Sean Trevethan '' Is NATO's 'Digital Ocean' the Answer to Securing Undersea Infrastructure?'' https://navyleaders.com/interview/is-natos-digital-ocean-the-answer-to-securing-undersea-infrastructure/
[12] NATO – MARCOM '' NATO Showcases Capabilities of Uncrewed Vessels with Demonstrations in the Baltic Sea'' 5 Jun 2025 https://mc.nato.int/media-centre/news/2025/nato-showcases-capabilities-of-uncrewed-vessels-with-demonstrations-in-the-baltic-sea
[13] Saildrone '' Unmanned, Unmatched: Saildrone Boosts Allied Awareness in NATO Task Force X Baltic Demo'' 7 Jul 2025 https://www.saildrone.com/news/unmanned-unmatched-saildrone-boosts-allied-awareness-in-nato-task-force-x-baltic-demo
[14] NATO – ACT '' Task Force X Baltic and the Future of NATO Maritime Vigilance'''18 June 2025 https://www.act.nato.int/article/tfxb-future-nato-maritime-vigilance/

maritime activity enhancing detection and tracking of potential threats to undersea infrastructure.[15]

This system undergirds the decision-making processes for UUV deployment and threat response, linking observed seabed activity to actionable intelligence.

The integration of UUVs into NATO's operations has profound implications, particularly within the SACEUR (Supreme Allied Commander Europe) area of responsibility. The SACEUR AOR includes geopolitically sensitive maritime regions such as the Baltic Sea, the North Sea, and parts of the Mediterranean and Arctic areas critical for undersea infrastructure. Persistent UUV deployments in these zones enhance surveillance of seabed assets, provide early detection of threats, and help NATO build a credible denial-based deterrence posture.[16]

Moreover, UUVs offer strategic advantages in command-and-control of Denied and Degraded Environments (C2D2E). Since underwater conditions often disrupt traditional communication channels, UUVs with onboard autonomy and AI can classify and respond to anomalies on their own.

On the fleet level, UUVs, USVs, and other uncrewed systems are reshaping what "future NATO fleets" will look like. Rather than relying solely on large, crewed warships and submarines, future naval forces will operate as hybrid task groups: manned platforms commanding and coordinating distributed swarms of unmanned systems.[17]

Another critical enabler for UUV integration is NATO's Allied Underwater Battlespace Mission Network (AUWB-MN). In September 2025, NATO formally launched this mission network, led by a Saab-led consortium (MANGROVE), to create a reference architecture and a test & reference environment for integrating crewed and uncrewed systems above, on, and below the water. The mission network will facilitate secure, rapid information exchange and multi-domain integration.

AUWB-MN is specifically designed to operate in contested underwater environments, where communications may be degraded or denied. Its architecture supports various communication modes acoustic, optical, radio (surface relay), and satellite and integrates autonomy so that uncrewed systems can continue their mission when disconnected. This resilience enables continued operations even when command links are disrupted, a key capability in undersea warfare.[18]

OPEX: REPMUS-DYNAMIC MESSENGER 2025 AND BOMA

NATO's maritime operational commanders are being forced to look toward unmanned autonomous systems to offset critical capability gaps, gaps created by an ever-expanding multi-domain area of operations, minimal manning, and scarce availability of resources.

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[15] NATO – ACT '' NATO's Mainsail: Enhancing the Security of Critical Undersea Infrastructure through Advanced Data Exploitation"'221 Jan 2025 https://www.act.nato.int/article/natos-mainsail/

[16] Naval Technology – Chris Lo ''Persistent littoral surveillance: automated coast guards" https://www.naval-technology.com/features/featurenavy-persistent-littoral-surveillance-auvs-uuvs/?cf-view

[17] 18th ICCRTS - Kevin Chan '' Coping with Degraded or Denied Environments in the C2 Approach Space'' https://apps.dtic.mil/sti/tr/pdf/ADA588003.pdf

[18] Defence Industry Europe – Lukaasz Pris '' Saab-led MANGROVE consortium chosen by NATO to develop Allied Underwater Battlespace Mission Network"'19 Sep 2025 https://defence-industry.eu/saab-led-mangrove-consortium-chosen-by-nato-to-develop-allied-underwater-battlespace-mission-network/

However, in order to make a meaningful impact toward future proofing stability in the maritime domain, NATO looks past the surface level trade-show-style demonstrations.

The experimentation and validation of UUV/USV concepts are not limited to just Task Force X. NATO's REPMUS (Robotic Experimentation and Prototyping using Maritime Uncrewed Systems) exercises, often held with the Dynamic Messenger series, provide a testbed for UUVs, autonomous behaviours, sensor integration, and interoperability. [19]

NATO's flagship platform for unmanned maritime experimentation is REPMUS (Robotic Experimentation and Prototyping with Maritime Unmanned Systems). In 2025, REPMUS and the major exercise Dynamic Messenger were integrated, combining experimentation with operational training. Over 300 unmanned platforms participated, focusing on realistic scenarios such as jamming, dummy mines, and anomaly detection.[20]

For REPMUS and DYMS, Troia may be geographically distant from the front lines of the war in Ukraine, but the cost of the battle raging in Eastern Europe is never far from the minds of Alliance leaders. Since Russia invaded Ukraine in February 2022, the US has directed over $75B in humanitarian, financial, and military support to Ukraine, 'almost 10% of the entire annual US defence budget and the largest foreign investment in a European country since the Marshall Plan post-World War II. Meanwhile, European Union institutions have donated a combined amount of almost $100B.[21]

Another key operational development is Bold Machina (BOMA), run by NATO Special Operations Forces (SOF). In these exercises, SOF units deploy, adapt, and even build uncrewed maritime vehicles to conduct reconnaissance, clandestine approaches, and resupply missions. While detailed, up-to-date open-source information on all BOMA iterations is limited, earlier publicly documented versions emphasize modularity, rapid prototyping, and SOF engagement with unmanned systems.[22]

STANDARDIZATION

STANAG 4817 is a NATO standard developed to ensure that underwater communication systems particularly those used by UUVs, underwater sensors, and manned submarines to operate in a secure and interoperable manner across all Allied navies. As UUVs become more common in operational fleets, the need for a unified communication standard is critical. Without a shared protocol, each nation's unmanned systems risk becoming isolated, unable to coordinate, exchange data, or contribute to a unified operational picture.

The primary strength of STANAG 4817 is that it harmonizes acoustic communication architectures, which remain the backbone of underwater connectivity. Acoustic communication is inherently challenging: it is slow, affected by temperature and salinity, and vulnerable to interference. STANAG 4817 addresses these obstacles by defining signal

[19] Naval News ''Rheinmetall deployed 'Mission Master' during REPMUS'' 18 Nov 2025 https://www.navalnews.com/naval-news/2025/11/rheinmetall-deployed-mission-master-during-repmus/
[20] NATO – MARCOM '' NATO advances maritime innovation and readiness through Exercise Dynamic Messenger 2025'' 29 Sep 2025 https://mc.nato.int/media-centre/news/2025/nato-advances-maritime-innovation-and-readiness-through-exercise-dynamic-messenger-2025
[21] Council Foreign Relations – Jonathan Masters and Will Merrow '' Here's How Much Aid the United States Has Sent Ukraine'' 15 Jul 2025 https://www.cfr.org/article/how-much-us-aid-going-ukraine
[22] SWZ Maritime – Mariska Buitendjik '' NATO tests underwater sensors to protect CUI'' 10 Jan 2025 https://swzmaritime.nl/news/2025/01/10/video-nato-tests-underwater-sensors-to-protect-cui/

structures, transmission methods, and data-handling procedures that allow UUVs from different countries and manufacturers to cooperate and communicate reliably.

For future fleets, this standard is essential for enabling combined and joint operations. NATO's maritime operations rely on integration whether it is mine countermeasures, anti-submarine warfare, or seabed protection. If UUVs cannot exchange mission data, sensor information, or status updates, their value is dramatically reduced.

In contested environments, where communication may be degraded or disrupted, the robustness of STANAG 4817 helps maintain mission continuity by ensuring messages are transmitted in a consistent and resilient format. As fleets evolve toward hybrid architectures of manned and unmanned platforms, STANAG 4817 becomes a foundational pillar supporting cross-platform coordination, improving situational awareness, and making UUVs a trusted operational tool for every NATO member.[23]

STANAG JANUS 4748 is NATO's first globally recognized digital underwater communications protocol designed specifically to allow different underwater devices UUVs, submarines, sensors, and communication gateways to "speak a common language." JANUS is revolutionary because it solves one of the most persistent problems in underwater operations: every nation and manufacturer historically used proprietary acoustic formats, making interoperability nearly impossible. With JANUS, any underwater vehicle that implements this open standard can exchange basic messages with any other device, regardless of origin.

JANUS also supports safer deconfliction. As UUV traffic increases in busy operational areas, the ability for unmanned vehicles to broadcast presence, intent, or emergency signals prevents collisions and misunderstandings. Future fleets will rely on these features as UUV density grows.[24]

Perhaps the most transformative aspect is JANUS's role in enabling networked maritime robotics. Future fleets will depend heavily on distributed swarms, autonomous relays, and cross-domain sensing networks. For NATO's future fleets, JANUS is therefore not just a technical standard; it is the foundation for a fully interoperable underwater digital ecosystem.

Without those underwater communication or onboard collision avoidance systems, careful waterspace management was still required to ensure there were no underwater collisions. Unmanned systems that could reduce-risk-human operators while providing similar sensor performance were considered state of the art over the last 20 years, but, in the next 20 years, unmanned systems will need a degree of autonomy that can also significantly reduce operator workload. Burden-sharing across NATO is uneven: not all Allies have the same industrial base or technical capacity, and interoperability standards must be widely adopted.[25]

[23] JANES ''STANAG 4817 completes NATO's MUS jigsaw'' 17 Oct 2025 https://www.janes.com/osint-insights/defence-and-national-security-analysis/stanag4817-nato-maritime-unmanned-systems-jigsaw
[24] ResearchGate – Joao Alves '' Moving JANUS forward: A look into the future of underwater communications interoperability'' Dec 2016 https://www.researchgate.net/publication/311545430_Moving_JANUS_forward_A_look_into_the_future_of_underwater_communications_interoperability
[25] CSIS – Audrey Aldisert ''Strengthening NATO Starts with Fixing Its Industrial Base'' 24 Jun 2025 https://www.csis.org/analysis/strengthening-nato-starts-fixing-its-industrial-base

UUVS AND FUTURE FLEET

UUVs are rapidly becoming indispensable assets for the future fleets of NATO and its member states. As the maritime battlespace becomes more complex, contested, and technologically advanced, UUVs provide a transformational capability that traditional crewed platforms alone cannot achieve. Their importance stems from several converging operational, strategic, and technological factors.

First, UUVs dramatically expand the reach, persistence, and survivability of naval forces. Unlike manned submarines or surface ships, UUVs can operate for extended periods without fatigue, risk to personnel, or the logistical footprint associated with crewed vessels. They can loiter silently on the seabed, conduct long-duration patrols, and collect high-resolution data on undersea activity enhancing NATO's persistent surveillance and early warning posture. This persistent presence is essential for monitoring critical seabed infrastructure such as pipelines, undersea cables, and sensor networks, which are increasingly targeted by adversaries.[26]

Second, UUVs give future fleets a scalable and cost-effective force multiplier. Instead of relying on a small number of expensive submarines or specialized ships, navies can deploy large numbers of low-cost autonomous vehicles that act as distributed sensors and effectors. This allows NATO fleets to cover wider geographic areas, complicate adversary decision-making, and generate deterrence through uncertainty: an adversary must assume they are being monitored, even if no manned platforms are present.[27]

Third, UUVs enhance survivability and resilience in C2D2E. Their onboard autonomy allows them to operate even when GPS, satellite communications, or acoustic links are disrupted. Future fleets will rely on these autonomous behaviors to maintain mission continuity during cyberattacks, jamming, or adversarial interference ensuring NATO retains underwater situational awareness even in contested conditions.[28]

Finally, integrating UUVs into future fleets enables the transition to hybrid, multi-domain naval operations. Crewed ships will increasingly act as command nodes, coordinating swarms of UUVs and USVs that extend their sensing, striking, and protective reach. This shift powered by AI, automation, and resilient command-and-control architectures will define the next era of NATO maritime dominance.[29]

In essence, UUVs are not an enhancement to future fleets they are a necessity for maintaining operational advantage, ensuring deterrence, and securing the undersea domain in an era of strategic competition.

Future naval fleets face a rapidly changing operational environment defined by deeper waters, more sophisticated adversaries, and the increasing strategic importance of the seabed. Underwater Unmanned Vehicles (UUVs) are emerging as essential tools for modern

[26] JANES - Nicholas Fiorenza ''Helsing offers SG-1 Fathom underwater gliders to increase NATO's maritime situational awareness'' 15 Jul 2025 https://www.janes.com/osint-insights/defence-news/c4isr/helsing-offers-sg-1-fathom-underwater-gliders-to-increase-natos-maritime-situational-awareness

[27] Breaking Defence - Justin Katz '' Defense Innovation Unit seeks undersea drone capable of 'long-range' payload deployment'' 17 Apr 2025 https://breakingdefense.com/2025/04/defense-innovation-unit-seeks-undersea-drone-capable-of-long-range-payload-deployment/

[28] U.S. Naval Institute - Chief Petty Officer John Minor '' The Navy Must Decentralize Information Warfare'' Jan 2022 https://www.usni.org/magazines/proceedings/2022/january/navy-must-decentralize-information-warfare

[29] JANES – Tom Barton '' Helsing acquires UUV maker Blue Ocean'' 16 Oct 2025 https://www.janes.com/osint-insights/defence-news/industry/helsing-acquires-uuv-maker-blue-ocean

navies because they offer capabilities that human-crewed vessels cannot match economically, safely, or technologically.[30]

One of the clearest drivers for UUV integration is the shifting nature of undersea competition. Adversaries are investing in quiet submarines, seabed-deployed surveillance networks, and covert systems designed to monitor naval activities. UUVs give future fleets the ability to counter these developments by operating in areas where submarines or divers cannot safely go such as ultra-deep trenches, narrow chokepoints, and hazardous minefields. Their small acoustic signatures and reduced detectability allow them to patrol discreetly, gather intelligence, and map adversary behavior without escalating tensions.

Another major advantage is the ability of UUVs to conduct continuous undersea presence. Traditional submarines and patrol ships require rotation, maintenance, and large crews. UUVs, however, can remain submerged for weeks or months depending on their power systems. This endurance allows navies to maintain constant awareness of maritime approaches, deep-sea installations, or sensitive areas without tying up manned platforms. This persistent presence is especially useful for monitoring zones that are too remote or politically sensitive for conventional naval forces.

Finally, UUVs bring strategic resilience. In a conflict where cyberattacks, satellite disruption, or anti-ship weapons threaten surface and subsurface vessels, UUVs offer distributed survivability. They allow missions to continue even when traditional communications or command systems are compromised.[31]

CONCLUSION

The seabed is now a critical battlespace. NATO's security and prosperity depend on undersea infrastructure that is increasingly at risk. UUVs provide a powerful, cost-effective, and scalable solution for protecting this domain. Integration of UUV technology into NATO's force structure is not merely an experiment, it signals a fundamental transformation. As NATO fleets evolve, unmanned systems will become indispensable, helping the Alliance maintain undersea dominance in a complex and contested future. UUVs become fundamental reshaping undersea deterrence ensuring the Alliance maintains superiority in an increasingly contested and strategically vital domain.

[30] SS National Lab - Chief Operating Officer Francisco Córdova ''Beyond the ISS: A Unified Vision for Crewed and Uncrewed Platforms'' 29 Sep 2025 https://issnationallab.org/iss360/beyond-the-iss-a-unified-vision-for-crewed-and-uncrewed-platforms/
[31] Georgetown University Wargaming Society – David Manley '' Cobalt Rocks: Wargaming Seabed Operations'' 31 May 2025 https://www.youtube.com/watch?v=QBr8bXwYsNU