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Blue Accounting for Tropical Countries: Enabling Sustainable Blue Economy Through an Underwater Domain Awareness Framework

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Abstract

This paper proposes an integrated Blue Economy Accounting (BEA) framework that combines Blue Accounting, the Underwater Domain Awareness (UDA) framework, and Modelling and Simulation-based Marine Spatial Planning (M&S-MSP) to support sustainable ocean governance in tropical countries. Marine and coastal ecosystems provide essential ecological, economic, and social benefits through fisheries, aquaculture, tourism, coastal protection, transportation, and other ocean-based activities. However, these systems face increasing pressures from climate change, pollution, overexploitation, habitat degradation, and competing uses of marine space.

The proposed framework enables systematic assessment and dynamic valuation of marine natural capital and ecosystem services, while integrating ecological conditions, economic activities, and human pressures into decision-making. Blue Accounting provides the basis for tracking changes in marine assets and ecosystem values, while UDA strengthens situational awareness by integrating ecological, oceanographic, technological, and human-activity data. M&S-MSP supports scenario-based planning by enabling policymakers to evaluate the ecological, economic, and social implications of alternative marine-use strategies.

By integrating accounting, underwater awareness, and predictive modelling, the framework promotes evidence-based policymaking, adaptive resource management, conflict reduction, and resilient blue economy development. It provides a foundation for balancing economic growth with ecological integrity and the regenerative capacity of marine ecosystems, thereby supporting sustainable and climate-resilient ocean governance in tropical regions.

Introduction

The blue economy has emerged as a strategic driver of economic growth, environmental sustainability, and climate resilience, particularly in tropical countries, where some of the world's most productive and biologically diverse marine ecosystems are found. Tropical waters are distinguished by warm year-round temperatures, extensive coral reef–mangrove–seagrass networks, exceptional marine biodiversity, significant blue carbon storage, and the strong dependence of coastal communities on marine resources for food security and livelihoods. These characteristics make tropical marine ecosystems both highly productive and exceptionally vulnerable to climate change, overexploitation, pollution, and accelerating coastal development. Consequently, a Blue Accounting framework for tropical waters must extend beyond conventional economic metrics to incorporate natural capital, ecosystem services, blue carbon, biodiversity, climate resilience, and community well-being (López-Rivas & Cardenas, 2024) (Costanza et.al., 1997. However, the absence of an integrated framework to measure the condition, value, and utilisation of these resources means that many ocean development decisions are based on incomplete evidence. As a result, short-term economic gains are often achieved at the expense of ecosystem health, leading to resource depletion, stakeholder conflicts, and declining resilience. A Blue Accounting framework, enabled by the Underwater Domain Awareness (UDA) framework (Das, 2014), addresses this

gap by providing continuous, evidence-based information to support informed decision-making, reduce environmental risks, and balance economic development with the long-term sustainability of tropical marine ecosystems.

Blue Accounting is the systematic measurement and valuation of marine natural capital, ecosystem services, ocean-based economic activities, and their social and environmental impacts. (Wielgus et al., 2025) Much like national economic accounts quantify financial assets, Blue Accounting seeks to quantify the contribution of ocean resources to economic development while accounting for the ecological assets that sustain them. Traditional economic indices measure outputs such as fisheries production, tourism revenue, or port throughput, but rarely account for the declining health of coral reefs, mangroves, fish stocks, or coastal ecosystems. Consequently, economic gains are often achieved at the expense of the natural capital upon which future prosperity depends. (Halpern et.al., 2012)

Table 1
Comparative study of different Environmental frameworks and Initiatives by Cathrine J, Maritime Research Center, Pune

(Sources – United Nations, 2015; OECD, 2016; SEEA EA, 2021; GOAP, 2022; Natural Capital Coalition, 2016; World Bank, 2019; MOES (GOI), 2021; MoPSW (GOI), 2015; FAO, 2022; UNESCO – IOC, 2021; UNEP, 2023; TEEB, 2010; European Commission, 2021)

Framework	Objective	Strengths	Limitations	BEA Relevance
SDG 14 (Life Below Water)	Sustainable use of marine resources	- Global sustainability targets - Strong conservation focus	- No accounting methodology - Limited economic valuation	Moderate – Defines sustainability goals, not accounting mechanisms.
OECD Blue Economy Framework	Sustainable ocean-based economic development	- Multi-sector integration - ESG orientation - Policy coherence	- Weak accounting standards - Inconsistent data frameworks	High – Supports integrated BEA but requires standardised accounting.
SEEA-EA	Integrate ecosystem services into national accounts	- International accounting standard - Natural capital valuation - Physical & monetary accounts	- Data-intensive - Complex implementation - Limited marine operational guidance	Very High – Strongest accounting foundation for marine natural capital.
UN Ocean Accounts Framework (GOAP)	Standardised ocean accounting	- Ocean-specific accounting - Aligns with SEEA Integrates environmental, economic, and social data	- Emerging framework - Limited country implementation	Very High – The closest existing framework to a comprehensive BEA.
Natural Capital Protocol	Value natural capital for organizations	- Corporate decision support - Ecosystem valuation - Risk assessment	- Voluntary framework - Weak national integration	High – Useful for corporate-level blue accounting.

Framework	Objective	Strengths	Limitations	BEA Relevance
World Bank PROBLUE	Sustainable blue economy investments	- Investment guidance - Governance support - Capacity building	- Not an accounting framework - Limited accounting indicators	High – Supports implementation but requires BEA for measurement.
Draft Blue Economy Policy (India)	Integrated marine sector development	- National strategy - Sectoral coordination - Livelihood focus	- No standardised accounting - Weak valuation framework	High (Strategic) – Provides policy direction but lacks accounting metrics.
Sagarmala Programme	Port-led development	- Infrastructure development - Logistics efficiency - Economic growth	- Weak environmental accounting - Limited ecosystem valuation	Moderate – BEA can incorporate ecological costs and sustainability metrics.
FAO Blue Transformation Roadmap	Sustainable fisheries & aquaculture	- Fisheries governance - Food security - Resource sustainability	- Sector-specific - Limited economy-wide applicability	Moderate–High – Useful for fisheries accounting within BEA.
Marine Spatial Planning (UNESCO-IOC)	Integrated ocean space management	- Ecosystem-based planning - Conflict resolution - Spatial decision support	- Limited accounting focus - Weak economic valuation	Moderate – Provides spatial information for marine asset accounting.
Inclusive Wealth Framework (UNEP)	Measure national wealth, including natural capital	- Comprehensive wealth accounting - Sustainability assessment	- Limited marine specificity	High – Complements BEA by incorporating marine assets into national wealth.
TEEB	Value ecosystem services	- Robust ecosystem valuation methods	- Not an accounting framework	High – Provides valuation techniques for marine ecosystem services in BEA.

Framework	Objective	Strengths	Limitations	BEA Relevance
		- Biodiversity economics		
EU Sustainable Blue Economy Strategy (2021).	Promote a sustainable, climate-neutral, and resilient blue economy	- Integrated multi-sector governance - Circular economy - Climate and biodiversity focus - Strong policy coherence	- No standardised accounting methodology - Limited natural capital valuation	Very High – A comprehensive governance framework that requires BEA to systematically measure economic, environmental, and social performance.

Tropical Considerations

Tropical countries face a unique combination of ecological, socio-economic, and institutional challenges that distinguish them from temperate maritime economies. Marine productivity is highly seasonal due to monsoon-driven oceanographic processes, while extensive coral reef, mangrove, and seagrass ecosystems provide disproportionately high ecosystem services and blue carbon storage. At the same time, dependence on small-scale fisheries, informal coastal livelihoods, fragmented governance, and limited underwater monitoring infrastructure constrain evidence-based marine management. Conventional economic accounting fails to capture these dynamic ecological processes, informal economic contributions, and rapidly changing ecosystem conditions. Consequently, Blue Economy Accounting in tropical regions must integrate continuous environmental observations, natural capital valuation, and adaptive spatial planning within a unified decision-support framework.

This challenge is especially acute because they are increasingly threatened by climate change, overexploitation, pollution, habitat degradation, and rapid coastal development. (Craig, 2012) Sustainable development, therefore, requires moving beyond conventional economic accounting towards an integrated framework that recognises the true value of marine ecosystems and incorporates this value into policy and investment decisions.

Underwater Domain Awareness (UDA) Framework and Marine Spatial Planning (MSP)

A prerequisite for effective Blue Accounting is accurate, continuous, and spatially explicit information on underwater environments. Underwater Domain Awareness (UDA) is fundamental because it provides that information. UDA enhances conventional maritime awareness below the sea surface by integrating observations of marine ecosystems, fisheries, oceanographic processes, underwater infrastructure, and anthropogenic activities. (Das & Bangara, 2019) (Das, 2014) Data from underwater sensors, autonomous

vehicles, hydrographic surveys, satellite observations, fisheries databases, ocean models, and artificial intelligence are combined to generate an in-depth understanding of underwater dynamics.

By providing near-real-time information on ecosystem health, fish stock distribution, habitat condition, pollution events, and climate-induced changes, UDA transforms Blue Accounting from a static inventory into a dynamic decision-support system. This capability is notably valuable in tropical oceans, where ecosystems respond rapidly to monsoons, cyclones, coral bleaching, sediment transport, and changing oceanographic conditions. Rather than relying on periodic surveys, governments can continuously monitor marine assets through UDA, identify emerging risks, and implement adaptive management strategies before irreversible damage occurs. (Das, 2023)

The value of Blue Accounting extends beyond environmental reporting. It enables better decisions across fisheries, tourism, ports, offshore renewable energy, coastal protection, and marine conservation by providing a common evidence base for evaluating trade-offs between economic development and ecosystem sustainability. Investors, financial institutions, and development agencies increasingly demand measurable sustainability indicators before financing blue economy projects. (Asian Development Bank, 2023) (United Nations Environment Programme Finance Initiative, 2018) Blue Accounting provides this transparency, improving access to climate finance, blue bonds, and sustainable investment while lowering long-term environmental and economic risks and strengthening the case for policy and financing support.

The true transformational potential of Blue Accounting is realised when it is integrated with Marine Spatial Planning (MSP). MSP allocates marine space among competing uses—including fisheries, shipping, tourism, offshore energy, conservation, and coastal infrastructure—to maximise ecological, economic, and social benefits. (IOC- UNESCO, 2021) However, many MSP initiatives rely on fragmented datasets that insufficiently represent ecosystem functions and the economic value of marine resources. (Lester et al., 2013)

Integrating Blue Accounting with MSP creates a powerful evidence-based planning framework. Blue Accounting quantifies marine natural capital, ecosystem services, and sectoral economic performance, while MSP uses this information to optimise spatial allocation of ocean resources. (Gacutan et.al., 2022) Together, they enable governments to identify areas suitable for development, prioritise habitats that require protection, minimise user conflicts, and maximise long-term social benefits. Instead of responding to ecological degradation after it occurs, planners can anticipate risks, evaluate trade-offs, and design adaptive governance approaches based on continuously updated information, improving the quality and defensibility of policy decisions.

Underwater Domain Awareness significantly strengthens this integration by providing the real-time environmental intelligence required for adaptive Marine Spatial Planning. (Ananthi et al., 2026) (Cathrine, 2024) Rather than relying on static maps, MSP can incorporate near-real-time observations from UDA on ecosystem condition, biological productivity, underwater infrastructure, and human activities, for tropical countries facing rapid environmental change and increasing pressure on marine resources, UDA, Blue

Accounting, and MSP together represent a next-generation decision-support framework for sustainable ocean governance.

Five Pillars Framework for Blue Accounting

Recognising the need for a comprehensive accounting system customised for tropical maritime nations, a Blue Economy Accounting (BEA) Framework is proposed that integrates Blue Accounting principles with an Underwater Domain Awareness (UDA) architecture. The framework uses UDA to support Modelling and Simulation-based Marine Spatial Planning (MSP), national ocean policies, and sustainable blue economy investments by linking environmental, economic, social, and governance information within a single decision-support system.

The proposed BEA framework is organised around five interconnected pillars. The Natural Capital pillar measures the condition and extent of marine ecosystems and biological resources, including fish stocks, coral reefs, mangroves, seagrass beds, and marine biodiversity. (Luisetti & Schratzberger, 2023) The Ocean Economy pillar captures the contribution of ocean-dependent sectors such as fisheries, aquaculture, shipping, tourism, offshore energy, and marine biotechnology to GDP, employment, trade, and investment. (UNCTAD, 2025) The Ecosystem Services pillar values benefits often excluded from conventional accounts, including coastal protection, blue carbon storage, climate regulation, food provision, and recreation. (Rao etal., 2015) The Social and Equity pillar assesses livelihoods, food security, employment quality, equitable access to marine resources, and community resilience, ensuring that blue economy development remains inclusive. Finally, the Governance and Sustainability pillar evaluates institutional effectiveness, regulatory compliance, marine protected areas, fisheries management, and policy performance to maintain long-term sustainability. (Mast etal., 2025) (IOC-UNESCO, 2020)

Unlike existing blue economy accounting approaches, the proposed BEA framework is enabled by UDA across all five pillars. Continuous underwater observations and integrated data analytics provide a dynamic information backbone that links ecological, economic, social, and governance indicators within a single accounting system. (Gacutan et.al., 2022) This enables evidence-based policy, adaptive management, and periodic assessment of sustainability outcomes, strengthening the framework's central purpose.

Implementation ought to follow a phased approach. Countries should first establish standardised accounting methodologies aligned with international environmental-economic accounting systems while adapting indicators to local priorities. Investments in underwater observation infrastructure, interoperable marine data platforms, artificial intelligence, and geospatial analytics are essential for generating reliable information. Capacity building across government agencies, research institutions, and coastal communities should accompany these technology-based investments, while stakeholder participation guarantees transparency and incorporation of local knowledge. (UNESCO, 2026)

Several challenges remain. Long-term underwater datasets are limited across many tropical countries, institutional responsibilities are fragmented, and technical expertise in marine data analytics is often inadequate. Financial constraints additionally restrict investment in monitoring infrastructure. (Frazão Santos et al., 2021) These limitations can be overcome through regional coordination, phased implementation, open data standards, public-private partnerships, a modelling and simulation-based approach (Das, 2014), and sustained investment in capacity development. (UNESCO - IOC, 2021)

Pilot Blue Accounting initiatives in selected ocean sectors can demonstrate how UDA-enabled accounting supports evidence-based policymaking, sustainable investment, and adaptive marine governance. Developing sector-specific accounting methodologies for fisheries, coastal tourism, ports, offshore energy, and ecosystem conservation will provide practical models that can be scaled nationally and adapted across tropical regions.

Conclusion

Blue Accounting extends beyond conventional accounting to serve as a strategic governance tool for sustainable ocean management. Integrated with Marine Spatial Planning (MSP) and enabled by the Underwater Domain Awareness (UDA) framework—particularly through modelling and simulation—it provides tropical countries with the capability to value marine natural capital, optimise ocean use, minimise stakeholder conflicts, and balance economic development with ecological sustainability.

By addressing the dynamic ecological processes, climate vulnerabilities, biodiversity richness, and dependence on coastal livelihoods that characterise tropical marine systems, the proposed framework provides a region-specific approach to Blue Economy Accounting that supports resilient, evidence-based, and adaptive ocean governance.

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Ethics

This study did not involve human participants, animal experimentation, or the collection of personally identifiable information. Therefore, formal ethical approval was not required.

Declarations

Consent to Participate:

Not applicable, as the study did not involve human participants or direct data collection from individuals.

Consent to Publish:

Not applicable. No identifiable individual data, images, or personal information are included in this manuscript.

Author Contribution

J. Cathrine: Conceptualization, literature review, development of the Blue Economy Accounting framework, analysis and synthesis of existing blue economy and marine governance frameworks, preparation of the manuscript, and visualization of the proposed framework.Arnab Das: Conceptualization, development of the Underwater Domain Awareness framework and its integration with Blue Accounting and Marine Spatial Planning, critical review of the manuscript, and supervision of the overall research direction.Both authors: Contributed to the interpretation of the research findings, refinement of the proposed framework, revision and editing of the manuscript, and approved the final version for submission.

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Figures

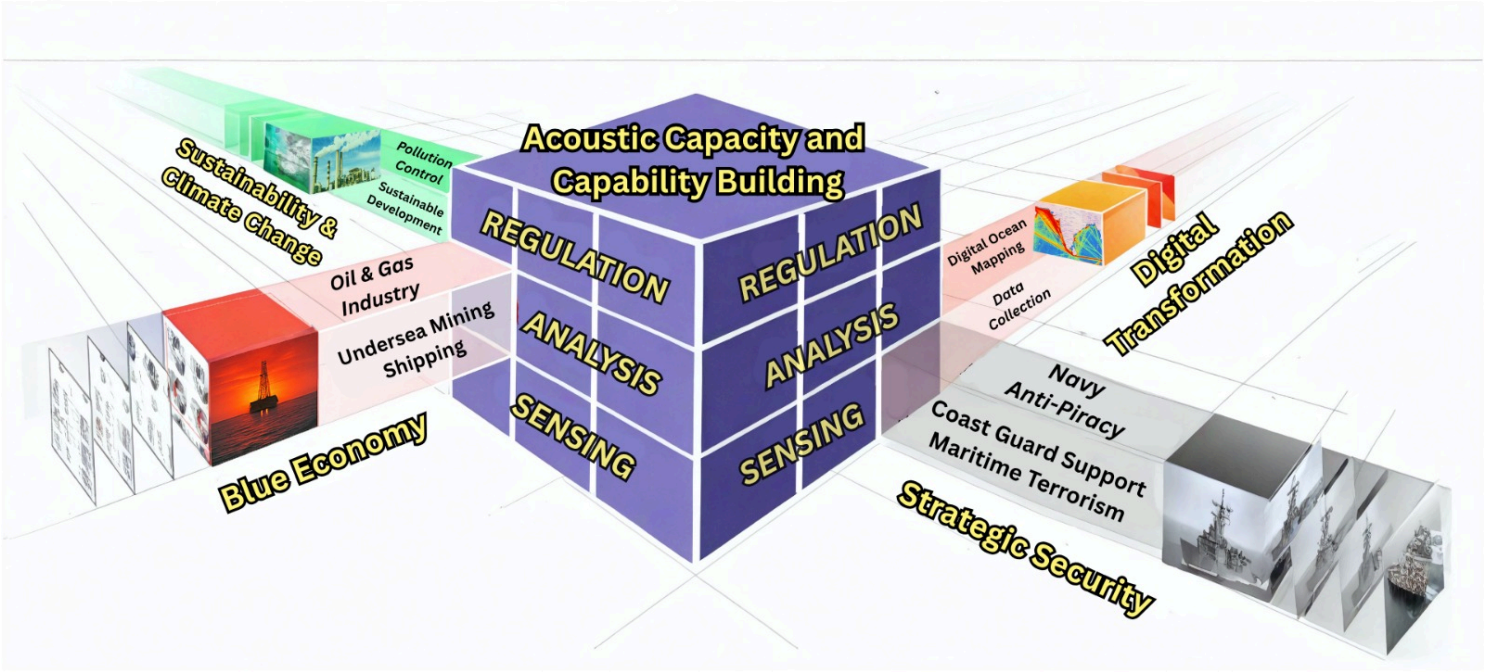


Figure 1

Underwater Domain Awareness (UDA) framework cube, Source: Maritime Research Center

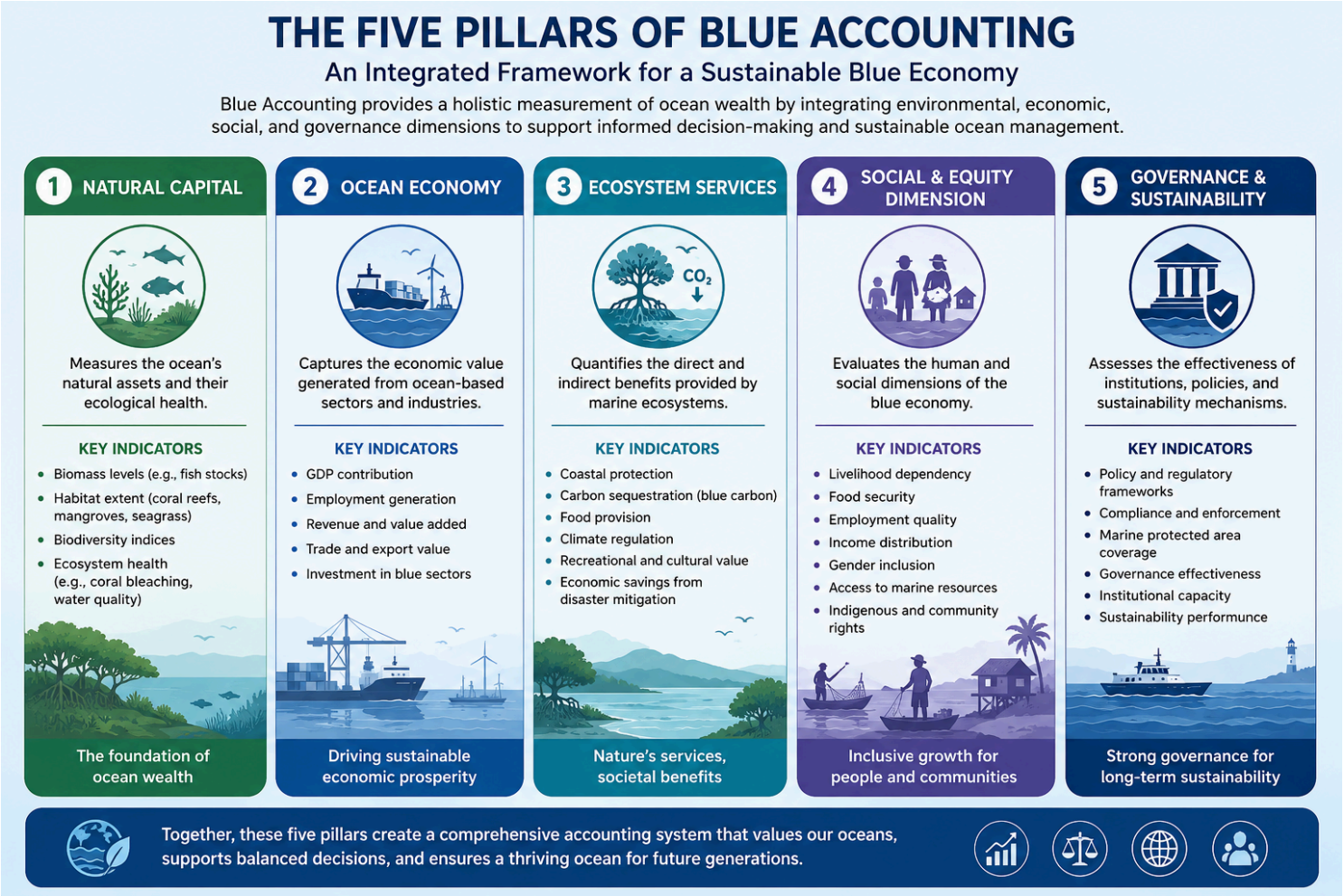


Figure 2

Five Pillars of Blue Accounting, Source: Maritime Research Center, Pune