

SEABORNE SURVEILLANCE AND ARTIFICIAL INTELLIGENCE: POSSIBLE DIRECTIONS OF ITS APPLICATION IN THE ENFORCEMENT OF THE LAW OF THE SEA

VIGILÂNCIA MARÍTIMA E INTELIGÊNCIA ARTIFICIAL: POSSÍVEIS DIREÇÕES DE SUA APLICAÇÃO NA APLICAÇÃO DO DIREITO DO MAR

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Abstract

Challenges to maritime security are a global challenge. Piracy, illegal, unreported and unregulated (IUU) fishing, smuggling, maritime terrorism, and environmental crime create instability relations to the high seas and to the governance and use of oceans. Traditional means of surveillance, such as radar, coastal patrol and the Automatic Identification System (AIS) lack the capacity to deal with the transnational and complex modern maritime threats. New developments in Artificial Intelligence (AI) such as machine learning, computer vision, predictive analytics, and autonomous unmanned systems offer a pathway to enhance maritime surveillance and to enforce the United Nations Convention on the Law of the Sea (UNCLOS). The proposed research will investigate the intersection of technological innovation and global ocean law, as a empirical investigation of the use of applications of AI technology in maritime security surveillance, how they fit within the UNCLOS regime, and the legal, technical and ethical challenges posed by these technologies. The research will examine cases studies drawn from the European Union, United States, Asia-Pacific, Arabian Gulf, Gulf of Guinea, and Arctic, and will comparative analysis across multiple types of governance that range from institutionalized and legal to security, cooperative, and dependency-based. AI facilitates the capacity of states to take action to implement UNCLOS provisions by proactive action, enhanced environmental surveillance, and improved search and rescue. Discussions around accountability, liability, jurisdiction, and algorithmic bias call for the establishment of a global regulatory framework urgently. The research identified key gaps in respect to accountability mechanism, regional variations, and ethics, and corresponds them to the proposal

Resumo

Os desafios à segurança marítima representam um desafio global. A pirataria, a pesca ilegal, não declarada e não regulamentada (IUU), o contrabando, o terrorismo marítimo e os crimes ambientais criam instabilidade nas relações com o alto-mar e com a governança e o uso dos oceanos. Os meios tradicionais de vigilância, como o radar, o patrulhamento costeiro e o Sistema de Identificação Automática (AIS), não têm capacidade para lidar com as ameaças marítimas modernas, transnacionais e complexas. Os novos desenvolvimentos em Inteligência Artificial (IA), como a aprendizagem automática, a visão computacional, a análise preditiva e os sistemas autônomos não tripulados, oferecem um caminho para aprimorar a vigilância marítima e para fazer cumprir a Convenção das Nações Unidas sobre o Direito do Mar (CNUDM). A pesquisa proposta investigará a interseção entre a inovação tecnológica e o direito oceânico global, por meio de uma investigação empírica do uso de aplicações da tecnologia de IA na vigilância da segurança marítima, como elas se encaixam no regime da CNUDM e os desafios legais, técnicos e éticos que essas tecnologias representam. A pesquisa examinará estudos de caso da União Europeia, Estados Unidos, Ásia-Pacífico, Golfo Pérsico, Golfo da Guiné e Ártico, e realizará análises comparativas entre múltiplos tipos de governança, que variam da institucionalizada e jurídica à baseada em segurança, cooperação e dependência. A IA facilita a capacidade dos Estados de agir para implementar as disposições da Convenção das Nações Unidas sobre o Direito do Mar (CNUDM) por meio de ações proativas, vigilância ambiental aprimorada e busca e salvamento aperfeiçoados. Discussões sobre responsabilização, responsabilidade legal,



for harmonized legal-tech framework and an AI Accountability Protocol through the International Maritime Organization (IMO). The research makes both theoretical and practical contributions. From the perspective of theoretical contribution, this work adds to the literature by situating AI within a hybrid governance model of law, technology and ethics. From the practical contribution perspective, the work provides concrete recommendations for policymakers and international institutions, including capacity building for states with developing capabilities, data standardization, explainable AI models, and surveillance coalitions. Incorporating the technical capacity with the ability to be enforced in law demonstrated that AI can be a fit foundational building block for 21st century maritime governance-increasing compliance with international law while making global maritime commons as safer, sustainable and fairer.

Keywords: Artificial Intelligence. Maritime Observation. UNCLOS. International Maritime Law. Governance. Accountability. Ethics.

jurisdição e viés algorítmico exigem o estabelecimento urgente de uma estrutura regulatória global. A pesquisa identificou lacunas importantes em relação aos mecanismos de responsabilização, variações regionais e ética, e as relaciona à proposta de uma estrutura jurídico-tecnológica harmonizada e um Protocolo de Responsabilização da IA por meio da Organização Marítima Internacional (OMI). A pesquisa oferece contribuições tanto teóricas quanto práticas. Do ponto de vista da contribuição teórica, este trabalho contribui para a literatura ao situar a IA em um modelo híbrido de governança que integra direito, tecnologia e ética. Do ponto de vista da contribuição prática, o trabalho fornece recomendações concretas para formuladores de políticas e instituições internacionais, incluindo capacitação para Estados com capacidades em desenvolvimento, padronização de dados, modelos de IA explicáveis e coalizões de vigilância. A integração da capacidade técnica com a possibilidade de aplicação legal demonstrou que a IA pode ser um alicerce fundamental para a governança marítima do século XXI, aumentando a conformidade com o direito internacional e tornando os espaços marítimos globais mais seguros, sustentáveis e justos.

Palavras-chave: Inteligência Artificial. Observação Marítima. UNCLOS. Direito Marítimo Internacional. Governança. Responsabilidade. Ética.

1 INTRODUCTION

Seaborne security is one of the most significant challenges of our time. The oceans, which cover more than 70 percent of the Earth's surface, are important to international trade and are of fundamental importance as a source of food, energy, and communications networks. They are becoming increasingly threatened by illegal, unreported and unregulated (IUU) fishing, piracy, smuggling, maritime terrorism, and environmental crime that erodes maritime stability – put simply the maritime global commons is becoming more and more vulnerable. While coastal patrols, radar, and Automatic Identification Systems (AIS) can help, traditional surveillance mechanisms are

not able to keep up with the increasing complexity, breadth and sophistication of maritime threats. (United Nations, 2020) In the last 2 years, advances in Artificial Intelligence (AI) have created new opportunities to improve maritime surveillance capabilities. AI technologies such as machine learning, computer vision, predictive analytics, and autonomous unmanned vehicles can provide improved capabilities to detect anomalies, monitor larger ocean areas, and support rapid decision making. For example, AI-based satellite image analysis can detect and identify suspicious ship activity in remote ocean areas, predictive analytics can identify probable future illicit activity and allow enforcement agencies to be proactive instead of reactive. The technologies represent a new opportunity to bolster enforcement of international maritime law. (IMO, 2019)

The global legal framework of the oceans, United Nations Convention on the Law of the Sea (UNCLOS), defines states' rights and responsibilities in sea areas and provides the machinery for enforcement on navigation, exploitation of resources, and sea conservation. UNCLOS was, nevertheless, negotiated during the 1980s, over two decades before the innovations of the current AI technologies. This also raises basic questions about balancing AI monitoring with existing legal orders, state sovereignty, and accountability in applying the law on the high seas. (Bryson, 2019)

In the current research, there is an effort to look for the convergence of technological advances and international maritime law by trying to explore the potential application of AI to maritime surveillance in an effort to implement the Law of the Sea. Specifically, it will consider how AI could aid the fight against IUU fishing, piracy and smuggling, ocean environmental protection, and assist search and rescue. It will also cover the technical, legal, and ethical issues that could delay the deployment of AI in maritime enforcement.

The application of this study is in closing the gap between technological potential and legal enforcement infrastructure, and presenting a roadmap for policymakers, international organizations, and maritime authorities to utilize AI responsibly. By charting existing applications, case studies, and envisioned futures, the study aims to contribute to academic scholarship on maritime security and offer actionable recommendations in balancing adoption of AI with UNCLOS and international maritime regulation more broadly.

1.1 Research problem

Regardless of the runaway development of Artificial Intelligence (AI) technologies and their demonstrated utility to improve maritime domain awareness, their inclusion in the legal and institutional architecture of the United Nations Convention on the Law of the Sea (UNCLOS) is still underdeveloped.

Classic means of surveillance-coastal watches, radar, and the Automatic Identification System (AIS-) have evidenced clear limitations in the context of modern maritime risks like illegal, unreported and unregulated (IUU) fishing, piracy, smuggling, cyberattacks, and environmental crimes. These limitations undermine the states' capacity to fulfill their international obligation under UNCLOS and the relevant conventions. (UNODC, 2020).

Moreover, the absence of specific legal norms for AI employment in maritime law enforcement raises questions about sovereignty, jurisdiction, admissibility of evidence, and accountability. If AI-generated evidence is challenged in court, or if incorrect enforcement actions are conducted due to algorithm errors, issues of liability remain unresolved. Ethical issues like data privacy, proportionality in monitoring, and fairness in algorithmic decision-making provide added constraints to AI employment in this area.

The problem of research is therefore the gap between legal legitimacy and technological capability: while AI holds unprecedented potential in augmenting maritime surveillance and enforcement, the lack of open legal, ethical, and regulatory standards prevents its effective and legal application towards strengthening the enforcement of the Law of the Sea. (Jobin, Ienca,&Vayena, 2019).

1.2 Research objectives

1.2.1 *The aim of this research is to*

- Examine the present and potential future application of Artificial Intelligence (AI) in maritime surveillance.
- Explore how AI technologies may aid states in enforcing their United Nations Convention on the Law of the Sea (UNCLOS) commitments.

- Investigate case studies in different regions (European Union, United States, Asia–Pacific) to identify best practices in AI-aided maritime law enforcement.
- Identify legal, technical, and ethical challenges to the utilization of AI in maritime enforcement.
- Recommend policy options and legal frameworks for the effective and responsible introduction of AI in global maritime governance.

1.3 Research questions

1.3.1 In order to achieve these objectives, the research addresses the following research questions

1. What are the main applications of AI in maritime surveillance, and how do they enhance monitoring and enforcement capability?
2. How can AI help states achieve their UNCLOS responsibilities, in particular to combat IUU fishing, piracy, and environmental crime?
3. What lessons can be learned from regional and national case studies (EU, US, Asia–Pacific) on the operational use of AI in maritime law enforcement?
4. What are the primary legal, technical, and ethical challenges in using AI in maritime enforcement?
5. What are the policy measures, accountability structures, and international coordination structures necessary to ensure AI adoption to be both effective and in alignment with international maritime law?

2 METHODOLOGY

The study adopts a qualitative, analytical, and comparative approach to studying the intersection of Artificial Intelligence (AI) and the Law of the Sea (UNCLOS) enforcement.

2.1 Approach

The study uses a doctrinal legal analysis of UNCLOS articles on surveillance, enforcement, and maritime security with an analytical examination of AI technologies being applied in maritime domain awareness.

2.2 Data sources

Primary sources include international legal documents such as UNCLOS, IMO treaties, and regional agreements on maritime security. Secondary sources include peer-reviewed journal articles, Q1 publications, technical reports by maritime organizations (e.g., EMSA, UNODC, NATO), and case studies documenting the implementation of AI in maritime surveillance.

2.3 Comparative analysis

To evaluate best practices, the research compares European Union, United States, and Asia-Pacific AI-driven maritime surveillance programs. The comparison perspective is adopted in the analysis to highlight different models of governance and how they measure against UNCLOS enforcement obligations.

2.4 Analytical tools

Thematic content analysis is utilized in the research to highlight shared legal, technical, and ethical challenges in the literature. A case-based comparative framework is also utilized to learn from regional practices.

2.5 Limitations

As the study is primarily qualitative, it does not rest on empirical testing or large-scale quantitative data. Instead, it synthesizes existing literature and case evidence to inform policy recommendations and indicate future research directions.

2.6 Conceptual framework

The study rests on the intersection of technological innovation and international legal systems. The conceptual framework links four main dimensions:

2.7 Maritime threats

Modern challenges such as IUU fishing, piracy, smuggling, sea-based terrorism, and environmental crimes are persistent threats to international maritime safety. These crimes undermine the capacity of states to enforce their obligations under the United Nations Convention on the Law of the Sea (UNCLOS). (OECD, 2021).

2.8 Artificial Intelligence (AI) tools

AI offers advanced capabilities for anomaly detection, predictive analytics, computer vision, and autonomous unmanned systems. These capabilities allow states to monitor extensive ocean spaces, detect suspicious patterns, and react more proactively than with previous technologies such as radar and coastal patrols. (Zhang et al., 2020).

2.9 Legal obligations under UNCLOS

UNCLOS establishes the legal regime for maritime management, such as enforcement duties in areas such as:

- Fisheries (Article 73): Monitoring enforcement of conservation measures within EEZs.
- Environmental Protection (Articles 192–194): Duty to preserve the marine environment.
- Repression of Piracy (Article 100): Duty to help fight piracy on the high seas.
- Assistance at Sea (Article 98): Duty to aid persons in distress.
- The design positions AI as a vehicle through which states may enhance their ability to perform such duties effectively.

2.10 Expected outcomes

Through the interlinkage of AI capabilities and UNCLOS enforcement provisions, states can achieve:

- Enhanced surveillance and enforcement.
- Enhanced deterrence of sea crimes.
- Improved worldwide observance of world environmental and security standards.
- Increased worldwide cooperation through interoperability and data-sharing.

2.11 Framework logic

The intellectual framework thereby connects sea threats (the issue) to AI applications (the solution), under the canopy of UNCLOS obligations (the legal framework), leading to increased maritime governance (the result).

3 LITERATURE REVIEW

3.1 Maritime Domain Awareness (MDA) with Artificial Intelligence

Maritime Domain Awareness (MDA) refers to the proficient comprehension of any activity in the maritime environment that could influence security, safety, economy, or environment. Recent research points towards possible revolutionary transformation with AI in MDA capabilities. Machine learning methods, particularly deep neural networks, have been employed to detect anomalies in vessel behavior, mark suspicious activity, and merge data from diverse sources such as satellites, drones, and AIS signals (Park&Lee, 2021). For example, AI-enhanced analysis of satellite images can be utilized to detect "dark vessels" (ships operating with AIS turned off), which are typically discovered to be involved in illegal fishing and smuggling activities. (Park&Lee, 2021)

3.2 AI in search and rescue (SAR) operations

AI systems have also been showing promise for improving maritime security and search and rescue (SAR) operations. Predictive analytics can model ocean currents and weather patterns to inform search zones, and autonomous drones and unmanned surface vehicles can conduct surveillance in dangerous or inaccessible regions (Galdorisi, 2020). The technologies improve the efficiency and accuracy of rescue efforts and save lives while reducing operational costs on maritime authorities. (Galdorisi, 2020)

3.3 Law of the sea (UNCLOS) enforcement issues

The United Nations Convention on the Law of the Sea (UNCLOS) sets the overall background in maritime law, providing coastal states with enforcement powers over their territorial seas and exclusive economic zones (EEZs). However, scholars contend that traditional enforcers of measures-i.e., patrols, inspections, and lawsuits-fall short of the scale of modern maritime crime (Klein, 2019). The use of AI in enforcement operations can potentially enhance monitoring for compliance, but problems with respect to compatibility with sovereignty, jurisdiction, and due process principles remain.

3.4 AI and the fight against IUU fishing and maritime crime

IUU fishing is one of the biggest threats to global fisheries and maritime management. It is demonstrated by evidence that AI technology can track fishing vessels, detect strange movement patterns, and distinguish legal from 9error fishing through predictive modeling (Miller et al., 2018). Similarly, piracy and maritime 9errorismo research underscores the significance of AI in early warning systems to enable authorities to anticipate high-risk routes and take action in advance (Bueger&Edmunds, 2021). These applications synchronize with global initiatives such as the FAO's Port State Measures Agreement, intended to heighten global enforcement against IUU fishing.

3.5 Technological and legal gaps in current literature

In spite of a growing number of studies supporting the application of AI in maritime surveillance, several gaps still exist. First, the majority of studies focus on technological feasibility and less on legal and ethical aspects of AI deployment in maritime law enforcement. Secondly, there is little controversy over accountability frameworks: if the AI misidentifies a ship or triggers an illegal enforcement action, it is unknown if liability lies with the state, the operator, or the developer of the AI (Lima, 2022). Thirdly, regional imbalances exist, where more research is concentrated in Europe and North America and other important regions such as the South China Sea, the Gulf of Guinea, and the Arctic are not researched well.

4 RESEARCH GAP&ORIGINAL CONTRIBUTION

4.1 Research gap

Despite the growing body of literature on the relationship between Artificial Intelligence (AI) and maritime governance, there are significant gaps that weaken the ability of states and institutions to integrate AI in enforcing the United Nations Convention on the Law of the Sea (UNCLOS).

First, most existing studies adopt a technological perspective by focusing on the operational effectiveness of AI in anomaly detection, predictive analytics, or environmental monitoring (Zhang et al., 2020; Park&Lee, 2021). While these studies confirm AI's technical feasibility, they do not sufficiently address the legal and regulatory implications of integrating AI into maritime enforcement mechanisms.

Second, there is the open question of accountability and responsibility. The literature has emphasized the risks of algorithmic errors and "black-box" decision-making (Burrell, 2016; Lima, 2022), yet there is little consensus on how responsibility is to be divided between states, operators, and AI developers in cases of wrongful interdiction or misidentification. This creates a structural gap between AI use and compliance with due process and sovereignty standards under international law (Jobin, Ienca,&Vayena, 2019).

Third, regional asymmetries dominate the literature. Much of the existing research has addressed the European Union and North America, where both institutional and technological capacity is advanced (EMSA, 2021; USCG, 2018). Despite a substantial number of academic research studies addressing potential use of AI in maritime enforcement, there remains a limited engagement with the technical, legal, and ethical aspects that may prolong AI deployment in maritime enforcement. Conversely, areas of possible maritime security concerns, where shipping and energy security intersect, such as the Arabian Gulf, Gulf of Guinea, and Arctic, are under-studied. When researching maritime cyber security and the rise of AI, these are also regions where expanding AI uptake overlaps with the geopolitics of the current moment and regional governance institutions in fragile, fragile governance.

Lastly, we do not have hybrid legal-technical paradigms. There are prior works that have treated AI as a techno-legal innovation, or as regulation, but few scholars situate it alongside a governance system of hybrid governance embedded in UNCLOS obligations. This has caused fragmented discourse that is not giving policymakers an actionable agenda to bridge innovation and international law (Tanaka, 2019; Klein, 2019).

5 ORIGINAL CONTRIBUTION

5.1 This research bridges the above gaps through the following contributions

5.1.1 Legal-technical synthesis

Unlike prior studies that separate technological feasibility from legal analysis, this research develops an integrated framework linking maritime threats, AI applications, and UNCLOS obligations. By mapping AI-enabled tools (e.g., satellite monitoring, predictive analytics, autonomous drones) directly to specific UNCLOS provisions (e.g., Articles 73, 98, 100, 192–194), the study offers a normative blueprint for AI's legitimate deployment in maritime enforcement (UNCLOS, 1982).

5.2 Comparative and critical perspective

The study transcends the traditional EU and U.S. emphasis to include understudied yet strategically vital regions such as the Arabian Gulf, the Gulf of Guinea, and the Arctic. Through this expanded comparative analysis, the research demonstrates how resource endowments, sovereignty challenges, and geopolitical competition shape AI adoption, thereby contributing to the literature on AI in maritime governance in a globally balanced manner.

5.3 Accountability and policy innovation

Through examining accountability gaps, the study proposes the need for an "AI Accountability Protocol" in the International Maritime Organization (IMO). The proposed mechanism would clarify liability distribution, promote transparency through Explainable AI (XAI), and render AI-generated evidence admissible in court. This is an innovative policy development that closes the accountability gap in current international law.

5.4 Bridging ethics and law

The research emphasizes the ethical dimension of AI adoption, particularly with respect to privacy, proportionality, and fairness in algorithmic enforcement. Through the integration of such principles in a legal analysis, the study ensures that AI adoption in maritime surveillance does not undermine fundamental human rights or exacerbate digital divide, especially between developing countries (Floridi, 2018; Bryson, 2019).

5.5 Practical policy recommendations

The research transcends theorizing as it makes practical and multi-level recommendations to states, international organizations, and private technological actors. Some include standardizing data-sharing protocols, the establishment of regional AI surveillance partnerships, and assistance to developing states through capacity-building

initiatives. The recommendations provide policymakers and practitioners with actionable guidance.

6 THEORETICAL AND LEGAL FRAMEWORK

6.1 The law of the sea and enforcement mechanisms

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) remains the primary legal framework for the utilization of seas and oceans. It sets out maritime zones, such as territorial seas, exclusive economic zones (EEZs), and the high seas, and prescribes the enforcement jurisdiction of states within these zones. There are sovereign rights for coastal states to explore and exploit resources within their EEZs (Article 56 UNCLOS) and the obligation to prevent illegal activities such as unlicensed fishing, pollution, and trafficking. Enforcement is, however, problematic in areas beyond national jurisdiction, particularly in the high seas where flag-state responsibility is ineffective or weak.

Traditional UNCLOS enforcement mechanisms rely on surveillance, inspection, arrest, and adjudication, which are resource-intensive and geographically limited. As maritime crimes evolve—especially with the advent of transnational threats like illegal, unreported, and unregulated (IUU) fishing and cyber-piracy—the need for more sophisticated surveillance tools that are aligned with UNCLOS commitments becomes urgent.

6.2 Artificial Intelligence as a surveillance and enforcement tool

AI functionalities provide states with greater maritime domain awareness capabilities that can be traced directly back to their UNCLOS responsibilities. Some examples are:

AI-enabled satellite monitoring enables coastal states to detect unauthorized vessels in their EEZs, enabling Article 73 enforcement of regulations and laws pertaining to fisheries.

Autonomous drones and unmanned vessels enhance the potential for surveillance of territorial waters without infringing on the principle of "peaceful uses of the seas" under Article 88.

Predictive analytics and anomaly detection allow authorities to foresee IUU fishing or smuggling activity, thereby adhering to the duty to protect and preserve the marine environment (Articles 192–194).

By integrating AI in such positions, states are in a better position to fulfill their international obligations, as well as enhance compliance monitoring and deterrence. (UNCLOS, 1982, Art. 56).

6.3 Alignment with international law

AI-based maritime surveillance raises significant concerns about its alignment with international legal norms:

Sovereignty: The use of AI-driven drones or satellites for cross-border surveillance may infringe on the sovereignty of other states if not strictly controlled.

Jurisdiction: Although coastal states possess enforcement jurisdiction in their EEZs, the extension of AI surveillance to the high seas must be coordinated with flag states and international organizations to avoid jurisdictional conflicts.

Due Process: AI generated evidence (for example, computer vision vessel identification) will be subject to admissibility provisions in courts, which will raise transparency and reliability issues and the potential for algorithmic bias as well.

6.4 Ethical and accountability considerations

After this, the greatest chasm between legal regimes is accountability for enforcement action under AI. If an AI system erroneously blames a vessel for IUU fishing, leading to a boarding or punishment, there appears to be no way to identify fault on part of the enforcing state or operator or AI producer. This raises problems in international law and domestic codes of conduct. Then comes surveillance ethics: pervasive AI surveillance will be in opposition to privacy and proportionality in policing.

6.5 Towards a legal-technical synthesis

6.5.1 *In order for AI to be UNCLOS compliant, academics and policy makers advance*

Promote an establishment of international standards for AI use in nautical law enforcement, ideally by the International Maritime Organization (IMO).

Establish regimes of accountability for determining liability when rogue AI conducts policing.

Enable the explainability and transparency of AI systems to a point that their outputs may be challenged in court.

Strengthening multilateral cooperation, as the majority of maritime offenses occur in transboundary or international waters where collective enforcement is necessary.

6.6 Applications of Artificial Intelligence in maritime surveillance

6.6.1 *Fighting illegal, unreported, and unregulated (IUU) fishing*

IUU fishing is one of the biggest international maritime management issues that lead to food insecurity, overfishing, and violation of coastal states' sovereign rights under UNCLOS Article 56. AI has proven to be effective in countering this threat. Through analysis of Automatic Identification System (AIS) signal patterns, satellite imagery, and oceanographic data, machine learning can detect anomalous vessel activity, such as "loitering" near protected areas or traveling without AIS signal transmission. As an example, the Global Fishing Watch program uses AI to monitor vessel activity worldwide to enable real-time detection of possible IUU activity. Such gear improves states' ability to enforce conservation measures in their exclusive economic zones (EEZs) and to unite the world in defense of the Port State Measures Agreement. (Global Fishing Watch, 2020)

6.7 Countering piracy, smuggling, and maritime terrorism

Piracy and smuggling remain enduring risks to security in critical maritime chokepoints like the Gulf of Guinea, the Strait of Malacca, and the Red Sea. Predictive

risk models utilizing AI can analyze historical reports of incidents, shipping routes, and weather patterns to forecast areas of higher risk. Additionally, computer vision algorithms applied to surveillance drones can detect automatically suspicious little boats approaching commercial vessels, hence enabling early warning. These applications directly support the state obligation under UNCLOS to act together in repression of piracy on the high seas (Article 100). By enabling proactive rather than reactive enforcement, AI improves regional and global maritime security.

6.8 Environment protection and anti-pollution surveillance

Degradation of the environment in terms of oil spills, dumping of waste without consent, and degradation of marine habitat is yet another area where AI can play a big role. Satellite and aerial imagery deep learning algorithms can identify oil slicks and chemical releases with high accuracy. Similarly, autonomous underwater or surface vehicles with AI-enabled sensors can monitor water quality and detect pollutants in real-time. These technologies enhance the capacity of states to enforce UNCLOS Articles 192–194, whereby states must conserve and protect the marine environment. Of particular interest, AI monitoring also enables verification of compliance under international environmental conventions such as the MARPOL Convention. (IMO, MARPOL, 1973/78)

6.9 Search and Rescue (SAR) and humanitarian operations

AI is also increasingly being used in search and rescue at sea, where every second counts to save lives. Predictive analytics can be utilized to model sea currents and wind patterns to track probable drift routes of stranded ships or persons adrift in the sea. Autonomous drones equipped with AI-capable cameras can cover vast oceanic regions better than crewed aircraft, and AI-assisted detection of distress signals accelerates the response time of rescue coordination centers. Such applications operationalize UNCLOS Article 98's state duty of rendering assistance to persons in distress on the sea.

6.10 Autonomous ships and naval law enforcement

A second future application involves the utilization of autonomous surface and underwater vehicles in law enforcement operations. These platforms, equipped with AI, are able to carry out sustained surveillance, intercept suspected vessels, and provide real-time intel to command hubs. Their legal status under UNCLOS is doubtful, but their operational value is certain. Autonomous patrol vessels, for instance, are able to patrol EEZs round-the-clock without the financial and manpower expenses of customary naval patrols.

7 CASE STUDIES / COMPARATIVE ANALYSIS

7.1 Comparative analysis

7.1.1 European Union: institutionalized and legalized governance

The European Union (EU) will possess the most formalized and best legally harmonized AI uptake regime for maritime monitoring. Through the European Maritime Safety Agency (EMSA), it has put in place mechanisms such as CleanSeaNet and the Vessel Detection Service that utilize Synthetic Aperture Radar (SAR) in conjunction with Automatic Identification System (AIS) data to detect unregistered vessels and oil spills. This template translates UNCLOS Articles 192-194 undertakings into the preservation of the marine environment. The EU model demonstrates how AI can be drawn into synchronization with international maritime law via law-based institutions, increasing compliance and openness. Coordination bottlenecks often arise, however, when member states prioritize either national security interests or economic gains over group enforcement. This criticizes both the strengths and weaknesses of a supranational institutionalized framework (EMSA, 2021; Tanaka, 2019).

7.2 United States: platform-centric and security-focused

The United States Coast Guard (USCG) uses a platform-centric, security-focused paradigm employing Unmanned Aerial Systems (UAS) such as the ScanEagle in order to maximize surveillance coverage and real-time interdiction capability. The paradigm is defined by mobility ease and rapid tactical response, as per UNCLOS Article 100, which mandates states to collaborate in anti-piracy efforts. The American model accentuates the efficacy of utilizing AI through mobile, defense-focused platforms over institutional ones. Its uni-directional character, however, is a cause of legitimacy concern, particularly where operations spill across international waters, where jurisdictional intersection and sovereignty sensibilities are more volatile (USCG, 2018; Bueger&Edmunds, 2021).

7.3 Asia–Pacific: cooperative and resource-constrained

Resource limitations in the Asia–Pacific have encouraged states to find partnership-based models. Indonesia, together with Global Fishing Watch, has provided Vessel Monitoring System (VMS) data to prevent IUU fishing, while the Philippines partnered with Canada to implement space-based Dark Vessel Detection technology. These examples illustrate the merits of collaborative agreements in aiding transparency and multilateral enforcement capacity. Nevertheless, South China Sea sovereignty disputes and fragmented governance structures prevent the consistency of AI use in the region. The Asia–Pacific showcases the degree to which cooperation can reduce enforcement gaps, but how geopolitical tensions compromise the neutrality of AI as an enforcement mechanism (Pramono, 2019; Park&Lee, 2021).

7.4 Arabian Gulf: security alliances and energy protection

For the Arabian Gulf, the uses of AI are strongly driven by energy security requirements and geopolitical rivalry. States such as the United Arab Emirates and Saudi Arabia have also acquired AI-driven drone monitoring and smart port surveillance systems to protect the Strait of Hormuz, which is one of the most strategic maritime chokepoints in the world. Such technologies allow for improved compliance with

UNCLOS Article 56 rules for resource protection but are more likely to be part of regional defense agreements such as the Gulf Cooperation Council (GCC). Such securitization results in AI having fewer applications in environmental conformity and increasingly applications towards strategically managing the flow of energy, which is a problem in neutrality and clarity of data in maritime governance (Bryson, 2019; OECD, 2021).

7.5 Gulf of Guinea: piracy emphasis and global support

The Gulf of Guinea continues to be the world's most pirated region and where the use of AI continues to be externally driven. Initiatives like the Yaoundé Code of Conduct and EU-funded surveillance projects have introduced satellite observation, predictive analytics, and vessel monitoring technologies to build local enforcement capacity. Although these do meet UNCLOS Article 100 compliant requirements for suppressing piracy, they also reveal an extreme reliance on external entities, for technical expertise and infrastructure. This is perilous for digital dependence and loss of sovereignty. Should coastal states desire to enable AI systems independently, institutionally they might lack sufficient capacity (Klein, 2019; UNODC, 2020).

7.6 Arctic: environmental monitoring and great power rivalry

The Arctic is a unique example of AI for environmental monitoring and great power competition. With the potential opening of new shipping routes due adjustment for climate change and the effects of China domestically, Norway, Canada, and Russia have instrumentalized AI-based satellite systems to track environmental compliance, and shipping in sea areas. Candidly, the dual-use of AI for both civilian and militaristic surveillance offers parallels to increasing competition in this area. This binary does offer legal considerations under UNCLOS Article 88 where the doctrine of "peaceful uses of the seas" is entrenched. As such, the Arctic represents an example of the tension or between cooperative or collaborative environmental stewardship and strategically appropriated militaristic application of AI surveillance (Floridi, 2018; Zhang et al., 2020).

7.7 Synthesis and critical insights

The Arctic is a unique case where AI is being used for both great power competition and environmental monitoring, wherein Norway, Canada, and Russia are utilizing AI-powered satellite systems to track environmental compliance and shipping more due to the new shipping lanes created from climate change. This is one way that we see the dual-use of AI--both civilian and military surveillance--demonstrated through the increasing competition in the Arctic. This division poses legal issues under UNCLOS Article 88 that enshrines the principle of "peaceful uses of the seas." The Arctic therefore best illustrates the conflict between collaborative management of the environment and adversarial military utilisation of AI monitoring (Floridi, 2018; Zhang et al., 2020).

The comparative examination finds three shared trends.

Governance Models: While the EU has a legalized-institutional model, the U.S. has a security-operational model, while Asia-Pacific and Gulf of Guinea regions have dependency and cooperative models. The Arabian Gulf and Arctic both have geopolitical and securitized approaches. (Tanaka, 2019; Klein, 2019).

Geopolitical Drivers: Strategic rivalry in the competition spaces and energy-sensitive spaces (e.g., Arctic, Arabian Gulf) generates AI adoption, which has a tendency to replace UNCLOS obligations. That is a symptom of the dilemma of how to make technological adoption align with international legal standards (OECD, 2021; Bryson, 2019).

Legal and Ethical Failures: Accountability gaps are universal across regions. Problems of accountability for wrongful interdictions, algorithmic bias, and violation of sovereignty define the necessity of a unified international system of accountability within the International Maritime Organization (IMO) (Lima, 2022; Jobin, Ienca,&Vayena, 2019).

8 CHALLENGES AND LIMITATIONS

8.1 Technical challenges

Despite the potential of AI, technical challenges remain significant.

Quality and availability of data: AI models must be trained on large, high-quality data sets for optimal performance. Data available in maritime environments can be piecemeal, partial, or tampered with (e.g., falsified AIS messages). This undermines the reliability of AI-based surveillance systems.

Algorithmic limitations: Deep learning systems may misidentify vessels or miss tiny, recalcitrant boats, particularly where there is congestion of maritime traffic or poor weather. False positives and false negatives create enforcement risks when evidence is needed for courtroom application.

Cyber risks: AI-powered systems connected to maritime networks are at risk of cyberattacks. Hackers can spoof AIS information, jam satellite transmissions, or disrupt autonomous drones, potentially resulting in operational failure or false information. (Sullivan, 2020)

8.2 Legal challenges

Jurisdictional conflict: UNCLOS divides the sea into distinct zones of sovereignty and rights. Monitoring across borders through AI may jeopardize other states' sovereignty unless regulated well. For instance, employment of autonomous drones near disputed maritime borders may attract conflicts.

Evidence admissibility: In order to be accepted by a court, the accuracy and transparency of AI-generated evidence (i.e., satellite detections or anomaly classifications) must be testable. Most AI algorithms are, however, “black boxes,” and their use in legal adjudication is thus questionable.

Loopholes in global law: UNCLOS itself does not specifically regulate the use of AI for maritime enforcement. Issues of liability for wrongful acts (e.g., wrongful interdiction based on defective AI) remain unresolved.

8.3 Ethical and accountability issues

Responsibility voids: When a ship is mistakenly labeled by an AI system and enforcement authorities act on this information, liability becomes fraught. Who is

responsible-state, operator, or AI developer? Lack of stipulated rules can dismantle trust in AI-driven enforcement.

Privacy issues: Large-scale AI monitoring of maritime activity can infringe commercial and personal privacy rights, especially when monitoring occurs beyond a state's territorial sea.

Bias and equity: Training data can reflect regional biases or coverage gaps, which may disproportionately impact certain regions or fleets, leading to fairness and equity concerns in enforcement.

8.4 Institutional and operational constraints

Costly: Satellite-, drone-, and big data-driven AI surveillance technologies are expensive. Developing countries with limited budgets may not be in a position to adopt these technologies, thereby leading to disparities in enforcement capacity.

Capacity building: Even with availability of AI technology, trained man-power must exist for effective utilization. Large numbers of maritime organizations are short on training, technical expertise, and institutional readiness to integrate AI into existing command-and-control systems.

International cooperation: Since the majority of maritime threats are transboundary in character, solo adoption of AI has limited use. Without harmonized frameworks for combined enforcement and data exchange, the potential effectiveness of AI is reduced worldwide.

While AI can potentially revolutionize Law of the Sea enforcement and maritime surveillance, its imposition is constrained by technical reliability, legal uncertainty, ethical difficulties, and institutional imbalance. These aspects need to be fixed before AI can be officially recognized as a trusted tool in international maritime management.

9 FUTURE PROSPECTS AND POLICY RECOMMENDATIONS

9.1 Future prospects

Multi-Sensor Network Integration: Maritime surveillance going forward will include integration of individual AI capabilities across platforms on hundreds of different vessels-including satellite constellations, networks of unmanned aerial vehicles, autonomous underwater and surface vehicles, with ground-based command, control, and communication, creating a more coherent and integrated "system of systems" that will afford a holistic views of the oceans in real-time.

Development of Explainable AI (XAI): Due to admissibility evidentiary challenges, development of explainable AI (XAI) software will become more relevant to develop. With algorithms that are transparent and auditable, states may produce evidence generated by AI with higher assurance in a court of law.

Global Maritime Data Sharing: Global fishing watch and other multi-national initiatives see an open global future where states and non-state actors share information referring to these standards on open access platforms. Expanding such initiatives can enhance collective monitoring capacity, particularly where enforcement capacity is lacking. Therefore, many initiatives focus on building capability.

AI-Driven Predictive Governance: Beyond detection, AI has the potential to also facilitate proactive governance. This would involve predictive projections of potential areas of IUU fishing, piracy, or environmental crime. This would constitute a major step towards addressing UNCLOS objectives and would represent a transition from reactive to predictive prevention.

10 POLICY RECOMMENDATIONS

10.1 Legal and regulatory frameworks

Streamline international law: While UNCLOS has the blueprint for maritime regulations, there should be concrete guidelines or process under the International Maritime Organization (IMO) particularly on AI in monitoring and surveillance.

Establish accountability mechanisms: There need to be transparent rules to determine liability when AI-enforced action leads to unfair outcomes, striking the balance between state obligation and private enterprise.

10.2 Institutional capacity building

Invest in competence and training: Coastal states and port states must invest in building technical competence for AI operations among coast guards, navies, and maritime authorities.

Assist developing states: International cooperation and development need to provide financial and technical aid to developing states to implement AI-based surveillance, and reduce the enforcement gap between resource-rich and poor nations.

10.3 Technical standards and cooperation

Standardize data protocols: Developing common standards for capturing, storing, and AI model compatibility data will facilitate information sharing and cooperation.

Encourage transparency of AI models: Explainable and auditable AI systems need to be adopted by states and institutions to increase trust and legitimacy in maritime law enforcement.

Encourage international collaboration: International and regional institutions (e.g., African Union, ASEAN) should have mutually collaborative AI-enabled surveillance programs to address transboundary security concerns such as piracy and IUU fishing.

10.4 Ethical protection

Respect human rights to privacy: AI application must not infringe on human rights through proportionality and necessity in surveillance.

Ensure bias-free application of AI: Eliminate algorithmic bias through diversification of data sets and cross-validation of models across maritime areas and ship types.

10.5 Policy implications

The research findings have immediate relevance to decision makers at various policy, practical, government and bureaucratic levels including policymakers, international bodies and private actors involved in the maritime governance. By successfully connecting the capabilities of Artificial Intelligence (AI) use to the UNCLOS enforcement responsibilities, the research gives practical examples that involve the synergies involved connecting maritime security, environment protection and international collaboration objectives.

11 IMPLICATIONS FOR STATES

Coastal states or port states could utilize AI-enabled observations systems to enhance capability and elicit compliance with their UNCLOS obligations like preventing IUU fishing (Article 73), piracy prevention (Article 100), and protecting and preserving the marine environment (Articles 192-194). Coastal states could use predictive analysis and satellite imagery to shift the paradigm and actually lead to proactive enforcement action rather than a reactive role. But all should also invest in law reform and capacity building to ensure that AI evidence can be admissible in court in specific cases and that enforcement actions remain controlled by sovereignty and due process (Tanaka, 2019; Lima2022).

11.1 Implications for international organizations

For global and regional intergovernmental organizations like the International Maritime Organization (IMO), Food and Agriculture Organization (FAO) and United Nations Office on Drugs and Crime (UNODC), this report emphasizes the pressing demand of formulating global provisioning norms for the use of AI in maritime law enforcement. An IMO's AI Accountability Protocol might set the precedent for defining standards for assigning liability both for AI systems design integrity (the money to install a compliant consumer product - as one example) at the very least, to assure that all AI systems can be interoperable and transparent. Additionally, institutions can offer essential

support to cross-border data-sharing platforms like scaled work, for instance, Global Fishing Watch, to other maritime areas of the highest priority (Jobin, Ienca,&Vayena, 2019; EMSA, 2021).

11.2 Implications for developing states

Coastal developing states tend to have limited technical capacities and funds, thereby constraining their ability to implement AI systems independently. International assistance and technology transfer are highlighted in this research as necessary to bridge the enforcement gap. Regional arrangements like those proposed in the Asia-Pacific and Gulf of Guinea show the promise of collaborative schemes that weigh external expertise against local enforcement complexities (Pramono, 2019; UNODC, 2020).

11.3 Implications for the private sector

Private industries that produce AI-driven surveillance equipment, satellite analytics, and autonomous platforms hold central roles in ocean governance. The study calls for mandating the private sector to develop explainable and transparent AI models that are evidence-admissible in international and domestic courts. Interactions with states and global organizations ensure that AI solutions respond not only to operational efficacy but also legal legitimacy and moral protection (Burrell, 2016; Floridi, 2018).

11.4 Implications for global governance

At a more general level, the research emphasizes that 21st-century maritime governance must be multilateral, evidence-based, and ethically driven. AI can become a source of commonality for states to put in place their UNCLOS obligations, but in the absence of harmonized global standards, the technology risks amplifying inequalities and creating new sources of conflict. The policy implication is thus clear: international cooperation must come before solo technology deployment if AI is to be utilized to add to, rather than subtract from, global rule of law at sea (Bryson, 2019; OECD, 2021).

11.5 Limitations and future directions for research

Notwithstanding the strengths of this research, a number of limitations must be identified to place its findings in context and guide directions for additional research.

12 METHODOLOGICAL LIMITATIONS

The research follows a qualitative and doctrinal methodology based on secondary data in the form of legal reports, journal articles, and technical reports. The method, although permitting expansive synthesis, is not based on empirical validation using field data, large surveys, or quantitative modeling. The results are consequently best described as conceptual rather than statistically generalizable (Klein, 2019).

12.1 Data availability and regional scope

Another limitation is in the unbalanced quality of data across regions. In-depth research and institutional studies are available for the European Union and the United States, whereas other regions such as the Arabian Gulf, Gulf of Guinea, and Arctic are less documented. This comes amidst limited comparative studies and potentially overlooking local contexts and regional practices (Pramono, 2019).

12.2 Legal and technical uncertainty

Legal aspects of AI deployment are still largely unexplored in international law. Matters regarding admissibility of evidence generated by AI, accountability for algorithmic mistakes, and sovereignty disputes are debated theoretically, but not yet resolved practically. Likewise, technical constraints such as data reliability, bias in algorithms, and cyber vulnerabilities introduce complexities that this research could not fully measure (Burrell, 2016; Lima, 2022).

13 ETHICAL DIMENSIONS

Although this research highlights some of the ethical issues such as privacy and justice, these were not critically explored by case-specific investigation. Ethical AI governance of naval enforcement remains an evolving domain that requires further investigation, particularly in light of global variation between technologically advanced and resource-poor nations (Jobin, Ienca, & Vayena, 2019).

14 FUTURE RESEARCH DIRECTIONS

14.1 According to these limitations, future research will try to address the following directions

- **Empirical Validation:** Conduct field research, pilot studies, or quantitative surveys on AI-based maritime surveillance to provide evidence-based perspectives on effectiveness and accuracy.
- **Regional Comparisons Expanded:** Extend comparison studies to include under-researched regions, such as the South China Sea, Gulf of Guinea, and Arctic, to include a variety of geopolitical and legal complexities.
- **Interdisciplinary Models:** Create hybrid models that combine legal studies, data science, and policy studies to overcome the difference between technology and regulating it legally.
- **Accountability Models:** Develop and test working accountability models, such as an AI Accountability Protocol in the International Maritime Organization (IMO) to reduce accountability concerns but improve transparency.
- **Ethical and Human Rights Approach:** Examine adoption of AI in seafaring surveillance from the perspective of international human rights law, specifically on proportionality, necessity, and fairness in surveillance operations.

Through addressing these areas, subsequent research will enhance our understanding of how Artificial Intelligence can be embedded within maritime regulation without deviating from either the letter or the intent of UNCLOS.

15 ETHICAL CONSIDERATIONS

Application of Artificial Intelligence (AI) in maritime surveillance is not only technically and legally problematic but also raises rooted ethical issues. If left unresolved, these issues have the potential to undermine the legitimacy of enforcement based on AI under the United Nations Convention on the Law of the Sea (UNCLOS).

15.1 Privacy and proportionality

Satellite-based, autonomous drone-based, and data fusion-based AI-based surveillance systems involve the collection of vast amounts of information about ships, goods, and individuals in the sea. This raises concerns about proportionality principle and the right to privacy. Despite the need for surveillance to combat illegal activities such as IUU fishing or piracy, mass surveillance through excessive or indiscriminate monitoring will infringe commercial confidentiality and the rights of individuals (Burrell, 2016; Jobin, Ienca, & Vayena, 2019).

15.2 Algorithmic bias and fairness

Algorithms are trained on data that may be incomplete, imbalanced, or biased toward particular regions and types of ships. For example, algorithms trained predominantly on technologically developed regions' data may not function well in areas such as the Gulf of Guinea or South Asia. This creates algorithmic discrimination hazards where ships from developing countries are overserved as suspicious, undermining fairness and equity in enforcement (Floridi, 2018; Lima, 2022).

15.3 Digital divide and inequality

The use of AI in maritime governance highlights the persistent digital divide between developed and developing countries. While advanced economies in Europe and North America have the means to implement advanced AI systems, some developing coastal states lack the financial, technical, and institutional ability to do the same. Such

disparity risks deepening power disparities at the international level, where technologically advanced states wield dominance over enforcement with a risk of marginalizing weaker actors (Bryson, 2019; OECD, 2021).

15.4 Human rights and accountability

Normatively, AI-imposed interdiction must be in harmony with global human rights law. Inaccurate interdictions or wrong targets because of algorithmic errors may lead to unlawful detention, deprivation of property, or even killing. Lacking clear frameworks of accountability, these may violate the maxims of due process, justice, and state responsibility under international law. Integrating ethical protection elements such as openness, interpretability, and external review mechanisms in AI systems is therefore necessary to guarantee legitimacy (Jobin, Ienca, & Vayena, 2019; Burrell, 2016).

15.5 Responsible innovation

Finally, ethical adoption of AI means the embedding of responsible innovation in systems and policy system design. This means that AI is fully transparent, fully auditable and open to third-party examinations so that the issues of illegal or unregulated surveillance arising from abuse of AI would be mitigated. Ostensibly addressing ethical value propositions of AI, along with legal and technical requirements, within an international governance framework in the IMO would not only generate trust in maritime governance but, more importantly, would not create trust deterioration (Floridi, 2018; Klein, 2019)

16 CONCLUSION

The research has investigated the capacity of Artificial Intelligence (AI) to change the face of maritime watching and monitoring compliance with the United Nations Convention on the Law of the Sea (UNCLOS). Through review of current applications, theoretical foundations, and nation-specific research, the study showed how AI technologies like machine learning, predictive analytics, computer vision, and

autonomous unmanned systems provide extraordinary capacity to surveil large areas of ocean space, identify anomalies, and assist pro-active law enforcement. Used in conjunction with UNCLOS obligations, these capabilities will benefit directly to help states counter illegal, unreported and unregulated (IUU) fishing, piracy, smuggling, marine environmental harm, and enhance search and rescue.

Parallel to the growth of technical, legal, and ethical problems, research found key technical, legal, and ethical problems. Technical limitations such as data quality, algorithmic bias, cyber-attacks, and uneven institutional capacities must be resolved in order to generate original outputs. Legal issues such as conflicts of sovereignty, overlapping jurisdictions, and admissibility of evidence produced by AI are still unresolved under the existing UNCLOS principles. Ethical issues of accountability, privacy, proportionality, and fairness also make it progressively more difficult to ensure that AI is responsibly used.

In relation to maritime governance, the research makes both theoretical and practical contributions. Theoretically, it contributes to the literature by fashioning a hybrid legal-technical framework which produces equivalence between AI usages and UNCLOS obligations, as opposed to the deconstructed model of recognizing AI purely as technical improvement or as a regulatory concern. This is an advancement for the project of advancing scholarly knowledge regarding global governance, sovereignty, and the legitimacy of AI-enabled surveillance under international law. Practically, the study provides direct policy options for policy makers and global actors and maritime administrators, i.e., an AI Accountability Protocol designed through the existing governing body of the International Maritime Organization (IMO) which recognizes issues of liability, transparency, and equity. The research showcases adaptive models through comparative lessons learned across including regions across the globe-EU, US, Asia-Pacific, Arabian Gulf, Gulf of Guinea, and Arctic-to inform policy globally. The study emphasis on capacity-building among the developing states also mirrors the importance of well-balanced incorporation of technology to ensure while AI will likely not eliminate disparity it will improve it across the globe on our planet. To conclude, AI cannot replace the past enforcement mechanisms, and can develop and reconceptualize them at a considerable advantage. For this to happen, we need international norms, a legal evolution, open AI systems, and multilateralism. While AI can be equivalent to an

enforcement mechanism, we can complete the technology gap of enforceability, thus making AI a foundation for a 21st century maritime regulatory mechanism. With a solid foundation of accountability, ethical safeguarding, and cooperation, AI will not only enhance the utilization of the Law of the Sea, but will contribute significantly in making the international maritime commons safer, sustainable, and secure.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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