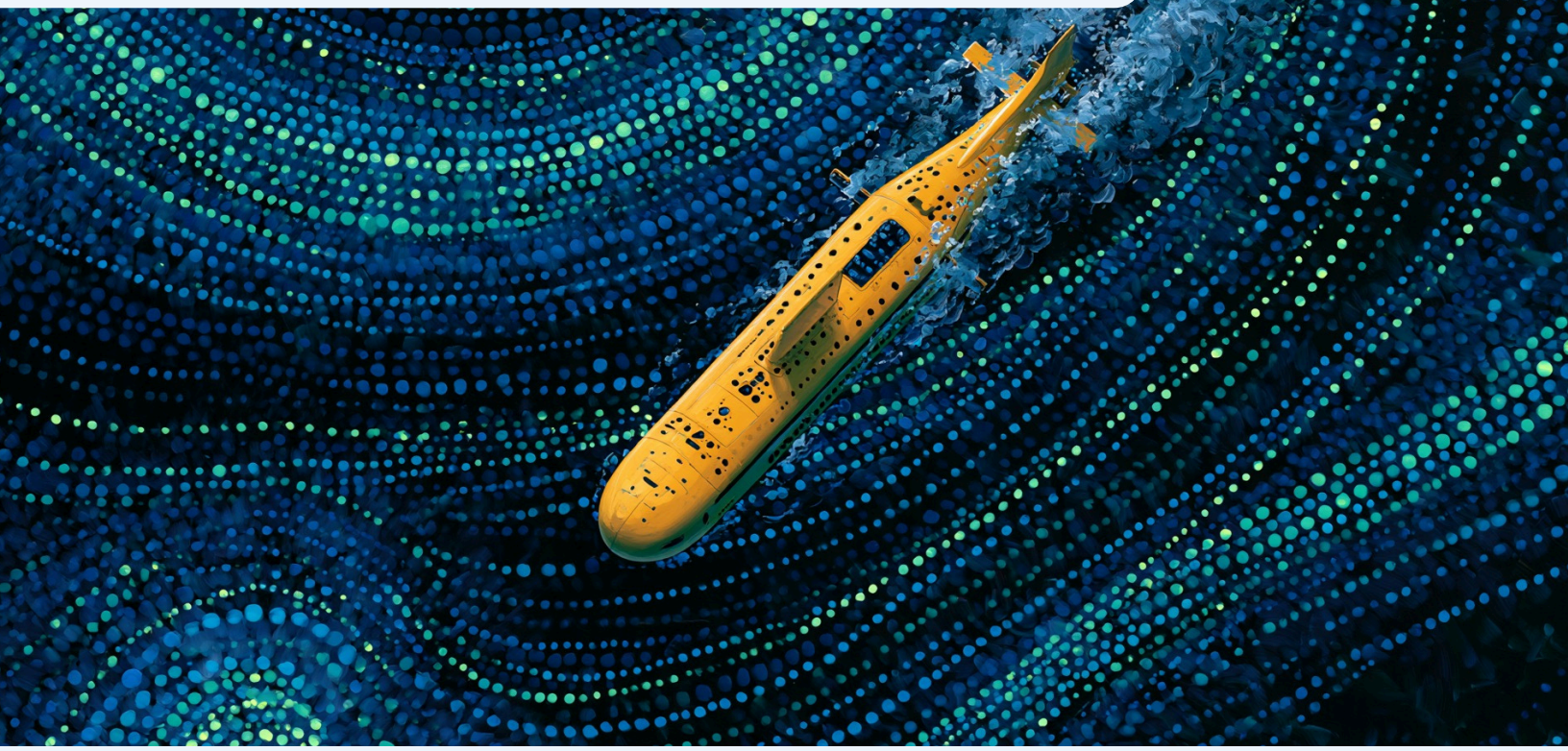
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Australia-India Underwater Domain Awareness (UDA) Cooperation

Uncrewed Underwater Vehicles (UUVs)

Dr Prakash Gopal
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UWA DEFENCE & SECURITY

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THE UNIVERSITY OF WESTERN AUSTRALIA

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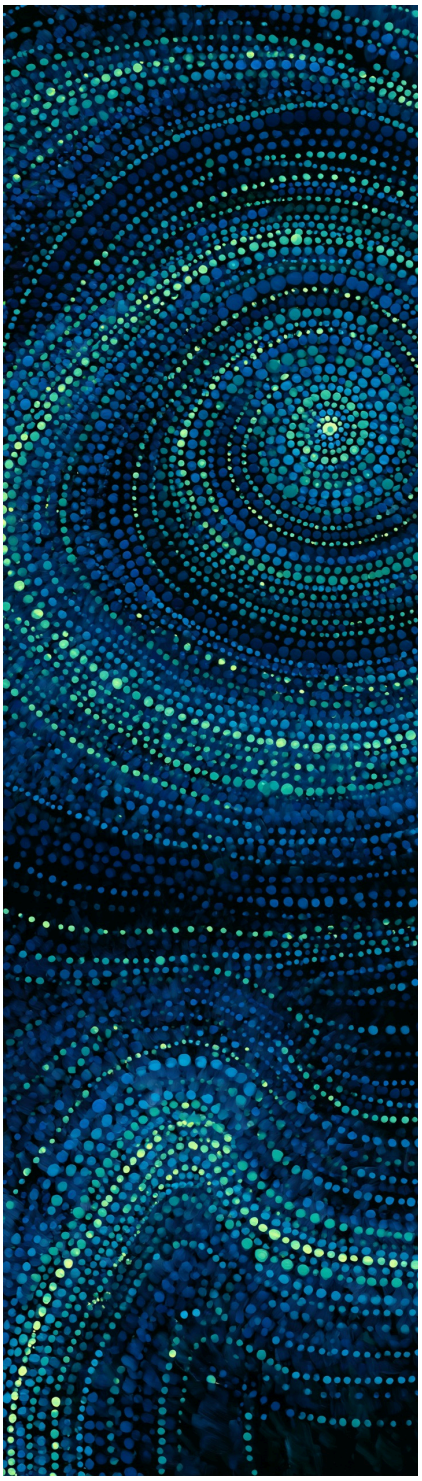
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Prakash Gopal is a former Indian naval officer with over two decades of experience in maritime security operations, policy and strategy. He was a Research Fellow at the National Maritime Foundation, India, from 2016-18. In 2018, Prakash took up a PhD position at the Australian National Centre for Ocean Resources and Security, University of Wollongong. His research examined littoral security and developed a framework for securing critical infrastructure in littoral areas. Prakash completed his PhD in April 2023.



Rear Admiral Puneet Chadha (Retd)

Puneet Chadha served the Indian Navy with distinction across operational, training, and administrative roles as a Flag Officer.

An experienced naval leader, he held key appointments including Deputy Commandant and Chief Instructor at the Indian Naval Academy, where he oversaw the training of over 1,500 cadets, and Flag Officer Commanding Tamil Nadu and Puducherry Naval Area, responsible for coastal defence and managing naval assets and personnel in the region.

He also served as Chief Staff Officer (Operations) at Eastern Naval Command, overseeing operations and Humanitarian Assistance and Disaster Relief missions across the eastern seaboard and adjoining maritime spaces. At the national level, as Additional Director General at NCC Headquarters, he managed the financial and administrative functions of one of the world's largest uniformed youth organisations, handling a budget of approximately Rs 2,500 crore.



ABOUT THE PROGRAM

This program represents a significant Australia–India initiative to strengthen cooperation in Underwater Domain Awareness (UDA) across the Indo-Pacific. Delivered jointly by the UWA Defence and Security Institute (DSI) and the Council for Strategic and Defense Research (CSDR), the initiative brings together expertise from academia, industry, and government to advance practical collaboration in maritime security.

Designed as a structured, multi-engagement series, the program seeks to deepen mutual understanding of capabilities and intentions, identify shared priorities, and generate tangible policy outcomes. It explores critical dimensions of Underwater Domain Awareness, including maritime domain understanding, anti-submarine warfare, uncrewed underwater systems, undersea search and rescue, and deep-sea awareness, recognising the strategic importance of the undersea environment to regional stability.

Underwater Domain Awareness refers to the capability to observe, detect, and assess underwater activities across oceans, coastal regions, and inland waterways, enabling comprehensive situational awareness of the undersea domain. As close maritime partners, Australia and India share a strong interest in enhancing cooperation in this area to support a secure, resilient, and rules-based Indo-Pacific, and to further strengthen the Australia–India Comprehensive Strategic Partnership.

This 24-month initiative is supported by the Australian Department of Foreign Affairs and Trade through the Australia–India Strategic and Technology Policy Initiative (SATPI). This report represents the third of five publications, as well as a white paper that will be generated from the high-level discussions and collaboration throughout the program. Through this collaboration, UWA DSI and CSDR aim to contribute meaningful policy insights, strengthen institutional linkages, and advance sustained maritime cooperation between Australia and India.



EXECUTIVE SUMMARY

This report examines the development of uncrewed underwater vehicles (UUVs) in Australia and India and the case for bilateral cooperation in the undersea domain. It argues that the two national ecosystems are complementary rather than competitive, and that a phased, capability-driven partnership that begins with benign and civil applications is more likely to endure than early collaboration in sensitive undersea warfare technologies.

The two countries have organised their innovation bases differently, and the difference is the point. Australia's UUV ecosystem is coherent in policy and effective at moving systems from prototype into service, but it is narrow and concentrated around a small number of programs and industrial actors. India's is broad and institutionally diverse, with substantial manufacturing depth, but uneven in technological maturity and still dependent on imported high-end subsystems.

That asymmetry is what makes cooperation worth pursuing. Australia's strengths in operational experimentation, systems engineering and high-readiness integration meet India's strengths in industrial scale, software-intensive innovation and engineering capacity. Mine countermeasures, hydrography, seabed mapping and underwater ISR offer the most practical early ground. Legal ambiguity over the status of uncrewed systems under the Law of the Sea, alliance sensitivities and unresolved intellectual property arrangements remain the binding constraints.

The report proposes a framework built on four concurrent pillars: operational cooperation, technological collaboration, industrial partnership and institutional coordination. It sequences them across near-term, medium-term, and long-term horizons and sets out eleven policy recommendations to advance them.

INTRODUCTION

The Indo-Pacific strategic environment is increasingly defined by the centrality of the maritime domain to national security and economic resilience. States across the region depend heavily on sea lines of communication to secure energy supplies, sustain trade flows, and access critical resources. However, this dependence is accompanied by progressively complex challenges, including growing threats to freedom of navigation and contested access to maritime resources.

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Intensifying geopolitical competition, both within the region and beyond, has further exacerbated these pressures, contributing to a deterioration in the overall strategic climate. In this context, the notion of a "free and open Indo-Pacific" is not a rhetorical aspiration but an urgent imperative that underpins global stability and prosperity. As maritime contestation deepens, ensuring transparency, security, and sustained access to the commons has become a priority for regional actors seeking to defend their interests while avoiding escalation.

Against this backdrop, the growing relevance of uncrewed and autonomous systems in enhancing maritime security—particularly for domain awareness—is widely acknowledged. As operational environments become more complex, states confront significant constraints in terms of financial resources, personnel, and long-term capability sustainment when developing conventional platforms. Uncrewed systems offer an asymmetric advantage in this regard, as demonstrated in recent conflicts such as the Russia–Ukraine war and ongoing engagements in the Middle East, where they have proven both effective and adaptable. Although these systems cannot fully substitute for crewed platforms, they serve as relatively low-cost and, to some extent, expendable force multipliers that enhance the reach, persistence, and effectiveness of traditional capabilities.

This report focuses on the development of Uncrewed Underwater Vehicles (UUVs) in Australia and India, examining the strategic drivers underpinning their adoption and the ways in which these technologies are integrated into maritime security frameworks. It further explores the opportunities and challenges for bilateral cooperation in advancing UUV capabilities and proposes policy measures to foster a robust and forward-looking collaborative framework between the two countries.

HISTORICAL AND DEVELOPMENTAL CONTEXT OF UUVs

The origins of UUV technology lie in early underwater exploration systems such as bathyspheres and primitive submersibles. Although these systems did not meet modern definitions of UUVs, they provided the foundation for later developments.

The conceptual origins of UUVs can be traced to early uncrewed underwater devices, such as torpedoes, with controlled underwater navigation and homing, to enable autonomous delivery of ordnance in the underwater domain.

The development of Remotely Operated Vehicles (ROVs) in the mid-20th century allowed operators to control underwater vehicles in real time from surface platforms, enabling applications in salvage, inspection, and deep-sea exploration. This reliance on tethers imposed constraints on range, manoeuvrability, and operational flexibility, thereby motivating the transition toward autonomous systems.[1]

Advances in onboard computing, inertial navigation, and acoustic positioning, in the 1970s and 1980s, saw the development of Autonomous Underwater Vehicles (AUVs) capable of executing pre-programmed missions with limited external control over greater distances and durations.[2] These technological advances also facilitated a broader range of applications, including oceanography and environmental monitoring.

UUVs started entering mainstream naval operations in the late 20th century. This transition was closely linked to the evolution of naval doctrine toward distributed and network-centric warfare.[3] The initial utilisation was in specialised missions such as mine countermeasures (MCM) and hydrographic surveys. This has expanded to include intelligence, surveillance and reconnaissance (ISR), anti-submarine warfare (ASW), and seabed operations. They can act as force multipliers by extending the reach and persistence of naval forces in contested[4] environments. The evolution of UUVs from tethered systems to networked autonomous platforms is shown in Table 1.

While the early development of UUVs was driven by advances in technologies, the evolution is increasingly being shaped by operational and strategic considerations of distributed, resilient and covert underwater capabilities reflecting the broader transformation in maritime operations from platform-centric to networked systems. The advances in AI and data processing will further accelerate this shift.[5]

Table 1: Developmental Evolution of UUVs

Phase	Early Uncrewed Systems	Remotely Operated Vehicles (ROVs)	Early Autonomous Systems	Operational AUVs	Present UUVs
Period	Pre 1950s	1950s-1970s	1970s-1990s	1990s-2010s	2010s-Present
Characteristics	• No real-time control or autonomy • Pre-programmed course and depth	• Tethered Systems with real time human control • Dependent on umbilical for power, communication etc	• Pre- programmed missions • Limited autonomy and decision making	• Increased endurance, reliability and payload capacity • Multi-mission capability (MCM, ISR, Oceanography) • Improved navigation and integration of advanced sensors	• High autonomy with adaptive decision making • Integration in networked & swarm operations
Technological Drivers	• Basic gyroscopes & depth keeping mechanisms	• Advances in electro-hydraulic actuators • Tethered fibre-optic/ electrical umbilicals • Development of sonar & television cameras	• Onboard computing and stored-pgme control • Inertial Navigation Systems (INS) and acoustic beacons • Early improvements in battery technology	• Advanced INS with Doppler Velocity Log (DVL) • Lithium-ion & fuel-cell batteries • Modular payload design and underwater communications	• Artificial Intelligence (AI) & machine learning (ML) for autonomy • Low-power high-density batteries & AIP systems • Acoustic/optical communications & network-centric architectures • Buoyancy controlled systems
Roles	• Basic Torpedoes	• Deep-Sea Exploration • Salvage • Inspection • Explosive Ordnance Disposal (EOD)	• Scientific surveys • Seabed mapping	• Ocean Survey • Military missions	• Persistent ISR • ASW Support • Seabed warfare
Examples	• Spar torpedo (1866)	• Hughes Cable-Controlled Underwater Recovery Vehicle (CURV) – (US, 1960s)	• REMUS 600 (US, 1980s)	• HUGIN 1000 (Norway, 2000)	• Bluefin-21 & ORCA (US) • Slocum G3 Glider and Blue Ocean SG-1

STRATEGIC AND OPERATIONAL UTILISATION OF UUVs IN INDIA AND AUSTRALIA

India's Strategic Context

The contemporary maritime environment is shaped by sustained competition below the threshold of armed conflict. Activities such as intelligence gathering, seabed mapping, and covert surveillance occur routinely, often designed to shape the operational environment without triggering escalation. Environmental variability affects acoustic propagation and limits sensing effectiveness, while the inherent opacity of the medium allows actors to operate with a degree of anonymity. The latest Indian Navy Maritime Doctrine 2025 (NSP 1.1) explicitly recognises the underwater dimension as an integral part of Maritime Domain awareness (MDA).

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> "MDA is inherently multi-domain, taking into ambit the sea (surface and under sea) and airspace, as well as threats emanating from land, space and cyberspace, not only for generation of an integrated picture for maritime battlespace transparency but also to address traditional issues and illegal activities such as Illegal, Unreported and Unregulated (IUU) fishing, pollution, piracy, contraband smuggling, dark shipping and human trafficking/ irregular migration etc. Underwater Domain Awareness (UDA), is a part of MDA and refers specifically to the complex and challenging underwater domain with its multiple stakeholders."[6]

India's maritime security environment is shaped by a convergence of conventional, grey-zone, and non-traditional threats, many of which manifest below the surface. The broader strategic setting highlights the significance of maritime space, including the Indian Ocean, as a critical arena of interaction and competition.

A central concern is the increasing presence of extra-regional forces, particularly submarines capable of operating covertly over extended periods. Detecting and tracking such platforms remains a persistent challenge, especially in environments where acoustic conditions are variable and complex.



The Shen Hai Yi Hao, one of four Chinese survey vessels spotted in the Indian Ocean in 2025.
Source: South China Morning Post

Grey-zone activities further complicate the picture. These include unacknowledged surveys, seabed mapping, and the deployment of uncrewed systems designed to operate below the threshold of conflict. Their ambiguous nature complicates attribution and necessitates sustained monitoring rather than reactive response.

The vulnerability of seabed infrastructure introduces an additional dimension. Maritime systems underpin economic activity to a significant degree, with doctrinal emphasis noting that a substantial proportion of trade and data flows through maritime channels, including submarine cables.[7]

Non-traditional threats, including illegal fishing and trafficking, add to the operational burden by requiring persistent surveillance across wide areas. At the same time, technological developments are lowering the barriers to entry for sophisticated maritime operations, enabling a wider range of actors to operate below the surface.

The strategic importance of UUVs for India is closely linked to this need for enhanced underwater domain awareness (UDA) in the Indian Ocean Region, where increasing submarine activity and seabed infrastructure vulnerabilities

necessitate persistent surveillance and data acquisition capabilities. Technological advances in autonomy, sensing, and data processing enable systems to operate independently, and improvements in battery and sensor technologies yield extended periods of operation, thereby supporting distributed and networked approaches to maritime operations.

Taken together, these dynamics create a security environment characterised by persistence, ambiguity, and multi-layered challenges—conditions that demand continuous and distributed monitoring. UUVs enhance these capabilities, particularly in littoral and choke-point environments in the Indian Ocean Region. Therefore, MCM UUVs for harbour and coastal security, ISR platforms for persistent surveillance and seabed systems for critical infrastructure protection will be the developmental priority.

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Australia's Strategic Context

Australia possesses the world's third-largest maritime jurisdiction, encompassing an extensive marine estate of approximately 13.86 million square kilometres, which is almost twice the size of its landmass.[8] This includes an exclusive economic zone (EEZ) of roughly 10 million square kilometres, over which Australia exercises sovereign rights on living and non-living natural resources. Stretching nearly 60,000 kilometres, Australia's coastline ranks among the longest globally, with around 90 per cent of the population living within 50 kilometres of the sea.[9] In addition, Australia's vast search and rescue region covers about 53 million square kilometres, or roughly one-tenth of the Earth's surface.[10] With strategic interests spanning the Indian, Pacific, and Southern Oceans, as well as the Timor, Arafura, and Coral Seas to its north, Australia's national security depends heavily on maintaining secure maritime borders and supporting a stable regional and global maritime order.

Australia's insular geography means that most national security vulnerabilities originate in the maritime domain, increasingly complemented by risks in cyberspace. The so-called "sea-air gap" acts both as a natural defensive barrier and as the primary conduit through which threats may emerge.[11] Consequently, safeguarding Australia's security largely depends on managing and protecting this maritime environment.

The 2024 National Defence Strategy highlighted an increasingly complex threat landscape, marked by both military and non-military competition across economic, diplomatic, and strategic domains. This competition is accompanied by a significant regional military build-up, conventional and unconventional, occurring with limited transparency or reassurance.[12] Such developments are unfolding closer to Australia than in the past, heightening the risk of miscalculation or escalation that could lead to major conflict. The 2026 National Defence Strategy further emphasises the transformative role of technological advancement, noting its "revolutionary promise" while also recognising its capacity to generate new forms of threat.[13]

Australia's maritime interests are therefore multifaceted, centred on protecting territorial integrity, securing trade and supply routes, safeguarding natural resources, and preserving marine ecosystems. Given the interconnected nature of the maritime domain, this requires addressing a diverse array of challenges, including transnational maritime crime, geopolitical rivalry, military encroachment, illegal, unreported and unregulated (IUU) fishing, climate-related impacts, and broader maritime instability.[14] Additionally, emerging concerns include cyber and technological vulnerabilities, grey-zone activities, and hybrid threats that blur the line between peace and conflict. Of particular concern is the prospect of economic warfare at sea below the threshold of armed conflict. This could involve attacks on undersea critical infrastructure, cyber-enabled disruptions to navigation systems, and interference with port operations or logistics networks. These threats are neither singular nor isolated; they may occur simultaneously, directly or indirectly, compounding the already complex and often unregulated maritime environment.

Australia's capacity to assert sovereignty over its territorial sea, and to exercise sovereign rights within its EEZ, depends on effective maritime security measures. The maritime domain presents a broad spectrum of challenges, ranging from great power competition to environmental pressures and criminal activity. While the vastness of Australia's waters provides strategic depth, it also creates inherent vulnerabilities that require sophisticated, multi-layered responses, supported by advanced technologies.

Regulatory and Legal Frameworks for UUV Operations

UUVs are increasingly central to maritime operations across scientific, commercial, and military domains, either as ROVs which remain tethered to a host platform, or as AUVs which operate independently using onboard sensors and pre-programmed instructions. Despite their expanding role, UUVs do not possess a clearly defined legal identity under the United Nations Convention on the Law of the Sea. While the Convention refers to "ships," "submarines," and "other underwater vehicles," it does not clarify whether uncrewed systems fall within these categories. [15] The absence of a clear legal category complicates the application of maritime law to UUV operations and leads to states treating UUVs as either vessels, military systems, or deployable equipment depending on context.[16]

Divergent state interpretations are particularly evident in the EEZ. Coastal states such as India and China tend to require prior consent for survey and data collection activities, especially where such activities may have strategic implications, whereas some, like the United States, maintain that military surveys fall within the scope of lawful

freedom of navigation. These differences are reflected in operational incidents like the 2016 South China Sea incident involving USNS *Bowditch* when a UUV (ocean glider) deployed from the vessel was seized by a Chinese naval unit. The United States protested the action as unlawful interference with a sovereign immune platform, while China justified its actions on grounds of navigational safety and security before returning the device.[17] This incident demonstrates that legal ambiguity in the EEZ is not merely theoretical. It is actively expressed through operational behaviour, particularly in activities involving underwater data collection. A similar pattern is visible in the Indian Ocean region, where India has raised concerns over the deployment of Chinese research vessels and underwater gliders within its maritime zones. Such activities, while often presented as scientific, are viewed with caution due to their potential dual-use applications in areas such as submarine detection and seabed mapping.

Unlike AUVs, ROVs are physically tethered to a host platform and controlled in real time by human operators and are, therefore, treated as equipment or extensions of the deploying vessel, bringing them more clearly within established legal frameworks under UNCLOS.

The legal and operational challenges associated with UUV deployment in peacetime or scenarios short of armed conflict become more pronounced in maritime chokepoints where they are either governed by the regime of transit passage or Archipelagic Sea Lanes Passage (ASLP).[18] However, these provisions are framed around identifiable platforms and do not explicitly address autonomous underwater systems. While transit may be defensible in legal terms, persistent or covert UUV operations are likely to attract intervention if detected.

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The impact of legal ambiguities on UUV operations varies across operational roles. ISR and Surveillance roles face the highest degree of legal constraint. Scientific and survey operations fall within the marine scientific research regime and require coastal state consent in the EEZ, which remains the principal zone of contestation. Underwater data collection, irrespective of its stated purpose, is always viewed with suspicion and triggers security-driven responses. These realities must be factored in when planning the deployment of UUVs.

Operational Concepts for UUV Employment

The effectiveness of UUVs lies in their integration into coherent operational constructs. The contemporary threat environment necessitates persistent, distributed, and networked approaches in which UUVs function as integral components of a broader maritime mosaic.[19]

Persistent underwater awareness can be achieved through layered surveillance architectures combining platforms with differing endurance and sensing capabilities. Long-endurance systems provide continuous baseline monitoring across wide areas, while other systems are dynamically tasked for focused surveillance. This layered construct enables continuous detection, classification, and tracking cycles, significantly enhancing situational awareness.

The integration of uncrewed systems with crewed platforms enables distributed operations in which sensing is decoupled from decision-making. Submarines and surface vessels can deploy UUVs as forward sensors, or use UUVs deployed by other means, extending their operational reach while maintaining standoff distances. This approach enhances survivability while increasing operational flexibility.

Submarine-launched UUV operations further extend these capabilities by enabling covert deployment for reconnaissance, seabed mapping, and sensor placement. Such operations allow underwater platforms to act as distributed nodes within a wider operational network.

Cross-domain integration enhances effectiveness by linking subsurface systems with surface and aerial platforms. This reflects a broader shift towards distributed maritime operations in which sensing, processing, and response functions are geographically dispersed but functionally integrated.

Air deployment provides the ability to rapidly position UUVs across large distances, enabling responsive operations in dynamic environments. These systems can establish surveillance coverage that may later be reinforced by longer-endurance platforms, if required.

Distributed deployment of multiple systems enhances scalability and resilience. Such approaches ensure that the degradation or loss of individual platforms does not significantly affect overall capability and are particularly relevant in contested environments.

The seabed is emerging as a critical operational domain. The requirement to monitor and protect infrastructure, combined with the potential for covert activity, necessitates capabilities that can operate persistently at depth. UUVs are well suited to these roles, providing both monitoring and mapping functions.

CURRENT STATE ASSESSMENT

Analytical Framework

The evolution of UUVs from the early ROVs to highly capable AUVs with advancements in technology necessitates an analytical framework that integrates technological, operational, and strategic dimensions moving beyond platform-centric thinking to a systems-of-systems perspective to enable better procurement/developmental decisions and doctrinal clarity in UUVs role in underwater warfare.

Dimension	What it covers
Functional Roles	This dimension classifies UUVs by their mission profiles across military and civilian domains. Military roles include Intelligence, Surveillance, and Reconnaissance (ISR), Mine Countermeasures (MCM), Anti-Submarine Warfare (ASW) support, seabed warfare/ infrastructure monitoring and payload delivery.[20] Civilian roles include oceanographic research, offshore energy inspection, environmental monitoring, and underwater archaeology.[21]
Platform Size & Design	Size and design influence the operational capability and deployment logistics of UUVs.[22] The UUVs can be classified based on platform type and size. Based on their mode of operation, they can be classified as ROVs (tethered, human-in-the-loop), AUVs (pre-programmed autonomy) and hybrid systems (optionally tethered/ autonomous). Based on their size, they can be classified as man-portable, lightweight, heavyweight and Extra-large UUVs (XLUUVs) with increasing payload capacity.
Autonomy Spectrum	Autonomy in uncrewed systems can be understood as a continuum reflecting varying degrees of human involvement and machine independence. In the context of UUVs, it ranges from human-in-the-loop systems to increasingly autonomous systems capable of adaptive behaviour, collaborative functioning and mission-level decision-making with advancements in Artificial Intelligence (AI) and miniaturisation of hardware. Higher levels of autonomy enable dynamic mission replanning and coordinated swarm operations.
Technological Subsystems	Key subsystems include navigation (INS, DVL), communication (acoustic and optical), power systems (batteries and fuel cells), and payloads such as sonar and imaging systems. These subsystems impose operational challenges, particularly in communication bandwidth and endurance.
Developmental Ecosystem	The developmental ecosystem spans research institutions, defence public sector units, academia and private industry. Lifecycle phases include R&D, prototyping, deployment, and sustainment.
Methodological Framework	The report employs a hybrid three-layered analytical framework consisting of chronological developmental analysis, ecosystem mapping and system-level capability assessment using Technology Readiness Levels (TRLs).[23]

INDIA'S UUV CAPABILITIES

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Scientific Foundations: Tethered Systems and Early ROV Capability (1990s–mid-2000s)

India's initial foray into underwater robotics was led by the National Institute of Ocean Technology (NIOT), Chennai. Established under the Ministry of Earth Sciences, NIOT was tasked with advancing ocean technology capabilities, including underwater systems for exploration and observation[24].

During this period, development efforts focused on tethered remotely operated vehicles (ROVs). The sensor suite of these systems was relatively basic, consisting primarily of low-light video cameras, lighting arrays, and simple environmental sensors. Some variants incorporated rudimentary manipulator arms, enabling limited intervention tasks such as sample collection or object retrieval. These early systems were typically classified as work-class or observation-class ROVs and were designed for relatively shallow to moderate depths for visual inspection of underwater structures, oceanographic research including seabed observation and underwater sampling.

Although technologically limited, these systems established foundational competencies in underwater engineering, including pressure hull design, tether management, and sensor integration. However, their reliance on surface control constrained operational flexibility and highlighted the need for autonomous systems.

Transition to Autonomous Systems (mid-2000s–2015)

Maya AUV

The development of *Maya* initiated in 2006 by National Institute of Oceanography (NIO), Goa, in partnership with Council for Scientific and Industrial Research (CSIR)and Indian Space Research Organisation (ISRO) marked a major milestone in development of indigenous AUVs[25].

Maya featured a torpedo-shaped hull (23 cm diameter, 174 cm long), modular payload architecture, and electric propulsion. Its navigation system combined inertial navigation with Doppler Velocity Log (DVL)-based velocity estimation, enabling dead-reckoning navigation with periodic acoustic correction.[26]

The platform was equipped with oceanographic sensors such as conductivity-temperature-depth (CTD) instruments, dissolved oxygen sensors, and optical imaging systems. It was deployed for coastal oceanographic surveys, environmental monitoring, and seabed mapping missions. Operationally, Maya demonstrated endurance of approximately 6–8 hours and depth capability of around 200 metres.

Later, in 2010, NIO transferred the technology to Larsen & Toubro which has re-engineered it into multiple configurations for diverse applications. It has been the catalyst for the development of follow on AUVs, *Adamya* and *Amogh*, by the company.

NIOT's Capability Centric Approach

NIOT has focused on developing AUV systems for deep sea exploration aligned with the national Deep Ocean Mission. These systems incorporated advanced sonar technologies, including side-scan and multi-beam sonar, enabling bathymetric mapping and seabed imaging. Acoustic modems provided limited underwater communication capability.

The platforms were designed for applications such as polymetallic nodule exploration, seabed mapping, and deep-sea scientific research.

Simultaneously, NIOT also worked in actively developing buoyancy-driven underwater technologies, including the Autonomous Underwater Profiling Drifter (AUPD) and the variable buoyancy engine for long duration deployments at depths exceeding 2000 metres.

However, a key limitation remained dependence on imported high-end components, particularly in navigation and sonar systems.

Commercial Expansion: Maturation of ROV Systems (2015-2020)

The emergence of companies such as EyeROV and Planys Technologies, led to the development of inspection-class ROVs tailored for industrial applications.

The *Trout* ROV, developed by EyeROV, is a compact tethered system equipped with high-definition cameras, imaging sonar, and LED lighting arrays. It features multi-thruster propulsion enabling precise manoeuvrability and operates at depths of up to approximately 300 metres. The system has been deployed for ship hull inspection, pipeline monitoring, and dam inspection, and has since received a USD 5 million order from the Indian Navy, indicating dual-use applicability.[27]

Similarly, Planys Technologies developed modular inspection systems optimised for confined environments such as ports and inland water infrastructure. These systems emphasise portability, modular payloads, and emerging integration of data analytics and image processing.

Defence Consolidation: Expansion into Tactical Systems

Naval Science and Technological Laboratory's (NSTL) legacy in torpedo development naturally positioned it as the lead Defence Research and Development Organisation (DRDO) lab for AUV development for defence applications, as the technological overlap between torpedoes and AUVs is substantial, encompassing propulsion systems, underwater navigation and hydrodynamic optimisation.

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During the late 2000s and early 2010s, NSTL extended this expertise into exploratory AUV research, focusing on autonomy, guidance algorithms, and platform stability. Collaborative research with academic institutions such as the Indian Institute of Technology Madras contributed to the development of a flatfish-shaped reconfigurable underwater vehicle (approx. 1.5 Tonne, 4 m length, 1.4 m wide) optimised for shallow-water operations. This system underwent first sea trials off Chennai in 2013.[28]

Technology Perspective and Capability Roadmaps (TPCRs) issued by the Ministry of Defence, have been central to the evolution of UUVs in the Indian Navy by providing a long-term view of anticipated capability needs for the Indian Navy. The first TPCR (TPCR-2013) referenced UUVs in relatively broad terms, reflecting the early stage of both technological maturity and doctrinal integration. TPCR-2018 expanded the scope of uncrewed systems to include AUVs for intelligence, surveillance, and reconnaissance (ISR), seabed mapping, and mine countermeasure roles. The most recent TPCR-2025 marks a significant conceptual advance, positioning UUVs not merely as standalone platforms but in cooperative operations with other uncrewed systems in the "uncrewed MCM suite" and High Endurance Autonomous Underwater Vehicle (HEAUV) for ASW and multi-mission roles. This progressive refinement of UUV requirements, from exploratory and support roles (in 2013) to integrated, networked and strategically critical capabilities (in 2025) is reflected in the development trajectory of the UUVs for defence applications.

Operational Induction of HUGIN AUV

The transition from experimental capability to operational deployment was achieved through the acquisition of the HUGIN AUV from Kongsberg Maritime, under the Survey Vessel Large program built by Garden Reach Shipbuilders & Engineers, with operational induction upon the commissioning of INS *Sandhayak* in Feb 2024.[29] This has provided the Indian Navy with a proven AUV against which indigenous systems can be evaluated.



A HUGIN AUV being deployed from the Indian Oceanographic Research Vessel Sagar Nidhi for deep-sea exploration by the National Institute of Ocean Technology (NIOT) in December 2024. Source: Defence.in
Bottom right: HUGIN AUV onboard INS Sandhayak. Source: Kongsberg

Man-Portable Autonomous Underwater Vehicle (MP-AUV) Program

Building on its foundational work, NSTL initiated the Man-Portable Autonomous Underwater Vehicle (MP-AUV) program in the mid-2010s. The system underwent iterative design and prototyping between 2018 and 2023, followed by successful field trials in Nov 25.

The MP-AUV program will deliver sub-50 kg, backpackable autonomous vehicles designed for rapid, diverless mine countermeasures in constrained waters. These compact AUVs integrate side scan sonar, electro optical cameras and lights, and deep-learning-based algorithms that can detect and classify mine-like objects with reported accuracies on the order of 95%, dramatically reducing operator workload while improving detection reliability. Multiple MP-AUVs are intended to operate as coordinated swarms, exchanging data over underwater acoustic modems to build a shared picture of the seabed and support networked search patterns, route clearance, and re-tasking in near real time.

The MP-AUV is a major milestone towards deployable, intelligent, and networked mine countermeasure solution.[30]

Shipyard-Led Development: Neerakshi AUV

The launch of the *Neerakshi* AUV by Garden Reach Shipbuilders & Engineers in July 2023 reflects the growing participation of defence shipyards in autonomous system development.[31] Developed over a short cycle between 2022 and 2023, the program involved collaboration with private sector firms such as Aerospace Engineering Pvt Ltd (M/s AEPL) and a broader MSME ecosystem.



Lightweight and man-portable AUV "Neerakshi", developed by India's Defence PSU Garden Reach Shipbuilders and Engineers (GRSE) Ltd and launched in 2023.
Source: DW Bureau



L&T's Amogh, a deep water AUV, provides high quality, high resolution data with excellent position accuracy. It is supplied with a proven LARS (Launch & Recovery System) allowing for safe and efficient launch/recovery.
Source: L&T

Neerakshi is configured as a lightweight AUV (around 45 kg) capable of operating at depths of approximately 300 metres, with an endurance of around four hours. Its mission profile aligns with mine countermeasure and surveillance roles, closely paralleling the MP-AUV.

A second-generation model, *Neerakshi* v2, has been developed by M/S Hyper Horizon (a spin-off from M/s AEPL) with reduced size and increased endurance and is reported to have carried out high-altitude trials in Pangongo Tso, Ladakh, showing suitability for Army requirements.[32]

Industry-led Innovation: L&T Amogh / Adamya AUVs

The emergence of private sector-led innovation in the UUV domain is exemplified by the work of Larsen & Toubro. After the transfer of the *Maya* project from NSTL in 2010, Larsen & Toubro has gone on to develop AUVs designed for varied naval roles, ranging from deep-sea hydrography to submarine-launched versions. *Amogh* and *Adamya* AUVs were subsequently showcased at major defence exhibitions such as DefExpo and Aero India between 2021 and 2023.

These systems are designed for ISR and seabed mapping roles and incorporate modular payload architectures. Their development reflects a distinct industrial pathway in which private firms assume primary responsibility for design and integration, supported by domestic supply chains and selective technology imports.

Long-Endurance Systems

HEAUV Program

The High Endurance Autonomous Underwater Vehicle program represents a significant expansion in scale and ambition. Initiated following a 2018 Request for Information issued by the Indian Navy, the program is led by NSTL with industrial participation from Cochin Shipyard Limited.

The development effort integrates contributions from multiple DRDO laboratories, including the Naval Physical and Oceanographic Laboratory and the Naval Materials Research Laboratory. The maiden surface run of HEAUV was carried out in March 2024. Subsequently, in Mar 2025 underwater trials were also undertaken in a lake.[33]

With an estimated length of approximately 10 metres and endurance extending to several weeks, the HEAUV is intended for long-duration ISR missions and seabed operations. The program remains under development.

Industry Participation in ASW-Oriented AUVs

The Make-II procurement framework of the Indian Navy has enabled broader industry participation in the development of AUVs tailored for anti-submarine warfare roles. Since 2023, shipyards such as Garden Reach Shipbuilders & Engineers and Mazagon Dock Shipbuilders Limited have initiated conceptual work on such systems.

These programs involve collaboration with MSMEs and academic institutions and remain at an early stage, but they signal an emerging shift toward integrating autonomous systems into underwater combat operations.

Extra-Large Uncrewed Underwater Vehicle (XLUUV) Jalkapi

This project is India's most ambitious AUV project. It is reported to be under development as a part of the larger crewed-uncrewed operational concept with the SSNs under Project-77.[34] It is likely to serve as a capability demonstrator for the more ambitious XLUUV program of the Indian Navy featuring a 100-tonne XLUUV with proposals to develop 500-tonne XLUUVs also to operate in tandem with crewed submarines or independent platforms as part of a layered underwater defence system.[35]

The Jalkapi project is India's most ambitious AUV project. It is reported to be under development as part of the larger crewed-uncrewed operational concept with the SSNs under Project-77.

Open-source reporting indicates that *Jalkapi* is a 20-tonne cylindrical hull design capable of operating up to 300 m depth with an endurance of 30-45 days and will have a modular payload structure. The endurance profile and payload flexibility position *Jalkapi* within the same broad category as advanced global XLUUV systems such as Boeing's *Orca*, indicating India's entry into a strategically significant capability class.[36]

Unlike the earlier DRDO-led programs, *Jalkapi* indicates a user-driven approach with design responsibility with the Indian Navy's Directorate of Naval Design (Submarine Design Group). Rekise Marine Private Limited secured the primary development contract under the iDEX ADITI 1.0 challenge. They are responsible for the fabrication, subsystem integration, and testing of the prototype. Krishna Defence and Allied Industries Limited (KDAIL) is the structural build lead responsible for the physical construction of the hull and structural components at their Halol facility in Gujarat. Construction commenced in June 2025 with the ceremonial steel cutting at Halol and the prototype is likely to be ready for trials by end-2026 based on the 18-month timelines of iDEX ADITI 1.0 framework.[37]



High Endurance Autonomous Underwater Vehicle (HEAUV) developed by India's Defence Research and Development Organisation (DRDO), during a surface-run test at the Cochin Shipyard's International Ship Repair Facility (ISRF) in March 2024.
Source: DRDO

Indian Navy's UUV Portfolio

The Indian Navy's UUV portfolio (current and under development) is as shown in Table 2.[38] While it reflects capabilities of swarm-capable MP-AUVs (for MCM), medium endurance platforms (*Maya*/ HEAUV) for EEZ ISR, tube launched (*Adamya*) for submarine integration and XLUUVs for strategic roles. These systems emphasise cost efficiency, modular payloads and hybrid energy systems. Key gaps remain in high endurance gliders, counter UUV hardkill systems and large swarm capability.

Table 2: India's UUV Portfolio

Program	MP-AUV	HEAUV	Jalkapi XLUUV	Maya AUV	Neerakshi AUV	100-tonne XLUUV
Developer	NSTL/DRDO	NSTL/DRDO	Rekise Marine (Navy)	NIOT/ Goa	GRSE (Navy)	Navy/DRDO (TBD yard)
Size/ Weight	~10-20 kg (man-portable)	~10m/1m/6t	11m/~20t	3.5m/~150kg	~5-7m/1-2t (est.)	~100t
Endurance	Hours (swarm)	15 days @3kts	30-45 days	2-3 hrs / 100km	8-12 hrs (est.)	Data NA
Depth	Shallow harbour	300m	300m	150-200m	300-500m	400-600m (planned)
Payloads	Side-scan sonar, AI cam	Sonar arrays, radar mast	Multibeam/passive sonar, EO/IR	CTD, ADCP, fluorometer, sonar	Side-scan sonar, cameras	Torpedoes, mines, heavy sonar
Status	Trials done; production	Dev. trials	Hull build; trials soon	Operational (research)	Launched 2023; trials	Approved 2024; tender soon
Roles	MCM swarms	ASW/ISR/MCM	ISR/ASW (arming pot.)	Ocean science survey	MCM/ISR	Strike/MCM/ surveillance

Analysis of India's UUV Ecosystem

Government scientific institutions, academic organisations, private startups, industrial actors, and defence organisations form the UUV ecosystem in India. Though indigenous capabilities have been developed, the distributed structure has also resulted in fragmentation, uneven technological depth, and weak integration across the lifecycle of development. In recent years, innovation frameworks such as Innovations for Defence Excellence (iDEX) have attempted to provide institutional linkages.

Government scientific institutions (like NIO, NIOT, CMERI) have played a pioneering role in developing indigenous UUV systems. The *Maya* AUV program demonstrates that India has the capability to design and deploy AUV platforms at a functional level.[39] The scientific institutions rely on key subsystem from external sources, whether indigenous or imported, to prove the system design and capability. Therefore, they demonstrate platform-level competence but lack commensurate capability in specialised components.

Academic Organisations, including the Indian Institutes of Technology, provide the technical foundation required for UUV development. They have also contributed to early-stage innovation through their innovation labs and participation in robotics challenges and competitions. The founder of successful startups like Planys Technologies (Tanuj Jhunjhunwala & Vineet Upadhyay) emerged through this pipeline.[40]

Startups have developed and deployed ROVs for inspection and survey applications, showing their effectiveness in real-world environment. EyeROV and Croatia technologies have also won orders from the Indian Navy. The growing confidence and maturity of the start-ups is reflected in their expanding overseas operations in a much more competitive market.[41] iDEX challenges have helped in rapid translation of civilian technologies into defence applications.

Though indigenous capabilities have been developed, the distributed structure has also resulted in fragmentation, uneven technological depth, and weak integration across the lifecycle of development.

Large industrial conglomerates like Larsen & Toubro, defence and private shipyards have the industrial capability to manufacture UUV hulls, as well as being the integrators of complete systems. Other defence weapon and sensor manufacturers, both in public and private sectors, like Bharat Dynamics Limited, Bharat Electronics Limited, Mahindra Defence, etc., have the latent capability to be the lead developer of the UUV systems while collaborating with niche technology startups and other players.

Technology Readiness Level (TRL) Assessment of India's UUV Capability

The Technology Readiness Level (TRL) framework, originally developed by the National Aeronautics and Space Administration, is widely used to assess the maturity of technological systems from conceptualisation to operational deployment and provides a structured basis for comparing the maturity of systems across scientific, commercial, and defence domains. As there is no open-source TRL analysis for UUVs available, the TRL analysis has been carried out by mapping observed developmental milestones (including reported trials, system demonstrations, and deployment status) to TRL bands, using the following classifications:

TRL 1–2	TRL 3–5	TRL 6	TRL 7	TRL 8	TRL 9
Conceptual stage	Research and/or component integration validation in laboratory setting	Prototype demonstration with integrated system/ subsystems	Prototype demonstration in operational environment	Completion of user trials	Successful operational deployment

Commercial and Industrial UUVs

Commercial underwater systems in India, particularly inspection-class ROVs developed by firms such as EyeROV, have been deployed in real-world environments including dams, reservoirs, and offshore infrastructure. These systems therefore fall within **TRL 8–9**. Globally, comparable systems developed by Kongsberg Maritime are firmly at **TRL 9**, with large-scale deployment across offshore oil and gas industries. The difference lies primarily in scale, depth capability, and global operational footprint.

Scientific Systems and Underwater Gliders

Scientific AUVs and gliders developed by the National Institute of Ocean Technology have demonstrated integrated system functionality and have been deployed in mission-oriented oceanographic studies. These systems therefore align with **TRL 6–7**, indicating prototype demonstration with integrated subsystems and limited operational deployment. In contrast, global glider systems such as *Slocum* and *Seaglider* have achieved **TRL 9**, reflecting long-term operational deployment in both research and naval contexts.

Medium and Deep-Water Survey Systems

India's capability in this segment is currently represented by the *HUGIN* AUV operated by the Indian Navy. As a system that has completed user trials and is in active operational use, *HUGIN* is assessed at **TRL 9**. However, this capability is import-dependent, highlighting a gap in indigenous development at the highest TRL levels.

Tactical AUVs and MCM Systems

Indigenous tactical AUVs, including the Man-Portable AUV developed by the Naval Science and Technological Laboratory, industry-led development like the Larsen & Toubro *Amogh,* and the *Neerakshi* platform developed by Garden Reach Shipbuilders & Engineers, have demonstrated integrated system functionality and undergone initial trials. These systems can therefore be assessed at **TRL** 6, unlike comparable global systems such as *REMUS* and *Knifefish*, which are at TRL 9, having been deployed operationally.

The submarine-launched AUVs fall in a niche category and though Larsen & Toubro *Adamya* prototype has been displayed, there are no reports of launch trials from submarines and therefore it is at **TRL 4-5**. The US *Razorback* UUV, based on the *REMUS* 600, is being developed in two variants (Mk 19 for launch/recovery from Dry Deck Shelter and Mk 20 from submarine torpedo tube launch/recovery). The Mk 19 has demonstrated submarine-based launch and recovery from submerged platforms in joint operational trials and is therefore at **TRL 9**[42] and Mk 20 is at **TRL 5-6.**[43]

High-Endurance Autonomous Underwater Vehicles (HEAUV)

The HEAUV program, led by NSTL in collaboration with Cochin Shipyard Limited, is currently in the stage of integrated system development. The prototype has been demonstrated and it is therefore assessed at **TRL 6**. Comparable global systems such as Ghost Shark are assessed at **TRL 6–7**, suggesting that India is broadly aligned with international developments in this category.

Extra-Large UUVs (XLUUV Class)

The *Jalkapi* program is currently in the construction and early integration phase and therefore falls within the **TRL 3–5 band**. Global XLUUV programs, including *Orca* and advanced Chinese systems, are generally assessed at **TRL 6–8**, indicating more advanced stages of prototype validation and early operational testing.

AUSTRALIA'S UUV CAPABILITIES

Uncrewed maritime systems are increasingly important for Australia, particularly for the Australian Defence Force (ADF), given the nation's vast maritime domain and relatively small population. Australia must protect distant territories and strategic interests both on land and at sea, which creates a persistent requirement for presence across large and often remote areas. Achieving this presence relies on a balance between human-operated and autonomous systems. In this context, uncrewed technologies offer a critical advantage by reducing risk to personnel while extending operational reach and endurance. They enable the ADF to maintain situational awareness without placing personnel and crewed platforms in hazardous environments.[44] Additionally, these systems can significantly enhance both platform effectiveness and workforce productivity by undertaking routine, dangerous, or time-intensive tasks. The development of such capabilities also contributes to Australia's broader technological innovation agenda. Building sovereign, tailor-made systems allows the Royal Australian Navy (RAN) to address the unique environmental and operational challenges of its region, strengthening both national security and industrial capability.

Uncrewed maritime systems are increasingly important for Australia, particularly for the Australian Defence Force (ADF), given the nation's vast maritime domain and relatively small population.

UUVs, while traditionally less developed than their land and air counterparts, have undergone rapid advancement in recent years. Historically, in Australia, UUVs have been successfully employed in oceanographic data collection, a role that has clear security and defence implications, particularly in understanding the underwater environment and supporting naval operations.[45] More recently, development efforts have focused heavily on mine countermeasures (MCM), where UUVs provide a safer and more efficient means of detecting and neutralising underwater threats.[46] This capability is especially valuable in contested or high-risk areas, where human involvement would otherwise be dangerous. In parallel, there has been significant momentum toward expanding UUV capabilities into high-end naval warfare roles. This is exemplified by the emergence of extra-large autonomous underwater vehicle (XL-AUV) programs, which are designed to perform complex, long-duration missions with greater payload capacity and autonomy. Together, these developments signal a transformation in undersea warfare and surveillance, positioning UUVs as integral components of future naval operations.

Policy and strategy processes that underpin Australia's UUV development

The Royal Australian Navy (RAN) took a significant step toward integrating emerging technologies with the release of its 2020 Robotics, Autonomous Systems and Artificial Intelligence (RAS-AI) Strategy. This document outlined both the challenges and opportunities presented by these rapidly evolving capabilities, while also articulating a clear vision for their adoption and operationalisation within the Navy. A key feature of the strategy was its strong emphasis on collaboration, highlighting the need for partnerships across industry, academia, and international allies to accelerate innovation and capability development.[47] Equally notable was the acknowledgement that Australia could no longer rely solely on allies to meet its operational needs. The document explicitly recognised that off-the-shelf solutions sourced from partners may not adequately address Australia's distinct geographic, operational, and strategic requirements. This acknowledgement underscored the importance of developing sovereign capabilities tailored to national circumstances. In doing so, the strategy laid the groundwork for a whole-of-nation approach, encouraging domestic capacity building and fostering innovation ecosystems capable of supporting advanced defence technologies, including uncrewed maritime systems.

The announcement of the Australia-United Kingdom-United States (AUKUS) partnership in 2021 further accelerated Australia's focus on advanced defence technologies, including uncrewed systems. While much public and policy attention has centred on Pillar 1—particularly the long-term plan to equip the RAN with nuclear-powered submarines—Pillar 2 carries equally significant implications, especially for emerging and disruptive technologies. Pillar 2 prioritises collaboration on advanced capabilities across eight key areas, three of which are directly relevant to the development of UUVs: artificial intelligence and autonomy, quantum technologies, and undersea capabilities.[48] These areas collectively underpin the future effectiveness of UUVs by enhancing their decision-making, navigation, sensing, and stealth characteristics. The integration of such technologies within an alliance framework also strengthens interoperability and ensures that Australia's capabilities contribute meaningfully to joint operations. This approach reflects a shift toward deeper technological integration among trusted partners, while simultaneously reinforcing Australia's domestic innovation agenda by linking it to broader allied research and development efforts.

Recent national defence policy documents have reinforced the central role of uncrewed systems, particularly UUVs, in Australia's future force structure. The 2024 National Defence Strategy clearly identified the development and deployment of uncrewed underwater and surface vehicles as a priority, emphasising their role in complementing both surface combatants and conventionally armed, nuclear-powered submarines within an integrated force.[49] Supporting this direction, the Defence Innovation, Science and Technology Priorities highlighted Project SEA 1200 Maritime Uncrewed Warfare as a critical initiative, including key programs such as the Ghost Shark extra-large autonomous underwater vehicle and the Speartooth large uncrewed underwater vehicle.[50] These programs demonstrate a tangible commitment to advancing sovereign capability in this domain. The 2026 National Defence Strategy further reiterated this focus, stressing the importance of enhancing naval strike capability through the

integration of uncrewed systems alongside traditional platforms.[51] The 2026 Integrated Investment Program outlines an investment of AUD 4.8-5.8bn in autonomous systems until 2036.[52] Collectively, these policy developments demonstrate that UUV capability development has become an enduring and consistent element of Australia's contemporary national security outlook and strategy.

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Mine Countermeasure Roles (Project SEA 1778)

Since their introduction in 1999, the Huon-class coastal minehunters have formed the backbone of the Royal Australian Navy's (RAN) mine countermeasure capabilities, providing a highly specialised and effective platform for detecting and neutralising naval mines in littoral and coastal environments. These vessels were designed with advanced mine warfare systems and operated sophisticated UUVs, most notably the Saab SUTEC Double Eagle mine disposal vehicles. These systems significantly enhanced the RAN's ability to conduct mine countermeasure operations safely and efficiently by allowing potentially dangerous tasks to be performed remotely. Each Double Eagle vehicle was equipped with a suite of sensors and tools, including a searchlight, a closed-circuit low-light television camera, and an onboard close-range identification sonar, enabling operators to accurately locate, classify, and assess mine-like objects in challenging underwater conditions.[53] Once a mine was positively identified, the vehicle could be fitted with either a disposal charge positioned beneath the platform or an explosive or mechanical cutter designed to sever the wire rope or chain anchoring moored mines, thereby neutralising the threat. Despite their proven effectiveness and technological sophistication, the Huon-class vessels are now approaching the end of their operational life. With only two ships currently remaining in service and both expected to be decommissioned in the near future, the RAN is transitioning toward newer, more autonomous and modular mine warfare capabilities.

Project SEA 1778 was initiated in 2007-2008 as part of RAN's effort to modernise mine warfare through deployable, autonomous systems. It focused on delivering a rapid, modular mine countermeasures (MCM) capability that could be embarked with maritime task groups rather than relying solely on dedicated minehunter vessels. The main elements of the system developed under SEA 1778 include 38-foot uncrewed support boats capable of towing the Australian Minesweeping System (AMAS), and 9- and 12-inch diameter Bluefin UUVs, both of which are fully autonomous and feature high-resolution sonars, removable data storage, long endurance batteries (up to 24 hours on Bluefin-12), and automatic target recognition software to identify mine-like objects. Bluefin-9 is two-man portable

and Bluefin-12 can be launched and recovered from the support craft.[54] These UUVs are capable of conducting other missions such as underwater surveys or advanced mapping of the seabed before an amphibious landing.

Project SEA 1905 was a much larger and more ambitious program aimed at replacing the RAN's legacy mine warfare and hydrographic capabilities. SEA 1905 was designed around a concept of modular, deployable, and largely uncrewed systems capable of operating from a variety of vessels or shore bases. The program comprises multiple tranches, beginning with the rapid acquisition of proven off-the-shelf systems, and evolving toward an integrated, sovereign capability. Alongside SEA 1778, this project was considered central to the Navy's adoption of RAS-AI by transitioning to distributed, technology-enabled mine warfare with flexibility, interoperability, and reduced risk to crews.[55] However, this project was cancelled in 2024 ostensibly due to budget constraints.[56] This has left the RAN with limited mine hunting capability for the foreseeable future, all of which resides within the SEA 1778 package of USVs and UUVs.



A pair of Bluefin-9 autonomous underwater vehicles is seen aboard a Steber mine countermeasures support boat of the RAN.
Source: ADF

Hydrography

The Royal Australian Navy (RAN) has effectively utilised uncrewed underwater vehicles (UUVs) for hydrographic and survey functions, with the *REMUS* 100 UUV being a key platform in this role. The *REMUS* 100 is a compact, lightweight autonomous underwater vehicle designed for shallow-water operations, making it particularly suited to coastal hydrographic tasks such as seabed mapping, environmental assessment, and the collection of oceanographic data. The *REMUS* 100S (Survey) weighs 37kg, has an endurance of 12 hours at depths of up to 100 metres. It is equipped with high-resolution side-scan sonar and other sensors, which gather detailed information on seabed composition, bathymetry, and potential underwater hazards.[57] This capability supports safe navigation, mine warfare preparation, and broader maritime domain awareness. The *REMUS* 100's portability allows it to be easily deployed from small vessels or even from shore, significantly enhancing operational flexibility while reducing reliance on larger, crewed survey ships.

Extra-large autonomous UUV program

The *Ghost Shark*, an extra-large autonomous underwater vehicle (XL-AUV), is being manufactured by Anduril Australia under Project SEA 1200 for the RAN. The program began with a 2022 co-development contract involving three prototype vessels. In September 2025, Australia awarded an A$1.7 billion contract for full-rate production over five years, moving rapidly from prototype to production.[58] The first *Ghost Shark* rolled off the Sydney production line in October 2025, signalling the start of initial sea acceptance trials ahead of planned delivery to the RAN in January 2026. Built domestically across a network of over 40 Australian small and medium enterprises, the *Ghost Shark* project also features a purpose-built 7,400 m² facility in Sydney.

Ghost Shark is designed for long-range intelligence, surveillance, reconnaissance, undersea sensing, strike, and mine warfare missions, and can carry multiple payloads simultaneously in a modular architecture. It has been tested operationally, including transporting a prototype to Hawaii via RAAF C-17 for Exercise RIMPAC.[59] The platform's all-electric propulsion, modular bays, and ability to operate from various launch platforms, including other vessels and shore bases, support persistent undersea operations. The core intellectual property of this platform is retained by Australia, thus offering sovereign naval autonomy and export potential.

The *Speartooth* is a large uncrewed underwater vehicle (LUUV) developed by C2 Robotics in Sydney. Beginning in 2021, *Speartooth* advanced via iterative prototype development, upgraded systems, and trials during exercises like Autonomous Warrior 2023. With an 8 m base length (extendable to 11 m), 1 m beam, hybrid lithium-ion/diesel propulsion, 2,000 m operational depth, and a 2,000 km range, *Speartooth* supports intelligence, surveillance, reconnaissance, mine countermeasures, and strike missions via its modular payload bays.[60] This UUV has also been exported to the U.S. Navy, with the first platform being symbolically "christened" at a ceremony in Canberra in May 2026.[61]

Marine Autonomous Systems Unit (MASU)

In April 2026, the RAN established the Maritime Autonomous Systems Unit (MASU) to provide a dedicated organisational focus for the development, integration, and operation of uncrewed maritime systems.[62] MASU was created in response to the rapid growth of autonomous technologies and the Navy's recognition that uncrewed surface and underwater systems would become central to future maritime operations. The unit brings together all existing UUVs with the RAN, specialist personnel, operators, engineers, and capability developers to accelerate experimentation, concept development, and operational testing of autonomous platforms. It is expected that MASU will play a critical role in bridging the gap between innovation and operational service, enabling rapid trials, data collection, and lessons learned to inform force design and acquisition decisions. It also aims to support closer collaboration with industry, academia, and international partners, particularly within alliance frameworks such as AUKUS. By centralising expertise and responsibility, MASU seeks to enhance the RAN's ability to safely introduce autonomous systems into fleet operations, reduce risk to personnel, and ensure that emerging capabilities are aligned with operational requirements and national defence strategy.



Former Commander Australian Fleet RADM Chris Smith and CDRE Darron Kavanagh inspecting the BlueBottle USV. The BlueBottles provide Navy with a persistent platform for ongoing UUV and USV experimentation.
Source: Defence Australia

AUSTRALIA-INDIA COOPERATION IN THE UUV DOMAIN

India and Australia present two distinct, though potentially complementary, models of UUV capability development. India's ecosystem reflects a broad and expanding developmental base, with multiple programs situated in the TRL 5–7 range. This indicates sustained activity in prototyping, subsystem integration, and early-stage field validation. Australia, by contrast, exhibits greater depth at the higher end of the TRL spectrum, supported by operational deployment of mature systems, access to advanced testing infrastructure, and institutional mechanisms designed to accelerate integration.

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The Australian and Indian UUV development trajectories reflect differences in how each country has organised its innovation ecosystem, including the relationship between research institutions, industry, and the end users, their navies. Australia's establishment of the MASU illustrates a deliberate effort to compress development cycles by integrating experimentation, testing, and doctrinal development. India's approach, while benefiting from close cooperation between research agencies and the Indian Navy, remains more distributed and less formally structured around rapid iteration.

Indian Strengths

India's UUV ecosystem's greatest strength is the breadth and diversity of institutions involved in underwater systems development. Scientific organisations such as the National Institute of Ocean Technology and the National Institute of Oceanography, defence laboratories such as the Naval Science and Technological Laboratory, academic institutions, startups, shipyards, and large private industry collectively contribute to a broad-based innovation ecosystem. This diversity encourages experimentation across multiple technological pathways simultaneously.

India also possesses substantial industrial depth and manufacturing scalability. Major firms such as Larsen & Toubro, Garden Reach Shipbuilders & Engineers, and Mazagon Dock Shipbuilders Limited provide the industrial infrastructure necessary for large-scale fabrication, systems integration, and long-term sustainment. India's lower production costs and large engineering workforce may provide an important advantage in future.

Another important Indian strength is the growing role of startups and innovation ecosystems. Companies such as EyeROV and Planys Technologies demonstrate that India's underwater robotics sector is no longer confined to government laboratories. The expansion of innovation frameworks such as Innovations for Defence Excellence (iDEX) has accelerated the translation of civilian and dual-use technologies into defence applications. This startup-driven environment may become particularly important in software-intensive domains such as AI-enabled underwater perception, swarm behaviour, and autonomous mission management.

A further strength lies in India's long-term developmental trajectory. Although several systems remain within mid-range TRL bands, the diversity of ongoing programs indicates that India is building a substantial indigenous knowledge base in underwater autonomy. The emergence of programs such as *Jalkapi* also demonstrates increasing ambition in long-endurance and extra-large autonomous underwater systems.

Indian Capability Gaps

India's most significant weakness remains dependence on imported high-end subsystems. While Indian organisations have demonstrated competence in hull fabrication, platform integration, and mission architecture, several critical enabling technologies continue to rely heavily on external suppliers. Advanced sonars, underwater communication systems, navigation packages, specialised batteries, and acoustic processing technologies remain areas of vulnerability. This creates limitations not only in technological autonomy but also in long-term operational resilience.

Institutional fragmentation also constrains capability development. Multiple organisations frequently pursue overlapping objectives with limited coordination between scientific institutions, defence laboratories, industry, and operational users. Although this diversity encourages innovation, it can also lead to duplication of effort, slower decision-making, and inconsistent prioritisation.

Another major gap is uneven technology maturity across the ecosystem. India possesses a broad range of developmental programs, but many remain within TRL 4–7 and have not yet achieved sustained operational deployment. India often experiences prolonged developmental cycles before induction into service. India therefore possesses growing technological capability but comparatively limited operational experience in large-scale deployment and doctrinal integration of autonomous underwater systems.

Institutional fragmentation also constrains capability development. Multiple organisations frequently pursue overlapping objectives with limited coordination between scientific institutions, defence laboratories, industry, and operational users. Although this diversity encourages innovation, it can also lead to duplication of effort, slower decision-making, and inconsistent prioritisation.

India also faces gaps in several specialised capability areas. High-end underwater gliders, persistent low-power autonomous systems, counter-UUV hard-kill systems, and advanced underwater networking architectures remain relatively underdeveloped. Large-scale autonomous swarm deployment beyond conceptual or limited experimental levels is also still emerging.

Australian Strengths

A major strength of Australia's UUV ecosystem is the high degree of strategic and policy coherence underpinning capability development. Autonomous underwater systems are not being pursued as isolated research initiatives but as integral elements of future naval force structure and maritime operations. The Royal Australian Navy's RAS-AI Strategy, subsequent National Defence Strategies, and the institutionalisation of experimentation through the MASU collectively demonstrate that Australia has embedded UUV capability development within long-term defence planning. This policy continuity has enabled relatively rapid transition from conceptual experimentation to operational integration.

Australia also possesses a strong advantage in operationalisation and technology transition. Systems associated with Project SEA 1778, *REMUS* hydrographic operations, and the *Ghost Shark* program indicate that Australia is comparatively effective at moving systems from developmental stages into fleet experimentation and operational deployment. In Technology Readiness Level terms, Australia demonstrates particularly strong "transition efficiency" between prototype demonstration and operational induction.

Another major Australian strength is access to advanced allied technology ecosystems through AUKUS and broader Western defence-industrial networks. Access to mature technologies in artificial intelligence, underwater communications, acoustic processing, quantum technologies, and autonomous navigation significantly reduces developmental risk.

Australia's industrial ecosystem, although limited in scale, also demonstrates strong systems integration capability. The ability to move rapidly from prototype design to production reflects not only technological competence but also institutional agility and close alignment between operational requirements and industrial development.

Australian Capability Gaps

Australia's defence-industrial base is technologically sophisticated but comparatively narrow and concentrated around a limited number of programs and industrial actors. This limited industrial scale is the most significant weakness of Australia's UUV ecosystem.

Australia also remains dependent on international technological partnerships for several critical enabling technologies. Although AUKUS provides privileged access to allied ecosystems, this dependency creates vulnerabilities if geopolitical or alliance dynamics shift. Australia possesses strong integration capability, but not complete technological self-sufficiency across all aspects of underwater autonomy.

Another gap lies in the relative narrowness of Australia's operational ecosystem. While the country has demonstrated impressive capability in high-end autonomous systems and mine warfare applications, it has comparatively fewer indigenous programs across lower-cost tactical UUVs, swarm systems, and commercial dual-use underwater robotics when compared with India's broader ecosystem.

Comparative Assessment

Australia and India possess fundamentally different but complementary capability profiles. Australia currently leads in operational maturity, systems integration, doctrinal adaptation, and access to advanced enabling technologies. India possesses broader ecosystem diversity, greater industrial scalability, lower-cost innovation pathways, and stronger long-term expansion potential.

Australia's ecosystem can, therefore, be characterised as "high maturity but narrow," whereas India's can be understood as "broad but uneven." Australia demonstrates stronger operational readiness and integration into naval doctrine, while India demonstrates stronger industrial capacity and innovation diversity. The Australian model emphasises rapid operationalisation of selected high-end systems, whereas the Indian model reflects gradual ecosystem-wide capability development across multiple sectors.

These differences create significant opportunities for cooperation. Australia's strengths in operational experimentation, systems engineering, and high-TRL integration could complement India's strengths in manufacturing scale, software-intensive innovation, and industrial depth. Cooperation in areas such as mine warfare, seabed mapping, underwater ISR, modular payload architectures, and autonomous coordination systems could therefore accelerate capability development for both countries.

The comparison also highlights shared challenges. Both countries continue to face unresolved technological barriers, including underwater communication limitations, endurance constraints, navigation in GPS-denied environments, and secure autonomous coordination. Neither country currently possesses a fully mature and completely sovereign end-to-end UUV ecosystem across all operational categories.



A delegation of Indian and Australian UDA experts on a tour of the L&T UAV testing facility in November 2025.
Source: Fiona Considine

STRATEGIC AND OPERATIONAL CHALLENGES

The growing strategic convergence between India and Australia has created favourable conditions for cooperation in advanced maritime technologies, including in the field of UUVs. Both countries recognise that UUVs will play an increasingly central role in future maritime operations involving intelligence, surveillance and reconnaissance, mine countermeasures, anti-submarine warfare, seabed mapping, and protection of critical maritime infrastructure. Their expanding engagement through bilateral naval exercises, defence dialogues, and wider Indo-Pacific frameworks has strengthened political understanding and maritime cooperation. Yet, despite these favourable trends, meaningful cooperation in the UUV domain remains constrained by several strategic, institutional, technological, and operational challenges.

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Strategic Challenges

One of the most significant challenges to Australia-India cooperation in UUVs arises from differences in strategic orientation and maritime priorities. Although both countries support a stable and rules-based Indo-Pacific maritime order, their operational focus areas are not identical. Australia's contemporary maritime strategy is increasingly influenced by alliance-centred deterrence frameworks linked to AUKUS. Recent Australian defence policy documents place significant emphasis on autonomous systems as part of distributed maritime operations, long-range ISR, seabed warfare, and support for future nuclear-powered submarine operations. Australia's investment in programs such as Ghost Shark reflects this orientation towards high-end autonomous undersea capability integrated with broader allied operational architectures.

India's strategic orientation remains comparatively centred on the Indian Ocean Region (IOR), with UUV development primarily linked to regional maritime security requirements such as harbour defence, mine countermeasures, coastal surveillance, seabed mapping, and underwater domain awareness. While India is gradually moving towards more ambitious systems such as the HEAUV and *Jalkapi* XLUUV, the overall focus remains more oriented to close coast requirements. This divergence in strategic emphasis may complicate efforts to define common capability priorities

within collaborative programs. Australia increasingly sees UUVs within the context of strategic competition involving advanced naval powers and the future balance of undersea capabilities in the Indo-Pacific. In contrast, India continues to balance maritime modernisation alongside border tensions, and broader multi-domain defence requirements. As a result, underwater autonomy may not always receive the same level of political or budgetary priority within Indian defence planning.

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Australia's defence modernisation program is already heavily burdened by the financial commitments associated with AUKUS Pillar I and nuclear-powered submarine acquisition. Although autonomous systems remain a declared priority within Australian defence planning, competition between crewed and uncrewed capabilities is likely to intensify over time. The cancellation of Project SEA 1905 despite its strategic importance demonstrates the extent to which fiscal pressures can affect even high-priority autonomous programs.[63]

India faces a different form of resource challenge. While India possesses a larger industrial and manpower base, its defence modernisation priorities are distributed across multiple competing sectors including land warfare, airpower, maritime expansion, indigenous production, and emerging technologies. Autonomous underwater systems therefore compete for funding within a highly complex and resource-constrained procurement environment. Sustained investment in advanced underwater technologies may consequently remain vulnerable to shifting operational priorities.

Another strategic complication concerns technological sovereignty and alliance sensitivities. Australia's integration into AUKUS and wider Five Eyes-linked technological ecosystems imposes limitations on the degree of cooperation possible in highly sensitive underwater warfare technologies. This may restrict the extent of technology sharing possible with India. India continues to emphasise strategic autonomy in defence capability development. Although India actively pursues defence partnerships, it has traditionally remained cautious of excessive dependence on external technological ecosystems. This may create limitations in relation to deeper integration within cooperative technological frameworks.

Institutional Barriers

There are institutional differences between the two countries' UUV ecosystems. Australia's UUV ecosystem demonstrates relatively strong integration between defence policy structures, operational experimentation, industry, and naval capability development. The establishment of MASU will accelerate the transition from prototype development to operational capability. India's institutional ecosystem is considerably broader but also more fragmented. Responsibility for underwater systems development is distributed across scientific organisations, defence laboratories, public sector shipyards, startups, academic institutions, and private industry. Organisations such as the National Institute of Ocean Technology, the National Institute of Oceanography, the Naval Science and Technological Laboratory, and multiple industrial actors often operate under different administrative and funding structures, making coordination difficult.

Intellectual property management presents another important institutional challenge. Joint development programs frequently encounter disagreements relating to technology ownership, export rights, subsystem access, and production responsibilities. These concerns become particularly acute in underwater systems because many technologies possess dual-use applications and significant strategic sensitivity. Without clearly defined frameworks governing intellectual property, technology transfer, and industrial participation, collaborative programs may struggle to progress beyond the conceptual stage.

Technological Challenges

India and Australia currently operate systems derived from different technological ecosystems. Australia's UUV programs increasingly integrate technologies aligned with Western and AUKUS-related standards, whereas India's underwater ecosystem combines indigenous development with technologies sourced from multiple international suppliers. This divergence creates challenges in relation to software architectures, mission management systems, acoustic standards, payload integration, and communication protocols.

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Underwater communication systems remain bandwidth-limited, environmentally sensitive, and often incompatible across different platforms. Establishing common communication standards or interoperable underwater networking architectures would require substantial technological coordination as well as significant mutual trust.

Artificial intelligence and autonomy architectures present additional complications. UUV autonomy increasingly depends on machine learning algorithms, adaptive mission management systems, sensor fusion, and AI-enabled target recognition. These systems are often closely guarded because they directly influence operational effectiveness and survivability. Differences in software ecosystems, autonomy certification procedures, and AI governance frameworks may therefore limit deeper technological integration.

Data sharing introduces another major technological and political challenge. Autonomous underwater operations generate highly sensitive acoustic, bathymetric, and ISR-related information. Such data may reveal operational patterns, seabed infrastructure locations, underwater signatures, or maritime vulnerabilities. Both India and Australia are therefore likely to remain cautious regarding the degree of operational data sharing possible within cooperative arrangements.

Operational Challenges

Operational integration represents another major challenge for Australia-India UUV cooperation. Even where technological and institutional barriers are partially addressed, effective operational cooperation requires compatible doctrine, training systems, deployment procedures, command structures, and operational concepts.

Maritime domain awareness integration represents another area of complexity. Effective use of UUVs increasingly depends on integration with wider ISR architectures involving satellites, maritime patrol aircraft, seabed sensors, crewed platforms, and surface vessels. India and Australia currently operate different maritime domain awareness networks linked to their respective operational environments and strategic partnerships. Integrating autonomous underwater systems across these architectures would require extensive technical and procedural coordination.

Operational security concerns are equally significant. Underwater operations remain among the most sensitive areas of naval warfare because they involve submarine movements, acoustic signatures, sonar performance, and seabed infrastructure. Navies traditionally remain highly cautious regarding disclosure of operational procedures, acoustic libraries, and underwater surveillance patterns. This culture of secrecy may constrain the depth of operational cooperation possible in the UUV domain.

Australia's operational focus extends across vast Pacific and Southern Ocean spaces, requiring long-endurance autonomous systems capable of operating over large distances. India's operational environment is centred more heavily on the Indian Ocean littoral and choke-point surveillance.

Australia's operational focus extends across vast Pacific and Southern Ocean spaces, requiring long-endurance autonomous systems capable of operating over large distances. India's operational environment is centred more heavily on the Indian Ocean littoral and choke-point surveillance. Environmental conditions, seabed characteristics, acoustic propagation patterns, and operational requirements therefore differ considerably between the two theatres.

Autonomous underwater systems are still emerging globally, and no universally accepted operational doctrine exists for many advanced UUV missions. Both India and Australia are therefore simultaneously developing technologies and operational concepts in parallel. This creates uncertainty regarding future operational architectures and complicates long-term cooperative planning.

OPPORTUNITIES FOR ENHANCED COOPERATION

Despite these challenges, the strategic rationale for Australia-India cooperation in the UUV domain is strong, as the two countries possess complementary strengths, shared maritime concerns, and increasing strategic convergence in the Indo-Pacific.

The future of Australia-India cooperation in the UUV domain will depend on whether both countries can move beyond broad strategic convergence toward practical and institutionalised collaboration. Rather than attempting immediate cooperation in highly sensitive undersea combat systems, a phased and capability-driven approach, focussed on benign, civil applications to begin with, is likely to prove more sustainable and politically feasible.

The first step should involve the creation of a structured bilateral framework dedicated specifically to maritime autonomous systems. Existing naval dialogues and defence cooperation mechanisms provide useful foundations, but they remain too broad to sustain long-term technological collaboration in underwater autonomy. A dedicated Australia-India Maritime Autonomous Systems Working Group involving naval operators, defence scientists, industry representatives, and policymakers could provide continuity and strategic direction. Such a framework would also help align capability priorities, identify areas of complementarity, and reduce duplication of effort.

Mine countermeasure systems and hydrographic cooperation represent the most practical areas for early collaboration. Both countries face growing concerns regarding protection of sea lanes, harbour approaches, and critical underwater infrastructure. Cooperation in modular mine warfare systems, seabed mapping technologies, autonomous survey platforms, and environmental sensing would carry relatively lower strategic sensitivity while still generating operational and industrial benefits. Joint experimentation in these domains could gradually establish trust and interoperability without immediately encountering the political complications associated with advanced undersea strike or deterrence systems.

Australia possesses advanced operational testing infrastructure and strong integration mechanisms between industry and the navy, while India offers a broad developmental ecosystem and cost-effective engineering capacity. Joint sea trials, technology demonstrations, and autonomous systems exercises could allow both countries to evaluate interoperability challenges under realistic maritime conditions. Such activities would also expose developers and operators to differing operational concepts and environmental conditions across the Indian and Pacific Oceans.

Academic and scientific collaboration should form another pillar of the partnership. Institutions involved in underwater robotics, oceanography, artificial intelligence, and marine engineering in both countries could undertake collaborative research programs focused on underwater communications, navigation systems, swarm coordination, energy storage, and AI-enabled autonomy. Joint innovation challenges, researcher exchanges, and university-industry partnerships would help create a longer-term technological ecosystem supporting bilateral cooperation.

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Industry participation will be equally important. India's expanding startup ecosystem and manufacturing base can complement Australia's strengths in systems integration and operational experimentation. Collaborative industrial models involving startups, shipyards, MSMEs, and larger defence firms could help develop scalable and modular UUV architectures tailored for Indo-Pacific operational conditions. This may prove particularly valuable in lower-cost autonomous systems intended for persistent ISR, seabed monitoring, and distributed maritime operations.

Importantly, cooperation must also remain realistic regarding technological sensitivities. Deep collaboration in highly classified underwater warfare technologies may remain constrained by export controls, alliance commitments, and strategic secrecy. Consequently, the success of Indo–Australian UUV cooperation is more likely to emerge through incremental trust-building, selective co-development, and operational experimentation rather than through immediate transfer of advanced strategic technologies.

Framework for Cooperation

Australia-India cooperation in UUVs should evolve through four concurrent and mutually reinforcing pillars: operational cooperation, technological collaboration, industrial partnership, and institutional coordination. Together, these pillars can provide a practical framework for moving bilateral cooperation from broad strategic convergence toward sustained capability development and operational collaboration.

Operational Cooperation

At the operational level, both navies should gradually incorporate autonomous underwater systems into bilateral exercises and maritime domain awareness frameworks. Initially, this could focus on low-risk activities such as seabed surveys, underwater search operations, environmental monitoring, and coordinated hydrographic missions. Over time, such engagement could evolve toward more sophisticated concepts involving coordinated ISR and autonomous mine countermeasure operations.

Technological Collaboration

Technological cooperation should prioritise enabling technologies that remain central to long-endurance and networked underwater operations. Important areas include underwater communications, navigation in GPS-denied

environments, AI-enabled mission autonomy, sensor fusion, energy systems, modular payload integration, and autonomous coordination technologies.

India and Australia should therefore prioritise open and modular architectures that support "plug-and-play" integration as technologies mature. Such an approach would allow individual subsystems to be upgraded without redesigning entire platforms. Common standards for software interfaces, payload integration, mission data formats, communication protocols, and autonomy management systems would also improve long-term interoperability and reduce integration costs.

Collaborative underwater programs frequently encounter delays because of uncertainty regarding technology ownership, export controls, licensing rights, and access to operational data. These concerns become particularly sensitive because many underwater technologies possess dual-use applications and direct operational relevance. To reduce such risks, both countries should establish clear IP and data-sharing frameworks early in the cooperation process. Rather than pursuing unrestricted sharing of sensitive technologies, the emphasis should be on defining protected collaboration zones where selected software modules, interface standards, and testing data can be jointly developed while safeguarding sovereign and classified capabilities.

Lower-sensitivity technologies such as hydrographic tools, environmental sensing systems, autonomous navigation software, and modular payload interfaces could be developed collaboratively with broader access arrangements. More sensitive technologies linked to acoustic intelligence, advanced autonomy, or operational mission data could remain compartmentalised under controlled-access frameworks.

Industrial Partnership

Industrial partnerships should seek to combine Australia's strengths in systems integration and operational testing with India's advantages in manufacturing scale, software development, and engineering depth. Collaboration involving startups, MSMEs, research institutions, shipyards, and larger defence firms could support development of scalable and modular UUV systems tailored for Indo-Pacific operational conditions.

Institutional Coordination

Long-term collaboration in underwater systems cannot rely solely on periodic government dialogues or naval exercises. It requires structured mechanisms that connect operational users, scientific institutions, industry, and academia. Personnel exchanges, collaborative experimentation programs, innovation challenges, and shared research initiatives will therefore be essential to sustaining momentum and reducing institutional fragmentation. Sustained political commitment, stable funding arrangements, and continuity across procurement cycles are prerequisites.

A practical approach could involve establishing a bilateral Australia-India Maritime Autonomous Systems Consortium or a similar special-purpose cooperative framework. Rather than functioning as a highly centralised organisation, such a mechanism should operate as a flexible coordination platform connecting operational users, researchers, developers, and industrial stakeholders from both countries. The objective should be to support experimentation, technology development, testing, and gradual operational integration. The proposed framework could operate through specialised working groups focused on:

- Underwater communications and networking.
- AI-enabled mission autonomy.
- Modular payload and software architectures.
- Seabed mapping and underwater ISR.
- Energy systems and endurance optimisation.
- Autonomous swarm coordination.
- Protection of critical seabed infrastructure.

Participation should involve a broad range of stakeholders from both countries. On the Indian side, organisations linked to Defence Research and Development Organisation, National Institute of Ocean Technology, and National Institute of Oceanography, along with shipyards, startups, and universities, could contribute to research, prototyping, and manufacturing. On the Australian side, entities associated with the Defence Science and Technology Group, maritime experimentation units, universities, and private industry could contribute strengths in systems integration, testing, and operational experimentation.

Governments would continue to provide strategic direction, testing infrastructure, and initial funding support, but industry and academia should remain central participants rather than peripheral contributors. Competitive innovation grants, joint technology challenges, collaborative testbeds, co-funded demonstrator programs, and personnel exchanges could help accelerate innovation while encouraging participation from startups and smaller technology firms. The objective should not be alliance-style technological integration, but the creation of a flexible structure capable of supporting selective and scalable collaboration in strategically important areas of underwater autonomy and underwater domain awareness.

Near-term Opportunities (1-3 Years)

The initial phase of cooperation should focus on practical and relatively low-sensitivity activities capable of generating early operational benefits while building institutional trust and interoperability, which would create the foundation for more ambitious future collaboration. The priority areas can be:

- Incorporation of UUV operations into bilateral naval exercises.
- Joint hydrographic and seabed mapping missions.
- Cooperation in mine countermeasure technologies and autonomous survey systems.
- Bilateral workshops on underwater communications, AI-enabled autonomy, and maritime robotics.
- Researcher exchanges between defence laboratories, oceanographic institutions, and universities.
- Startup and MSME engagement through bilateral innovation challenges and technology forums.
- Joint environmental sensing and maritime monitoring projects.
- Collaborative studies on seabed infrastructure protection and undersea cable security.
- Creation of pilot “plug-and-play” architecture standards for modular payloads and software integration.

Medium-Term Opportunities (3-5 Years)

The medium-term objective should be to move beyond dialogue-based engagement toward collaborative capability development, technological interoperability, and sustained operational experimentation. The priority areas can be:

- Co-development of modular and scalable UUV architectures.
- Joint experimentation in underwater networking and autonomous communication systems.
- Collaboration on AI-enabled mission management and autonomous coordination technologies.
- Shared development of persistent ISR and seabed monitoring systems.
- Bilateral autonomous systems sea trials and operational experimentation programs.
- Development of common standards for payload integration, software architecture, and mission planning.
- Cooperation in energy storage, endurance optimisation, and low-power underwater systems.
- Establishment of bilateral autonomous systems testbeds and innovation accelerators.
- Development of shared digital simulation and testing environments for autonomous underwater operations.

Long-Term Opportunities (5-10 Years)

Over the longer term, Australia-India cooperation could evolve toward a broader strategic partnership centred on resilient UDA across the Indo-Pacific. The priority areas can be:

- Development of federated Indo-Pacific underwater domain awareness networks.
- Collaborative programs involving extra-large uncrewed underwater vehicles (XLUUVs) and long-endurance autonomous systems.
- Distributed maritime surveillance architectures integrating seabed sensors, UUVs, and wider ISR networks.
- Coordinated frameworks for protection of subsea cables and critical seabed infrastructure.
- Shared doctrinal development for autonomous and distributed maritime operations.
- Integration of autonomous systems into broader maritime ISR and decision-support architectures.
- Joint Indo-Pacific capacity-building initiatives in hydrography, autonomous systems, and seabed awareness.
- Selective cooperation in advanced underwater autonomy and autonomous coordination concepts as trust and interoperability mature.

Policy recommendations

Australia-India cooperation in UUVs should evolve through a gradual, capability-driven, and institutionally supported approach. Given the sensitivities and operational complexities of the undersea domain, cooperation is likely to be most effective when built around selective co-development, operational experimentation, modular architectures, and sustained engagement between governments, navies, scientific institutions, industry, and academia. The following recommendations provide a practical framework for advancing bilateral cooperation.

Ser	Recommendation	Purpose and Benefits
1	Establish an Australia-India joint working group for underwater autonomous systems, possibly as part of a larger working group on uncrewed and autonomous systems under the existing bilateral defence framework	Develop policy roadmap identifying collaboration possibilities and importantly, establish the limits of cooperation. Identify areas (hydrography, mine hunting etc) where co-design and co-development may be possible.
2	Establish a jointly funded Australia-India Maritime Autonomy Innovation Fund to support collaborative R&D projects involving government laboratories, universities, startups, and MSMEs.	Incentivise private sector cooperation between Australia and India. Support MSMEs and startups by lowering risk. Encourage innovation in enabling technologies such as underwater communications, AI-enabled autonomy, batteries, sensor fusion, and navigation systems.
3	Develop common modularity and interoperability standards for payload integration, communication protocols, mission software, and data architectures.	Enable plug-and-play integration as technologies mature. Reduce long-term integration costs and technological incompatibility. Facilitate future interoperability between Indian and Australian autonomous systems.
4	Establish a bilateral framework for intellectual property protection, export controls, technology access, and operational data management at an early stage of cooperation.	Reduce uncertainty relating to ownership and technology transfer. Protect sensitive technologies while enabling selective collaboration. Organisations such as Defence Research and Development Organisation, National Institute of Ocean Technology, National Institute of Oceanography, Defence Science and Technology Group, create confidence for industry and research organisations participating in joint programs.
5	Identify existing platforms where modular components could be designed and/or manufactured by collaboration, particularly in India.	Lower cost of existing platforms by driving down production costs. Develop habits of co-production, harmonisation of quality standards, and dispel IP-related apprehensions.
6	Create platforms for scientific cooperation in UUV technologies between organisations such as DRDO, NIOT, NIO, DSTG, and CSIRO.	Catalyse joint research and development across these organisations in underwater communications, AI-enabled autonomy, energy systems, underwater navigation, and swarm coordination. Develop sustained scientific linkages supporting long-term cooperation.
7	Establish bilateral autonomous systems testbeds, simulation environments, and sea-trial mechanisms in both the Indian Ocean and Pacific theatres.	Enable realistic operational experimentation under differing environmental conditions. Accelerate transition from prototype development to operational deployment. Improve interoperability and doctrinal adaptation.
8	Establish a platform for interaction between customers (navy, coast guard) with joint industry forums comprising Australian and Indian MSMEs.	Expose industry to customer profile and requirements of the partner country. Provide direct interface for end-users to gain perspectives of industry in partner country.
9	Include technology demonstrations in each bilateral navy-navy and ABF-coast guard engagement	Expose end-users in both countries to technologies available in partner countries. Provide environment where industry, particularly small enterprises, is motivated to showcase products to an international audience.

Ser	Recommendation	Purpose and Benefits
10	Promote industrial partnerships involving Indian manufacturing capability and Australian systems integration expertise for scalable and modular UUV platforms.	Combine India's industrial scale and engineering depth with Australia's operational experimentation strengths. Lower production costs and improve scalability. Build habits of co-production and quality harmonisation.
11	Develop collaborative programs focused on protection of critical seabed infrastructure and underwater domain awareness in the Indo-Pacific.	Address growing vulnerabilities relating to undersea cables, offshore infrastructure, and maritime chokepoints. Expand cooperation beyond traditional naval missions into broader maritime security applications.

CONCLUSION

The Indo-Pacific maritime environment is characterised by intensifying competition, growing grey-zone activity, and accelerating technological change, conditions that collectively elevate the strategic importance of underwater domain awareness. UUVs have emerged as a critical enabler in this environment, offering persistent, distributed, and increasingly autonomous capabilities that complement and extend the reach of conventional naval forces. Australia and India, as significant maritime powers with shared interests in a stable and rules-based Indo-Pacific order, are both investing substantially in UUV capability development, albeit through distinct developmental pathways and in response to different operational priorities. Australia's ecosystem is distinguished by its high degree of policy coherence, its effectiveness in transitioning systems from prototype to operational deployment, and its privileged access to advanced allied technologies through AUKUS. India's ecosystem, by contrast, is characterised by its breadth and diversity, encompassing scientific institutions, defence laboratories, private industry, and a growing startup sector, supported by substantial manufacturing depth and engineering capacity. These differences reflect fundamental choices regarding how each country has organised its innovation base and structured the relationship between technology development and operational requirements. Importantly, these divergent profiles are complementary rather than competitive, creating a foundation for cooperation that is strategically meaningful precisely because each country possesses capabilities the other currently lacks.

The case for bilateral cooperation in the UUV domain ultimately rests on strategic logic rather than technological convergence alone. Both countries confront shared challenges, including protection of critical seabed infrastructure, persistent surveillance of extensive maritime zones, and the growing complexity of operating in contested underwater environments, that neither can fully address through purely national means. The framework proposed in this report, structured around operational and technological collaboration, industrial partnership, and institutional coordination, provides a practical pathway for translating strategic convergence into sustained capability development. Progress will necessarily be incremental, and cooperation will remain constrained by legitimate sensitivities regarding strategic autonomy, technology sovereignty, and alliance obligations. However, the trajectory of Australia–India maritime engagement, deepening bilateral exercises, expanding defence dialogues, and growing industrial linkages, provide a favourable foundation on which a more structured and enduring partnership in underwater autonomy can be constructed. With sustained political commitment, stable funding, and engagement from a broad range of institutional, industrial, and academic stakeholders, Australia and India are well positioned to develop a complementary capability partnership that enhances the security and stability of the broader Indo-Pacific maritime commons.

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