Application of Electronic Monitoring in Marine Area Governance: Literature Review

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Abstract

Marine space is witnessing continuous changes, having implications on its ecosystem and its productive ability, a continuous source of human interest. Human dependency on the coastal and ocean for its ecosystem services and latter degradation driven by irregular exploitation is a matter of concern, which has been accelerated by issues like climate change, etc, leading to a man-made marine protection system, which in turn proved inadequate, needing an effective conservation system. In recent years, policy-makers have underscored the inadequate information on these subjects' undermining governance efforts and sought reliable data. Thus, electronic monitoring and collection of data-supported analysis become an effective tool for the lawmakers and implementing agencies. Further, acknowledging the fact that the ocean and its species are always in motion, undermining the static conservation efforts, urging mobile marine conservation efforts. This study conducts a literature review highlighting the inadequacies of the traditional marine conservation outcomes, leading to the emergence of electronic monitoring, data analysis, etc, supporting a marine conservation system, which is again looking for a responsive mobile marine protected areas governance system.

Keywords: *Electronic monitoring of marine space and species and governance efforts*

Introduction:

Marine space represents the majority of this planet. Coastal areas are the homes to a large portion of the global population and ecosystem. Coastal ecosystems and coastal communities have shared a bond since time immemorial. These ecosystem services, such as fisheries, are the primary source of livelihoods to the local communities. Coastal ecosystem services include nutrient cycling, food production, provision of habitat/refugia, disturbance regulation, natural barriers to erosion, control of water quality, and nursery grounds etc.[1] Coastal ecosystem representing coral reefs, oyster reefs, mangroves, and saltmarshes, seagrasses, and polychaete reefs acts as a natural guard against destructive waves and wind forces. [2] Its benefits remain a continuous attraction to the local and other dependent population for their livelihood and wellbeing.[3] Over the years, coastal communities have penetrated deep into this ecosystem, exploiting these resources, leading its irregular exploitation-related issues that need control and regulations.

Existing records state that over the centuries, human activities concentrated in coastal areas, whose ecosystem losses are severe.[4] These resources are under pressure linked to multiple stressors.[5] Overexploitation of these resources, such as fisheries, using destructive, unplanned and illegal fishing means and tools, and sedimentation extend pressures on other vulnerable resources. Coastal erosion is occurring fast and has had

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[1] Laura Airoldi & Michael W. Beck, 2007 Loss, Status and Trends for Coastal Marine Habitats of Europe, 45 Oceanography and Marine Biology: An Annual Review, 345 - 405.

[2] V Perricone, M Mutalipassi, A Mele, M Buono, D Vicinanza, P Contestabile, Nature-based and bioinspired solutions for coastal protection: an overview among key ecosystems and a promising pathway for new functional and sustainable designs, ICES Journal of Marine Science, Volume 80, Issue 5, July 2023, Pages 1218–1239

[3] Utpal Kumar Raha et al, (2021) Policy Framework for Mitigating Land-Based Marine Plastic Pollution in the Gangetic Delta Region of Bay of Bengal -A Review, 278 (1) Journal of Cleaner Production. P 1.

[4] Laura Airoldi & Michael W. Beck, 2007 Loss, Status and Trends for Coastal Marine Habitats of Europe, 45 Oceanography and Marine Biology: An Annual Review, 345 - 405.

[5] Shumham Krishna et al., (2025) Interactive Effects of Multiple Stressors in Coastal Ecosystems, Frontiers in Marine Science,

adverse impacts on the environment, economic and sociocultural implications.[6] Marine plastic pollution has serious adverse consequences for the coastal ecosystem services as well.[7] Coastal and marine resources depletion can be linked with multiple-use conflicts, lack of awareness and understanding, and ineffective management approaches.[8]

Global coastal regions' ecosystem loss intensification accelerates due to climate change, manifested by severe storms and wave actions, leading to rising sea levels. Further, increased population, infrastructure, ports, economic drives, etc, add to the vulnerability of the coastal biodiversity habitat losses.[9]

Thus, coastal and marine ecosystem health promotion, protection and resiliency efforts crucial to the existence of this civilisation are also an ongoing process. The Sustainable Development Goals (SDG) 14 where Target 14.5 prescribes '*By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information*' reflects the global community's commitment towards the conservation of coastal and marine areas.[10]

A majority of the legislative and institutional conservation arrangements recommended directly or indirectly managing and regulating human intervention in the coastal and marine ecosystem, leading to its loss. In particular, in contrast to the traditional sectoral approach of management, the integrated ecosystem-based approach of management has earned much reputation.[11] Ecosystem approach of management also includes adaptive management that recognises a continuous process of action based on doing, learning, sharing, and improving, depending on changing circumstances as driving factors as climate change, human pressure, etc. It aimed at a self-correction and mutual learning approach of conservation management suitable for the marine and coastal areas. A genuine Knowledge gap on marine and coastal species and their mutual interactions acknowledges the precautionary approach in conservation strategies, which is incorporated in the global and regional conservation agreements.[12] Spatial or area-based marine and coastal protected area management is gaining significance, acknowledging determined areas subjected to a law or other effective means to protect this enclosed environment.[13] All of these marine and coastal conservation management approaches bear certain fruits, still have proved to be weak conservation means in the long run. Their ability to produce effective conservation results is further compromised due to constant, however, dynamic change taking place in the coastal and marine ecosystem. Thereby, a potential marine and coastal conservation strategy should be responsive to the marine *movescape* (the flows and movements of the ocean and its inhabitants).

In this context, the current study intends to conduct a literature review showcasing the role of electronic monitoring of marine space and species for real-time data collection and analysis, supporting a marine and coastal conservation management system inspired by the digitally-driven Earth system governance. In particular, marine *movescape* is a conservation challenge and undermines area-based conservation benefits. Marine and coastal species in this ecosystem have a natural migratory nature. Thus, it is a challenge for an area-based conservation management plan seeking to implement a man-made discipline to a targeted ecosystem which keeps on moving and changing. The potential ecosystem depletion countermeasures may be less effective due to their inability to move with the targeted species. These vulnerable species and ecosystems naturally keep on moving by their choice and do not wait giving human an opportunity to complete their assistance programme.

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[6] V Perricone, M Mutalipassi, A Mele, M Buono, D Vicinanza, P Contestabile, Nature-based and bioinspired solutions for coastal protection: an overview among key ecosystems and a promising pathway for new functional and sustainable designs, ICES Journal of Marine Science, Volume 80, Issue 5, July 2023, Pages 1218–1239

[7] Utpal Kumar Raha et al, (2021) (2021) "Policy Framework for Mitigating Land-Based Marine Plastic Pollution in the Gangetic Delta Region of Bay of Bengal -A Review", 278(1)Journal of Cleaner Production,

[8] R. Ramesh, et al., (2011) Integrated Coastal and Estuarine Management in South and Southeast Asia, Eric Wolanski and Donald McLusky Eds.,11 Treatise on Estuarine and Coastal Science, Academic Press, Pages 227-263,

[9] Mohammad Aminur Rahman Shah, Quan Van Dau, Xiuquan Wang, 2025 Social-ecological vulnerability and risk to coastal flooding and erosion in major coastal cities, 118 International Journal of Disaster Risk Reduction

[10] See < https://www.globalgoals.org/goals/14-life-below-water/ > last visited 16th May 2025.

[11] AIDEnvironment, National Institute for Coastal and Marine Management/Rijksinstituut voor Kust en Zee (RIKZ), Coastal Zone Management Centre, the Netherlands.(2004). Integrated Marine and Coastal Area Management (IMCAM) approaches for implementing the Convention on Biological Diversity. Montreal, Canada: Secretariat of the Convention on Biological Diversity. (CBD Technical Series no. 14).

[12] Convention the Biological Diversity, the Code of Conduct on Responsible Fisheries, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Framework Agreement for the Conservation of Living Marine Resources on the High Seas of the South Pacific (The Galapagos Agreement).

[13] Convention the Biological Diversity, the Code of Conduct on Responsible Fisheries, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Framework Agreement for the Conservation of Living Marine Resources on the High Seas of the South Pacific (The Galapagos Agreement).

Therefore, in order to achieve conservation benefits, an effective conservation management strategy must be developed, keeping the migratory nature of the coastal and marine species in account. A potential conservation effort cannot avoid cohabiting and moving with these species. A proposed conservation management strategy also needed to be supported by the legislative and institutional efforts, which cannot be effective without knowing the whereabouts of the targeted victim species within its jurisdiction. A robust, digitally driven data collection and analysis may help effective policy making and implementation. The following section would like to trace evidence in the existing literature on how technology-driven real-time data collection has helped in reshaping marine and coastal conservation management.

Electronic Monitoring Driven Coastal and Marine Governance: Literature Review

Contemporary studies have underscored mobile boundaries in contrast to the traditional spatial management plan in coastal and marine biodiversity conservation. It is highlighting emerging digitally driven data-supported coastal and marine area governance.[14]

Chitra Sabapathy Ranganathan et al., (2023) Electronic monitoring of marine space helps safeguard its environment. This study used IoT and sensors, 4G, and Zignee technologies to collect, receive, transfer, analyze, process, query, and release data in monitoring the marine environment. It has taken the help of the tracking system of marine stations and buoys, collecting data wirelessly, wireless data transmission, control system of the platform, multiple sensors and the Internet of Maritime Things (IoMT) platform for long-range and high-rate maritime communication. This study suggested that an IoT-based maritime monitoring system provides precise and current readings of water quality, salinity, temperature, oxygen concentration, nutrient content and indicators of pollution, ecosystem degradation, and global warming effects. Such real-time data is indeed a great help to the response mechanism and implementing conservation measures, helping in protecting ocean biodiversity and health.[15]

Aloysius T.M. van Helmond et al. (2020), studied on global EM trial and programme in fishing activities, given the relevant data requirement on fish population status for its potential role in fish stocks management. EM on fishing activities has emerged as an effective tool for regulators and policymakers for monitoring and control in fisheries due to the limitations of traditional fish stock recording methods.[16] It has studied 100 EM trials and 12 fully implemented EM programmes worldwide in North America, Tropical Tuna Fisheries, Australia and New Zealand, South and Central America and Europe.[17] Among these countries, the US and Canada have used the highest number of EM equipped vehicles. This study suggested EM generated data as a reliable source of catch information.

C. Vilas et al. (2020) studied the use of iobserver on board fishing vessels for digital monitoring.[18] **Karen Bakker, (2022)** also pointed out smart ocean initiatives. It consists of an engaging improved ocean monitoring system with the help of 'computationally intensive, wide-scale deployment of multiple digital technologies to monitor multiple oceanographic and marine ecological variables in real time, at scale'. **Jorge E. Corredor (2018)** provided a detailed work on integrated coastal ocean observing systems.[19] **Ines Dumke, et al., (2018)** dealt with the application of cable networks in deep-sea area study.[20]

EM driven data supported conservation appears to be effective in contrast to the human observers' data helped conservation.[21] **Barreiro et al., (2025)** have conducted a thorough study on the efficacy of modern EM in

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[14] Sarah Burch *et al*., (2019) New directions in earth system governance research, 1 Earth System Governance

[15] Chitra Sabapathy Ranganathan *et al*., (2023), Proceedings of the International Conference on Sustainable Communication Networks and Application (ICSCNA 2023) IEEE Xplore.

[16] Aloysius T.M. van Helmond et al., (2020) Electronic Monitoring in Fisheries: Lessons from Global Experiences and Future Opportunities, 21 Fish and Fisheries.

[17] Aloysius T.M. van Helmond et al., (2020) Electronic Monitoring in Fisheries: Lessons from Global Experiences and Future Opportunities, 21 Fish and Fisheries.

[18] C. Vilas et al., (2020). Use of Computer Vision onboard Fishing Vessels to Quantify Catches: the iobserver, Marine Policy.

[19] Jorge E. Corredor (2018) Coastal Ocean Observing, Springer

[20] Ines Dumke, et al., (2018) First hyperspectral imaging survey of the deep seafloor: High-resolution mapping of manganese nodules, 209 Remote Sensing of Environment,
Volume 209,

[21] Barreiro et al., (2025) Development of Smart Electronic Observation Onboard Technologies for more Sustainable Fisheries Management, Frontiers in Marine Science.

monitoring, surveillance and controlling catch and bycatch in Europe. It is suggested that EM is an effective management tool. This study has suggested that the EM data can be imported with the help of artificial intelligence tools to contribute improved conservation management system. A series of case studies using EM demonstrated positive conservation outcomes in species management. **Christopher J. Brown (2021)** studied across the Exclusive Economic Zone of three Western-Pacific Island nations: the Republic of Palau, the Republic of the Marshall Islands and the Federated States of Micronesia and argued for Electronic Monitoring (EM) systems in fishery critical to ensure sustainable management of tuna fisheries, mitigating their environmental impacts and managing trans boundary fish stocks and manage environmental impact on the bycatch species. They compared catches of tuna and bycatch species corresponding EM, logbook and human observer data. It revealed an under-reported retained catch by up to three times and no report on discarded species, bycatch species, in the logbooks. The discarded species include threatened species such as marine turtles. Further, EM records show higher species diversity than the logbook. Finally, this study suggests EM feed information can contribute to the improved management of catch and bycatch species.[22]

Sara M. Maxwell et al., (2020), again in the context of draft biodiversity beyond national jurisdiction negotiations underscores static management system challenges in the protection of mobile migratory species in the High Sea.[23] **Karen Bakker, (2022)** has pointed out that real-time information, comprehensive spatial coverage, and both temporal and geographical mobility are crucial to a dynamic ocean management system. For this large amount of contemporaneous data to be generated digitally (cloud computing architectures and ocean monitoring networks including satellites, sensors and cable subsea instrumented observatories with the help of artificial intelligence processing and integration.

Paolo Cappa et al. (2024) have produced a comparative study between AIS estimated likely catch volume and reported catches in Exclusive Economic Zone or high seas areas of the Indian Ocean Industrial fisheries between 2018 and 2020. The difference between reported catch statistics (to the FAO) and unreported catches and discarded bycatch appears to have a detrimental implication on effective management and control in the Indian Ocean fisheries. It has studied data provided by the Global Fishing Watch on AIS signals and efforts to estimate fishing efforts by vessel indicators of catches. This study showed that IOR countries' fish catches statistics are underreported by approximately 25%, linked with poor and questionable data reporting by some IOR fishing countries; thus, AIS-driven data prescribes more reliable information on fisheries. This study also indicated the IOR countries' reliance and avoidance of IAS and the distant water fishing countries' pattern of using this system, leading to the unreported catches and bycatches in this region. It has concluded that AIS-equipped vessels' potential role in estimating fishing activities in the Indian Ocean, helping to bridge gaps between estimated, actual and reported catches and bycatches by IOR countries, distant water countries and more specifically by IIU fishing. It has highlighted that a large number of fishing vessel do not has AIS facilities, or the avoidance of this system by both the distant water fishing countries (China) and IOR countries is a barrier to sustainable fishing in terms of monitoring, controlling and regulating of Indian Ocean fishing.[24] Further, AIS-equipped vessels' ASI catch estimates are much lower than reported catches, indicating they stop using AIS to avoid surveillance by local authorities. Finally, this study underscored the significance of AIS-equipped fishing vessels for a reliable set of estimated catches, actual catches and bycatch for a healthy fishery management in IOR.

Jie Li et al. (2024) studied the satellite automatic identification system (ASI) and remote sensing monitoring of fishing vessels in the Northern Indian Ocean, including the Red Sea to the Bay of Bengal.[25] It signifies ASI-led data use in global fishing and sought to study the spatial-temporal distribution and variation of fishing vessels in the Northern Indian Ocean between March 2020 and February 2023, which may provide spatial–temporal distribution of fishery resources information supporting marine ecological protection, marine spatial planning and management. This study suggested high concentrations of fishing vessels surrounding areas of the Exclusive Economic Zone of the Maldives, the Palk Strait, the coastal areas of India, the Seychelles, and the Gulf of Bahrain during the northeast monsoon (October to March). Moreover, in contrast to the summer monsoon (April-September), the northeast monsoon (winter) appears to be suitable for fishing operations.

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[22] Christopher J. Brown et al., (2021) Electronic Monitoring for Improved Accountability in Western Pacific Tuna Longline Fisheries, Marine Policy.

[23] Maxwell SM et al., (2020). Mobile protected areas for biodiversity on the high seas. Science. Jan 17;367

[24] Paolo Cappa *et al*., (2024) Estimating Fisheries Catch from Space: Comparing Catch Estimates Derived from AIS Fishing Effort with Reported Catches for Indian Ocean Industrial Fisheries 77 Regional Studies in Marine Science.

[25] Jie Li et al., (2024) Monitoring Off-Shore Fishing in the Northern Indian Ocean Based on Satellite Automatic Identification System and Remote Sensing Data, 24(3) Sensors.

In the Indian context, there are studies on electronic monitoring in the coastal waters. **T.M. Balakrishnan Nair, et al., (2024)** has studied the use of the Water Quality Nowcasting System (WQNS) by the Indian National Centre for Ocean Information Services (INCOIS) for addressing water quality monitoring in Indian coastal waters. It is supported by two buoys equipped with different physical-biogeochemical sensors, data telemetry systems, and integration with satellite-based observations for real-time data transmission to land. This study indicated the ability of this electronic monitoring system to detect changes in the water column properties.[26]

The setting up R&D Hubs in the nine coastal states to promote the use of Artificial Intelligence (AI) and other new technologies in marine sectors such as deep-sea mining, marine logistics and shipping will further catalyse the development of the Blue Economy.[27] Further, the defence ministry recently signed a Rs 1,600 crore agreement for six AI-equipped patrol vessels for the Indian Coast Guard.[28]

Electronic Monitoring system Driven MMPS in ocean governance

Anthropocene ocean governance systems are designed for a tenure focusing on a marine space that often fails to respond to changes taking place in this marine space, linked with the dynamic marine system. A dynamic marine system is linked with large-scale evolution in boundary conditions, including interlinked processes of climate change, transgressions of planetary boundaries, and socio-economic transformations etc. A static ocean governance framework based on the prior study can be strengthened with the help of information concerning real-time environmental variability, species mobility, and disturbance dynamics. Existing knowledge by the scientists and regulators is increasingly recommending the deployment of these AI-powered computational systems in the world's oceans based on Mobile Marine Protected Areas.

MMPAs have become pertinent in the governance of environmental transformations and the use of digital transformation, and evolving earth system governance norms, frameworks, and paradigms. In this context, we can refer to certain studies, focusing on AI algorithms for driving in monitoring marine environments and their potential role in environmental regulations and (re)negotiation of global marine governance.

Bruch et al. (2019) have identified the gap in the existing earth governance system, indicating alternative futures governance suitable for the environmental transformations. The following studies indicate how technology-driven information supports meeting governance outcomes. **Karen Bakker, (2022)** has focused on potential coastal and marine governance transformation when it is supported by Artificial Intelligence-driven information. His study further indicated the possible transformation in environmental regulation and global commitments in the marine space. This study has mapped the governance subject. In simple words, the oceans are continuously in motion, with winds, thermohaline circulation currents - the conveyor belt, transferring energy, mass, driving the concentration of food and marine predators. Marine space's natural conditions are again affected by temperature and climate change implications to varying degrees. As **Brian R Mackenzie et al. (2014)** suggested, Atlantic tunas are travelling thousands of miles to the coast of Greenland - an example of the ocean's movescape and governance challenge with a manmade jurisdiction. In this context, monitoring subjects and adopting and implementing governance mandates becomes challenging. **Karen Bakker (2022)** provided evidence of EM application to identify and track the location of endangered whales in the Santa Barbara Channel, Right Whales in the Gulf of St Lawrence, and Tuna in the Great Australian Bight. Thereby, mobile catch restrictions can be prescribed and implemented for the conservation of these species.

Sara M. Maxwell et al., (2015) reiterated the distinction between the terrestrial and marine features and highlighted for suitable management system for marine space as distinct from the terrestrial management system.[29] This study categorically stated that a static approach for terrestrial management may not be suitable for the oceans' temporal and spatial variability. In contrast to the static terrestrial management approaches, this study argues for a dynamic ocean management system which is fluid in space and time, suitable to the dynamic marine

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[26] T.M. Balakrishnan Nair, *et al*., (2024) An integrated buoy-satellite based coastal water quality nowcasting system: India's pioneering efforts towards addressing UN ocean decade challenges, 354 Journal of Environmental Management.

[27] (India'a Blue Economy, A Draft Policy Framework 2020)

[28] < https://indiaai.gov.in/article/guardians-of-the-waves-harnessing-ai-for-coast-guard-excellence > visited Feb 20th 2025.

[29] Sara M. Maxwell et al., (2015) Dynamic Ocean Management: Defining and Conceptualising Real-time Management of the Ocean, Marine Policy

environment, marine species movements (probable animal habitat), and marine resource users. Thus, there is emerging ideas of mobile marine protected areas (MMPAs).

Bakkar defines MMPAs are geographically dynamic with mobile boundaries which change position as endangered species migrate through the ocean.[30] In contrast to the traditional approach to protect fixed areas, mobile protected area boundaries respond to changing environmental conditions, movements of protected species and disturbance dynamics. MMPAS rely on digitally driven information derived with the help of e.g. nano-satellites, drones, environmental sensor networks, digital bioacoustics, marine tags, deep-sea UAVS. It gets further support by analytics provided by machine learning algorithms, computer vision and ecological informatics techniques.[31]

Concluding Remarks:

MMPAs are an approach to Marine Governance focusing on the environmental transformation in the marine *movescape*. It suggests digital marine monitoring tools can be helpful in studying and prescribing responsive conservation strategies in the Marine space. MMPAs are an emerging ocean management system of this digital age, reliant on digital data and algorithms. It says '*follow the fish*'.

[30] Karen Bakker, (2022) Smart Oceans: Artificial intelligence and marine protected area governance, 13 Earth System Governance, p 1.
[31] Karen Bakker, (2022)