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Developing an AI-Enhanced Maritime Threat Detection Model: Predictive Security Framework for Illegal Fishing and Piracy in the Natuna Sea

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Abstract

This research proposes a predictive security framework based on artificial intelligence to counter non traditional maritime threats such as illegal fishing and piracy in the geopolitically critical North Natuna Sea at the southern boundary of the South China Sea. The framework integrates multiple maritime data streams-including vessel tracking, satellite imagery, radar observations, and logbook entries-and applies advanced machine learning methods such as long short term memory networks and computer vision to identify anomalous vessel behaviour. The results indicate that the artificial intelligence system can reliably distinguish between lawful and illicit maritime operations, enabling the development of early warning capabilities. The study also highlights that the effectiveness of this predictive security approach relies on supportive regulatory frameworks and coordinated action among relevant agencies. This work presents a novel, context specific solution tailored to Indonesia's maritime environment, combining behavioural vessel modelling, multisource data fusion, and geopolitical awareness. The proposed model facilitates a shift from reactive to proactive maritime threat management and offers a scalable approach applicable to other high risk maritime regions.

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Keywords: maritime security, artificial intelligence, predictive analytics, illegal fishing, vessel behaviour, data fusion, natuna sea.

INTRODUCTION

The North Natuna Sea, located at the southern end of the South China Sea, plays a critical role in the maritime geopolitics and security dynamics of the Indo-Pacific region. This area, part of Indonesia's sovereign maritime territory, is rich in natural resources, including some of Southeast Asia's largest gas reserves and abundant fisheries. As a vital artery connecting the Indian and Pacific Oceans, the region is not only an economic asset but also a symbol of Indonesia's maritime identity and sovereignty. However, the strategic position and resource wealth of the North Natuna Sea have made it increasingly vulnerable to non-traditional maritime security threats. The presence of overlapping maritime claims, particularly China's assertive nine-dash line and its associated sea-denial strategies (Pizzolo, 2022), has intensified tensions. Regional naval patrols, including those by India and Japan (Vo et al., 2023; Yazuru, 2022), underscore the growing contestation in these waters.

Among the most persistent and damaging threats are Illegal, Unreported, and Unregulated (IUU) fishing and piracy. These activities not only inflict significant economic losses but also threaten marine ecosystems, coastal community livelihoods, and regional maritime governance. The increasing complexity of these challenges highlights the need for a transformative approach to maritime security-one that shifts from reactive measures to predictive and preventive strategies. This article introduces a predictive security framework powered by artificial intelligence (AI), designed to detect and anticipate maritime threats in the North Natuna Sea. Leveraging big data sources such as AIS signals, satellite imagery, drone sensors, and maritime logbooks, the model uses machine learning algorithms to identify anomalous behavior and generate early warnings.

While IUU fishing contributes to biodiversity degradation, market distortion, and transnational crime, piracy threatens maritime trade routes and endangers seafarers' lives. These twin threats are interconnected and amplified by weak maritime surveillance, fragmented inter-agency coordination, and insufficient legal frameworks. By proposing an AI-enhanced threat detection model that is specifically tailored to the geopolitical, geographic, and socio-economic context of the Natuna region, this study aims to offer both theoretical contributions and practical solutions to Indonesia's maritime security posture. The introduction also outlines the scope, objectives, and novelty of the research, filling a crucial gap in the current maritime defense

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discourse.

METHODS

This study adopts a qualitative-descriptive research design, supported by technological modeling to develop a predictive security framework tailored for maritime threats in the North Natuna Sea. The methodology integrates supervised machine learning techniques particularly Long Short-Term Memory (LSTM) networks and anomaly detection algorithms to identify irregular vessel behavior such as AIS deactivation ("going dark"), illegal rendezvous, and non-standard navigational routes. The AI model is trained using historical vessel movement datasets and cross-validated with regulatory fishing zones, seasonal activity patterns, and archival incident records.

A data fusion strategy is implemented to combine structured and unstructured data sources. This includes Automatic Identification System (AIS) data, Vessel Monitoring System (VMS), coastal radar, satellite imagery (SAR and optical), and electronic logbooks. The framework employs behavioral-based risk scoring to assess potential threats, flagging high-risk vessels for further analysis. These risk scores provide real-time decision support to maritime patrol units, enabling targeted responses in high-threat areas.

To ensure local relevance, geographic and geopolitical features specific to the North Natuna Sea are embedded within the model's operational parameters. Data collection is conducted in collaboration with national maritime institutions including the Indonesian Maritime Security Agency (Bakamla), the Indonesian Navy (TNI AL), the National Research and Innovation Agency (BRIN), and the Ministry of Marine Affairs and Fisheries (KKP). The model architecture emphasizes feasibility for phased implementation via a centralized Maritime Data Fusion Center, aligning with Indonesia's strategic maritime governance priorities.

RESULTS AND DISCUSSION

Threat Landscape in the North Natuna Sea

The North Natuna Sea constitutes a high-risk maritime zone due to overlapping maritime claims, particularly China's nine-dash line claim, which conflicts with Indonesia's Exclusive Economic Zone (EEZ) as recognized under UNCLOS 1982 (Pizzolo, 2022). These disputes have triggered recurrent standoffs between Indonesian patrols and Chinese maritime enforcement. Incidents of state-sponsored encroachments, often under the guise of distant-water fishing—have escalated geopolitical tensions in the region (Vo et al., 2023).

In parallel, the area continues to face critical threats from Illegal, Unreported, and

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Unregulated (IUU) fishing and piracy. Foreign fishing vessels, particularly those from nearby countries, frequently exploit Indonesian waters without authorization, using destructive methods that severely damage marine habitats (Karakasnaki et al., 2023). Moreover, many of these vessels disable their AIS to evade detection, becoming "dark vessels" that complicate enforcement efforts. Although piracy has declined due to increased naval presence, latent threats remain around adjacent chokepoints such as the Strait of Malacca (Raza et al., 2023). The convergence of geopolitical instability, environmental degradation, and economic exploitation makes maritime security in the Natuna region particularly challenging. Furthermore, transnational organized crime networks often exploit these vulnerabilities for illegal transshipment, human trafficking, and smuggling activities, making the enforcement landscape even more complex.

AI-Based Surveillance and Risk Detection

Artificial Intelligence (AI) offers transformative capabilities for maritime threat detection and response. Through Long Short-Term Memory (LSTM) networks and unsupervised anomaly detection algorithms, the proposed model can learn vessel behavior patterns and identify anomalies such as AIS spoofing, suspicious rendezvous, or erratic navigation (He et al., 2023; Fan et al., 2024). These patterns often precede illegal activity and thus are valuable for predictive analysis.

AI-driven analysis of Synthetic Aperture Radar (SAR) and optical satellite imagery enables detection of non AIS emitting vessels often referred to as dark vessels by applying computer vision algorithms (Rawson & Brito, 2023). These detections, when fused with AIS and logbook data, contribute to a dynamic risk scoring system that prioritizes threats and provides actionable intelligence for patrol deployment (Li et al., 2023; Guo & Guo, 2023).

Moreover, AI can process streaming drone footage to identify fishing gear types, transshipment behaviors, and illegal practices, strengthening enforcement with visual evidence. This technology enables real-time monitoring and more efficient resource utilization, shifting maritime security from reactive operations to proactive threat prevention. AI's capabilities also extend to understanding seasonal and temporal behavior patterns, allowing authorities to predict high-risk periods for IUU fishing based on previous years' data. Furthermore, integrating historical incident databases enables the system to learn from past enforcement outcomes, thereby enhancing future prediction accuracy.

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Localization and Political Contextualization

To ensure operational relevance, the AI-based model incorporates the specific geographic, environmental, and political parameters of the North Natuna Sea. This includes the mapping of Marine Protected Areas (MPAs), traditional fishing zones, and recurrent incursion hotspots. Similar approaches have been successfully used in conservation zones such as the Bird's Head Seascape in Indonesia (Wahyudin et al., 2023). Furthermore, the model distinguishes between generic IUU activity and state-backed incursions involving coast guard or militia escorts an increasingly common manifestation of hybrid maritime conflict (De Castro, 2024). AI algorithms trained to detect swarming behavior and escort formations offer a novel tool for identifying sovereign threats disguised as fishing activity. By embedding local knowledge, seasonal fishing cycles, and enforcement jurisdiction into the model, the system can also differentiate between local artisanal fishing and industrial-scale intrusions. This hybrid awareness enhances national capacity to manage both resource protection and sovereignty defense. To deepen localization, the system is designed to incorporate culturally embedded community reporting data (HUMINT), such as sightings and log entries from local fishermen and coastal surveillance outposts. These grassroots-level inputs improve granularity, contextual depth, and the legitimacy of enforcement actions.

Institutional Gaps and Strategic Recommendations

Despite technical advancements, Indonesia's maritime surveillance suffers from institutional fragmentation. Key agencies such as the Indonesian Navy (TNI AL), Bakamla, and the Ministry of Marine Affairs and Fisheries (KKP) operate independently, leading to redundant systems and data silos (Siahaan et al., 2023).

To resolve this, the establishment of a centralized Maritime Data Fusion Center is proposed. This center would aggregate data from AIS, VMS, coastal radar, e-logbooks, and satellite imagery into a shared Common Operational Picture (COP). The integration would allow for synchronized multi-agency responses and reduce latency in threat mitigation. Furthermore, inter-agency trust must be institutionalized through policy frameworks that mandate data sharing and standardize operating procedures. Technological infrastructure should be supported by robust legal instruments to ensure that digital intelligence is admissible in court and can inform enforcement without legal ambiguity.

Moreover, investment in human capital particularly in AI competence and inter-agency communication will be essential to maximize the value of the system (Cahoon & Haugstetter,

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2023; Raza et al., 2023). This includes tailored training programs for maritime analysts, legal officers, and patrol unit commanders to interpret AI outputs and translate them into timely and coordinated operational decisions. Integration of AI into national security doctrines and maritime law enforcement curricula should also be prioritized.

Lastly, collaboration with academia and private sector partners, particularly in satellite and software development, will be vital for ensuring the long-term sustainability and innovation of Indonesia's AI-based maritime surveillance architecture. Multi-helix partnerships involving government, research institutions, and tech industries will be crucial for fostering innovation, ethical standards, and local ownership over AI infrastructure.

In conclusion, while AI-enhanced systems offer unprecedented advantages in maritime security, their full utility depends on political will, institutional coordination, legal clarity, and sustainable investment in talent and infrastructure. The integration of socio-political localization, predictive analytics, and robust inter-agency ecosystems will position Indonesia to shift from reactive maritime policing to strategic, proactive ocean governance..

CONCLUSIONS

This study has demonstrated the potential of integrating Artificial Intelligence (AI) technologies into Indonesia's maritime security architecture, specifically in the North Natuna Sea. By combining the literature, real-time sensor data, and localized contextual awareness, the proposed predictive security model offers a paradigm shift from reactive to proactive maritime threat detection.

The findings emphasize the need for systemic change-not only through technological innovation but also via institutional reform and policy integration. Establishing a centralized Maritime Data Fusion Center and investing in AI literacy are critical to operationalizing this model. With proper implementation, this framework can significantly strengthen Indonesia's maritime domain awareness, sovereignty enforcement, and regional stability.

REFERENCES

Cahoon, S., & Haugstetter, H. (2023). Enhancing maritime safety and security through education and training in the Western Indian Ocean. WMU Journal of Maritime Affairs, 22(2), 241–263. https://doi.org/10.1007/s13437-023-00295-w

De Castro, R. C. (2024). Exploring the Philippines' evolving grand strategy in the face of China's maritime expansion: From the Aquino administration to the Marcos administration.

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Journal of Current Southeast Asian Affairs, 43(1), 94–119. https://doi.org/10.1177/18681034241234670

Fan, Q., Qi, Z., Chai, J., & Zhang, Y. (2024). Research on ship collision risk assessment based on improved temporal convolutional network. Sensors, 24(12), 3912. https://doi.org/10.3390/s24123912

Guo, J., & Guo, H. (2023). Real-time risk detection method and protection strategy for intelligent ship network security based on cloud computing. Symmetry, 15(5), 988. https://doi.org/10.3390/sym15050988

He, J., Li, S., Liu, J., Mou, J., & Jiao, Y. (2023). A ship track and status prediction method based on improved long short-term memory neural network. Sensors, 23(24), 9897. https://doi.org/10.3390/s23249897

Karakasnaki, M., Pantouvakis, A., & Vlachos, I. (2023). Maritime social sustainability: Conceptualization and scale development. Transportation Research Part D: Transport and Environment, 121, 103804. https://doi.org/10.1016/j.trd.2023.103804

Li, K. X., Fu, Y., Chung, S. H., Zhang, J., & Ng, A. K. Y. (2023). Digital transformation of the maritime industry: A systematic review. Maritime Policy & Management, 50(3), 359–378. https://doi.org/10.1080/03088839.2021.1963283

Pizzolo, P. (2022). The legacy of Admiral von Tirpitz: A geopolitical understanding of China's naval buildup through sea-denial strategies. Italian Political Science Review, 52(2), 297–312. https://doi.org/10.1017/ipo.2021.40

Rawson, A., & Brito, M. (2023). A survey of the opportunities and challenges of supervised machine learning in maritime risk analysis. Transport Reviews, 43(1), 108–130. https://doi.org/10.1080/01441647.2022.2036864

Raza, Z., De Silva, G. S. S. S. J., Kumar, D., Yang, Z., & Haleem, A. (2023). Developing a maritime transportation resilience framework: A systematic review and future research directions. Ocean & Coastal Management, 245, 106847. https://doi.org/10.1016/j.ocecoaman.2023.106847

Raza, Z., Samarakoon, M. M. S. C., Kumar, D., Al-Shami, A. M., & Yang, Z. (2023). Digital tools and challenges in human resource development and its potential within the maritime sector through bibliometric analysis. WMU Journal of Maritime Affairs, 22(3), 335–358. https://doi.org/10.1007/s13437-023-00301-1

Siahaan, A. P. S., Simamora, H. M., Suharyo, O. S., Sudradjat, T., Rum, M. N. I. K., & Setiawan, B. (2023). Implementation of maritime security policy in the border area of Indonesia–

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Singapore. Heliyon, 9(7), e17639. https://doi.org/10.1016/j.heliyon.2023.e17639

Vo, V. T., Le, T. L., & Ta, Q. T. (2023). Maritime security policy of India in ear century: Vietnam's perceptive of its implication on the Asia-Pacific region. Journal of International Studies, 19(2), 67–92. https://doi.org/10.32890/jis2023.19.2.3

Wahyudin, Y., Adrianto, L., Boer, M., Yonvitner, Damar, A., & Madduppa, H. H. (2023). Assessing the Marine Protected Area management effectiveness in the Bird's Head Seascape, Indonesia. Marine Policy, 154, 105677. https://doi.org/10.1016/j.marpol.2023.105677

Yazuru, W. (2022). New strategy Japanese military in the Asia Pacific region and the impact on international security stability. Jurnal Pembaharuan Hukum, 9(2), 265–273.

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