MARITIME ACTIVITIES MAPPING FOR MARINE SPATIAL PLANNING USING GEO-INFORMATICS TECHNOLOGY

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ABSTRACT: Marine Spatial Planning (MSP) has emerged as a critical approach for the sustainable management of marine resources and activities. The Gulf of Thailand, renowned for its rich marine biodiversity and significant economic importance, faces increasing challenges in balancing various maritime sectors and conserving its fragile ecosystems. This study proposes a novel methodology utilizing the Day/Night Band (DNB) imagery from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor to detect and monitor maritime activities in the Gulf of Thailand. The DNB data captured by VIIRS provides a unique perspective by capturing both daytime and nighttime human activities. This comprehensive approach enables a more holistic understanding of the region's dynamic nature of maritime activities. Through the analysis of VIIRS DNB imagery, we aim to identify and map different types of maritime activities, including vessel traffic, fishing operations, and offshore infrastructure. The application of VIIRS DNB imagery in MSP offers significant advantages. First, it allows for detecting and characterizing spatial and temporal patterns of maritime activities, providing valuable insights into their distribution and intensity. This information can support evidence-based decision-making processes, facilitating the establishment of marine protected areas, and fisheries management zones, and the reduction of potential conflicts among different maritime sectors. By integrating VIIRS DNB data with other relevant datasets in the future, such as Automatic Identification System (AIS) data and environmental variables, a more comprehensive understanding of the relationships between maritime activities and their impacts on the marine environment can be achieved. This integrated approach enables the identification of potential hotspots of human activity and their ecological consequences, aiding in the development of targeted conservation and management strategies. The findings of this study have broader implications for sustainable ocean governance and the development of MSP frameworks. The proposed methodology provides a powerful tool for policymakers, marine spatial planners, and stakeholders involved in the management and conservation of the Gulf of Thailand's marine resources. By utilizing VIIRS DNB imagery, decision-makers can gain valuable insights into the complex interactions between human activities and the marine environment, allowing for more informed and effective management strategies. Furthermore, the utilization of VIIRS DNB imagery contributes to the growing field of remote sensing in marine spatial planning. The integration of advanced technologies and data sources enhances our ability to monitor and assess maritime activities on a broader scale, leading to a more comprehensive understanding of marine ecosystems and their interactions with human activities. This study demonstrates the potential of utilizing VIIRS DNB imagery to detect and monitor maritime activities in the Gulf of Thailand. By providing detailed insights into spatial and temporal patterns of human activity, this methodology supports evidence-based decision-making and sustainable management practices. The findings contribute to the broader field of marine spatial planning and offer valuable guidance for policymakers and stakeholders working towards the conservation and sustainable use of marine resources in the Gulf of Thailand.

1. INTRODUCTION

Thailand possesses a total coastal expanse measuring 350,682.86 square kilometers, encompassing 60% of its land area. This coastal region extends for a total of 3,148.23 kilometers, with 2,055.18 kilometers along the Gulf of Thailand, encompassing 17 provinces, and 1,093.04 kilometers along the Andaman Sea, covering 6 provinces. The marine and coastal resources of Thailand are both abundant and aesthetically pleasing, serving crucial roles in the nation's tourism sector, fisheries, maritime logistics, and related marine activities. Consequently, the utilization of these marine areas has significantly expanded in line with the country's economic development plan. While this utilization promises positive economic and societal impacts, it also raises concerns about resource degradation and conflicts stemming from overlapping activities (DMCR, 2013). Marine spatial planning (MSP) represents a public process aimed at analyzing and allocating spatial and temporal distributions of human activities within marine areas to attain ecological, economic, and social objectives. MSP should be ecosystem-based and is an integral component of marine resource management, involving diverse regulations and protocols for sea management and utilization. MSP serves as a tool for managing marine spatial planning to ensure equilibrium and sustainability across environmental, economic, and social domains. A pivotal aspect of this endeavor involves gathering information and mapping the spatial, temporal, and density characteristics of significant human activities within marine management zones, encompassing commercial and recreational fishing, maritime transportation, renewable and non-renewable energy production, sand and gravel mining, among other activities (Ehler and Douvere, 2009).

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument is employed for the collection of visible and infrared images worldwide, facilitating observations of terrestrial, atmospheric, cryospheric, and oceanic conditions. Presently, the Suomi NPP and NOAA-20 satellite missions employ VIIRS instruments to generate essential environmental data encompassing snow and ice cover, cloud formations, fog, aerosols, fires, smoke plumes, dust, vegetation health, phytoplankton abundance, and chlorophyll levels. VIIRS-derived maritime forecasting products pertaining to sea ice and ocean nutrients offer tangible benefits to maritime and commercial fishing sectors, enhancing vessel routing and optimizing fishery management (National Environmental Satellite, Data, and Information Service). The VIIRS day/night band exhibits proficiency in detecting artificial lighting on Earth's surface (Román, 2020), primarily emanating from human settlements, industrial sites, and transportation corridors. Offshore, such lighting emanates predominantly from fishing vessels employing lights to attract fish. In 2015, the Earth Observation Group (EOG) developed the VIIRS Boat Detection (VBD) algorithm with support from NOAA's Joint Polar Satellite System (JPSS) proving ground program and the United States Agency for International Development (USAID). VBD data is generated nearly in real-time, with nightly records dating back to April 2012 in the Asian region. Applications for VIIRS boat detection data encompass: 1) Cross-referencing location data with vessel monitoring systems (VMS) or automatic identification systems (AIS) to identify fishery vessels lacking location beacons. 2) Overlaying data with marine protected area outlines or seasonally restricted fishing zones to identify instances of illegal fishing. 3) Detecting potential incursions by foreign fishery vessels across Exclusive Economic Zone (EEZ) boundaries. 4) Identifying fishery vessels exceeding prescribed wattage limits for lighting. 5) Tracking shifts in fishing grounds over time and identifying stationary vessels within a fleet of fishing boats using monthly summary data. 6) Targeting enforcement actions and inspections in areas exhibiting concentrated fishery vessel activities (Elvidge, 2023).

The VIIRS Closure Index (VCI) is computed by comparing the number of boat detections during a fishing closure period with those during a regular period (Elvidge et al., 2018). VCI serves as a means to assess the monthly efficacy of closures, expressed as a percentage. VCI results facilitate the evaluation and comparison of closure effectiveness, the estimation of adherence probabilities, and the identification of instances requiring heightened enforcement measures due to non-compliance with fishing closures. VCI analysis encompasses three distinct closure scenarios: ad hoc fishery closures linked to toxic industrial discharges, seasonal fishery closures, and permanent closures within restricted coastal waters. VCI is calculated as a percentage, with 100% indicating full adherence to closure periods. A VCI value of 0% signifies no deviation between closure and normal periods. In cases where the count of detections during the closure period is lower than in the normal period, the VCI value is positive; conversely, it is negative if the count is higher. A VCI of 50% denotes a 50% reduction in boat detections compared to the normal period, while a VCI of -50% indicates a 50% increase in boat detections during the closure month compared to the normal period (Elvidge et al., 2019).

2. MATERIALS AND METHODS

2.1 Study area

The research site is strategically positioned within the Exclusive Economic Zones (EEZs) of Thailand, delineated as the nation's maritime boundaries, as depicted in Figure 1. This particular research site encompasses regions within both the Andaman Sea and the Gulf of Thailand. These EEZs represent vital territorial and jurisdictional zones under international maritime law, where Thailand exercises sovereign rights and jurisdiction over the exploration, utilization, and conservation of marine resources. This dual geographical presence within the Andaman Sea and the Gulf of Thailand significantly contributes to the site's ecological and socioeconomic complexity, offering a diverse and dynamic context for comprehensive scientific investigation and analysis.

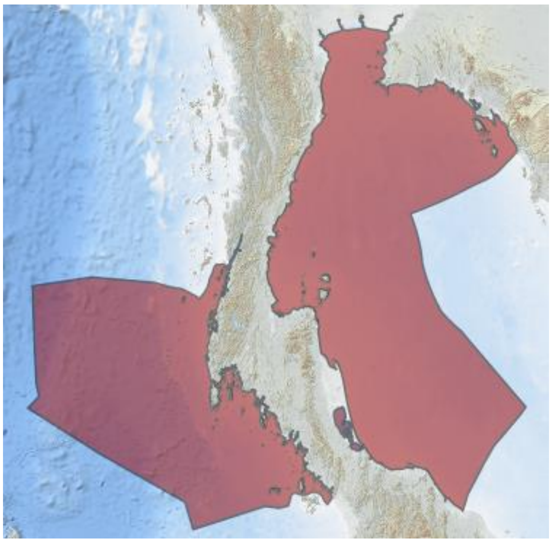


Figure 1. Exclusive Economic Zones of Thailand (https://www.marineregions.org).

Table 1. Description of the studied closures

ZONE	Closure Location	Study Years	Start Date	End Date
1	The southwestern part of the Gulf of Thailand from Surat Thani to Prachuap Khiri Khan's Mueang	2021	15 February	15 May
2	The western part of the Gulf of Thailand from Prachuap Khiri Khan's Mueang to Prachuap Khiri Khan's Hua Hin.	2021	16 May	14 June
3	The northwestern part of the inner Gulf of Thailand from Prachuap Khiri Khan's Hua Hin district to Samut Sakhon's Mueang.	2021	15 June	15 August
4	The northeastern part of the inner Gulf of Thailand from Samut Sakhon's Mueang to Si Racha district in Chon Buri.	2021	1 August	30 September

2.2 Data

The VIIRS Boat Detection (VBD) dataset employed in this scholarly investigation spans a continuous temporal window, encompassing the entire calendar year from January 2021 to December 2021, thus encompassing 12 months of data. This extensive dataset was procured from a reputable source, namely the Earth Observation Group (EOG), which makes it publicly accessible via their dedicated VBD section accessible at the following web address: https://eogdata.mines.edu/products/vbd/. It is important to note that the EOG website provides access to the VBD dataset subject to certain specified terms and conditions, thereby ensuring responsible and ethical usage.

The VBD dataset is thoughtfully made available in two distinct data formats to cater to varying research needs and analytical preferences. For the purposes of our investigation, the Comma-Separated Values (CSV) format was selected as the primary data source. This choice was deliberate and well-founded, as the CSV format aligns seamlessly with geospatial analysis methodologies and can be effortlessly integrated into geoinformatics workflows, streamlining the data processing and analysis pipeline. Furthermore, the selection of the VBD dataset from the year 2021 was made with careful consideration, as this specific temporal frame offers an expansive and comprehensive annual coverage. This temporal scope is pivotal in capturing a holistic view of the boat detection patterns and dynamics within the maritime environments under examination, facilitating a robust and in-depth assessment of the phenomena under investigation in our research study.

2.3 Methods

The following steps were analyzed and processed by GIS software.

2.3.1 Converting a CSV file to a Shapefile. This process will transform the VBD dataset in CSV format into a standard geospatial format for vector data storage (Shapefile). This will enable us to analyze, visualize, and merge it with other geospatial datasets.

2.3.2 Classification of Boats and Non-Boats. The goal is to classify boat and non-boat detections in the VBD dataset by analyzing the QF_Detect field values. The QF_Detect is an integer quality flag for the VBD pixel, providing information about the quality and type of detection shown in Table 1.

Table 2. Definition of QF_Detect

Quality Flag	Definition
1	Boat
2	Weak Detection
3	Blurry Detection
4	Gas Flare
7	Glow
8	Recurring Light
10	Weak and Blurry
11	Platform

2.3.3 Monthly Summary. The VBD data for each day was combined into monthly datasets using the merge method to create monthly summaries.

2.3.4 Annual Summary. The VBD data for each month was combined into yearly datasets using the merge method to create annual summaries.

2.3.5 Boat Density Calculation. To calculate the boat density from a monthly and yearly summary using count points in a polygon grid, take a boat point and a polygon and count the number of boat points from the first one in each polygon of the second one.

2.3.6 VIIRS Closure Index (VCI) Calculation. To calculate the number of boat detections during a fishing closure period compared to the number of boat detections during a normal period. The VCI formula is shown in Equation 1.

$$VCI = 100 \frac{(\text{VBD\_cl} - \text{VBD\_ref})}{(\max(\text{VBD\_ref}, \text{VBD\_cl}\ )} \qquad (1)$$

Where VBDcl" represents boat detections during the closure period and "VBDref" corresponds to boat detections during the normal period.

2.3.7 Mapping. To generate a thematic map showing the calculated boat density for each hexagon, use color gradients or varying shades to illustrate patterns of fishing boats during nighttime monthly and annual.

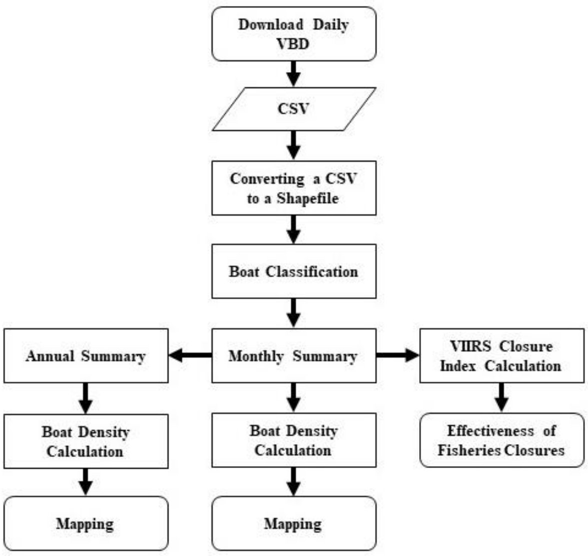
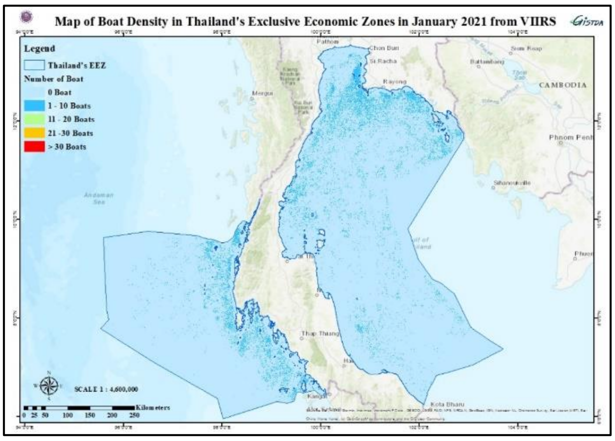


Figure 2. Flow of method.

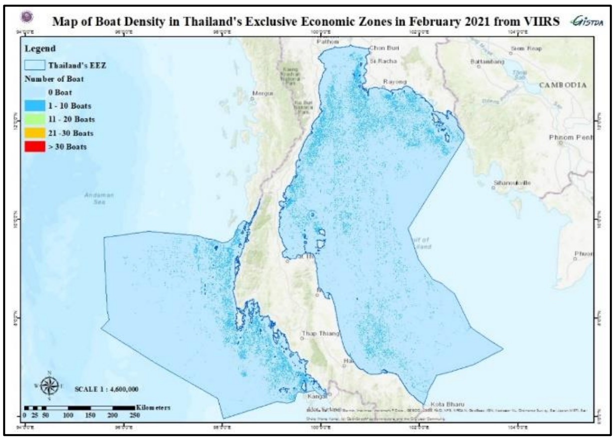
3. RESULTS AND DISCUSSION

The findings presented herein delineate the spatial distribution of boat density within Thailand's Exclusive Economic Zones (EEZ) during the calendar year of 2021. Figures 7 through 19 present a comprehensive monthly summation of boat density, as ascertained through the utilization of nighttime fisheries lights detection technology, spanning the duration from January through December 2021. It is conspicuously evident that the density of boats predominantly aligns with the coastal regions bordering both the Gulf of Thailand and the Andaman Sea. In the initial month of January, a notable concentration of boats is observed along the eastern coastline of the Gulf of Thailand, extending from Chonburi Province to Trat Province. A corresponding heightened boat density is similarly discernible along the Andaman coast, spanning from Ranong Province to Satun Province. As the calendar progresses to February, the Gulf of Thailand maintains its boat density along the eastern coast, stretching from Chonburi Province to Trat Province. Simultaneously, an escalation in boat density is witnessed along the western coast, encompassing Prachuap Khiri Khan Province to Chumphon Province. Meanwhile, the density of boats along the Andaman coast remains relatively consistent during this period. From March to July, a discernible decrease in boat density occurs in the eastern Gulf of Thailand, concomitant with an increase in boat density in the western Gulf of Thailand, particularly in the region from Prachuap Khiri Khan to Surat Thani Province. Notably, the lower Gulf of Thailand experiences a noticeable upward trend in ship density during this timeframe. In contrast, the boat density along the Andaman coast remains fairly stable throughout this period. August emerges as the month characterized by the lowest recorded boat density in both the Gulf of Thailand and the Andaman Sea (see Figure 10). Subsequently, between the months of September and December, there is a resurgence in ship density, notably in the eastern Gulf of Thailand, spanning from Chonburi Province to Trat Province, which experiences a pronounced increase in density. Along the Andaman coast, a similar pattern emerges, with ship density once again reaching elevated levels, particularly from Ranong Province to Satun Province (refer to Figure 3).

Analyzing the aforementioned data, it becomes apparent that the western coast of the Gulf of Thailand experiences heightened wave and wind activity during the northeast monsoon season, typically occurring from November to January. Consequently, boats tend to exhibit higher density along the eastern coast of the Gulf of Thailand during this period due to the milder wave and wind conditions experienced there. Conversely, in the period spanning from May to October, corresponding to the southwest monsoon season, both the eastern coast of the Gulf of Thailand and the Andaman coast experience increased wave and wind activity. Consequently, there is an augmented density of boats along the western coast of the Gulf of Thailand during this period, attributable to the relatively less turbulent wave and wind conditions prevalent in that area. Here, the data derived from the VIIRS boat detection (VBD) methodology yields valuable insights into the spatial distribution and seasonal fluctuations of fisheries activities within Thailand's Exclusive Economic Zones.



January



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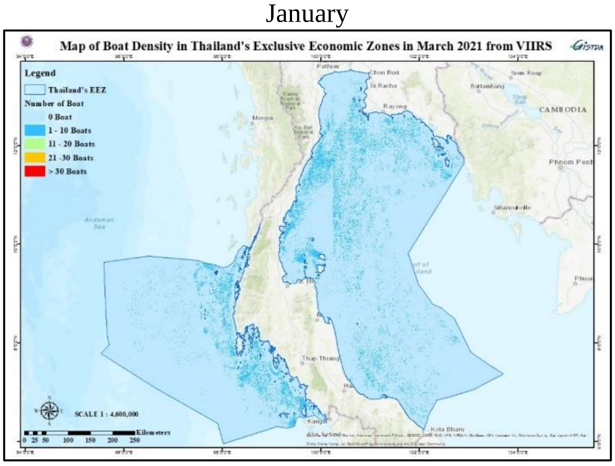

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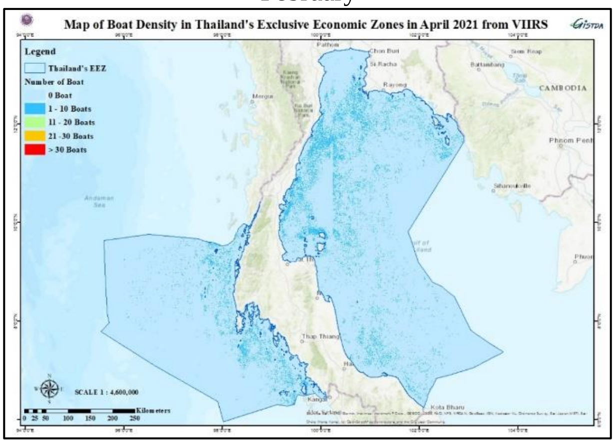

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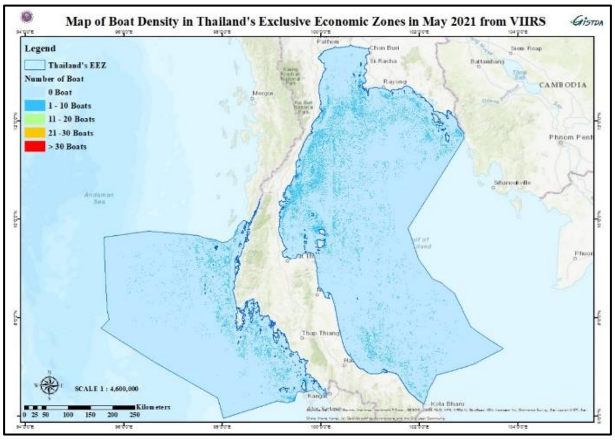
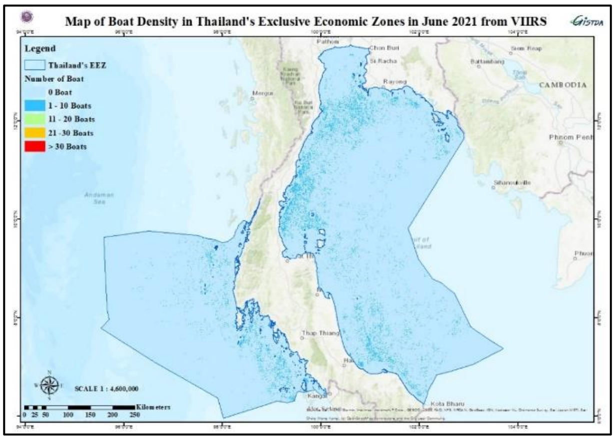


May



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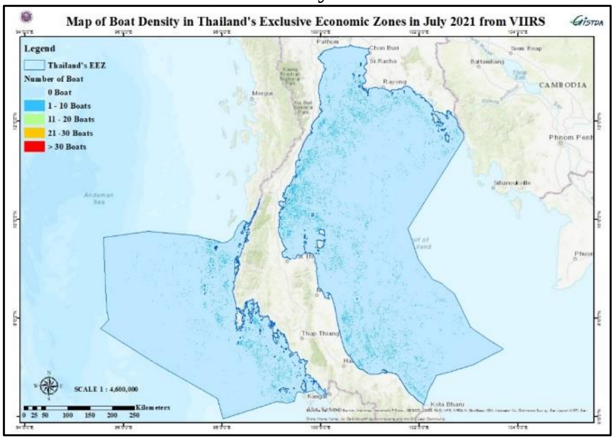

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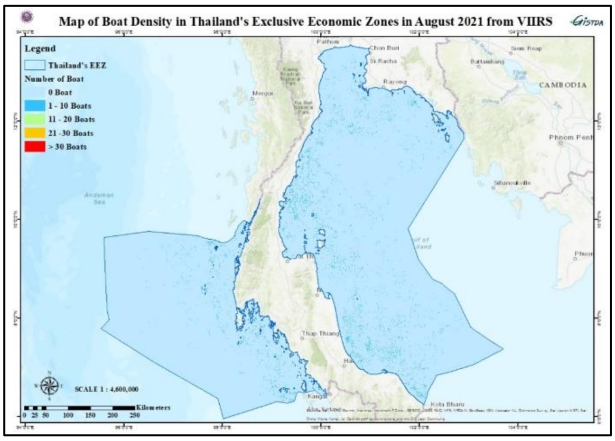
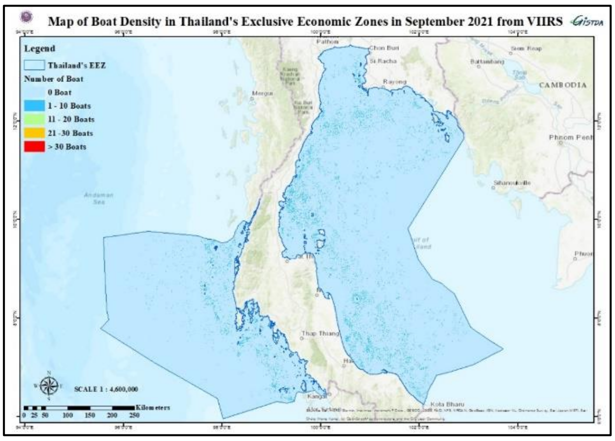
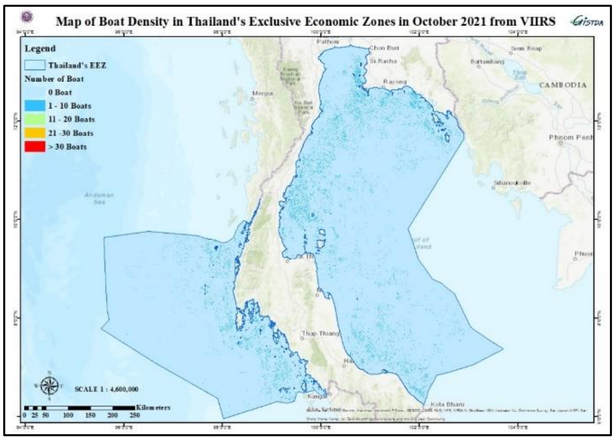


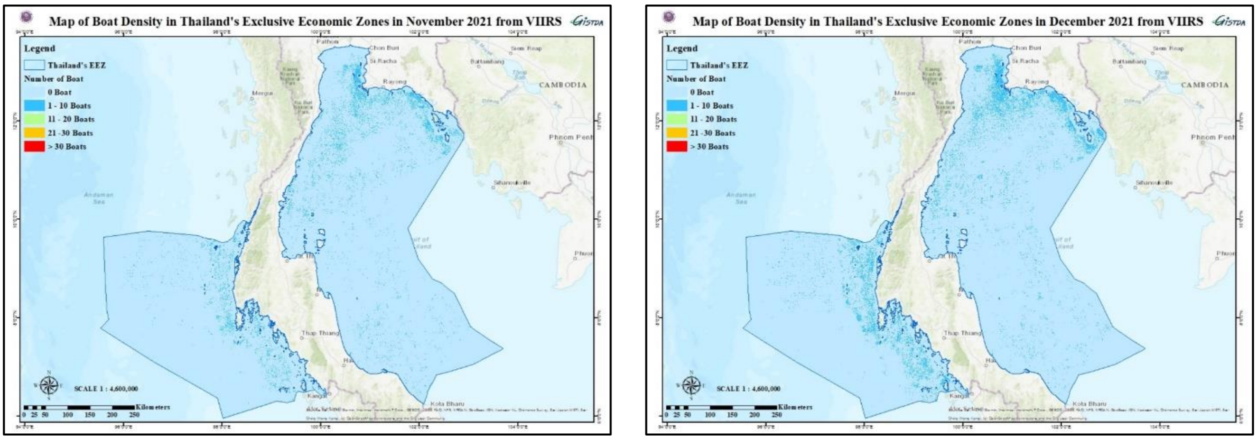
August



September



October



November December

Figure 3. Map of boat density in Thailand's Exclusive Economic Zones in January to December 2021

Delineates a discernible trend in boat counts within the research domain. The highest recorded boat count is manifest in the month of March, followed by a gradual decrement, ultimately reaching its nadir in the month of August. Subsequent to this diminishment, there is an incremental augmentation in boat counts during the ensuing months, which notably coincides with the seasonal patterns elucidated earlier, particular to the geographic context of Thailand. It is noteworthy that the southwest monsoon season, occurring from May to October, exerts a significant influence on this observed phenomenon. During this period, both the eastern coastline of the Gulf of Thailand and the Andaman Sea experience heightened wave and wind activity, which, in turn, leads to a conspicuous reduction in the number of boats. This reduction may be attributed, in part, to the potential hindrance posed by substantial cloud cover, which may diminish the effectiveness of satellite-based ship detection methodologies, thus contributing to the observed decline in recorded boat counts (refer to Figure 4).

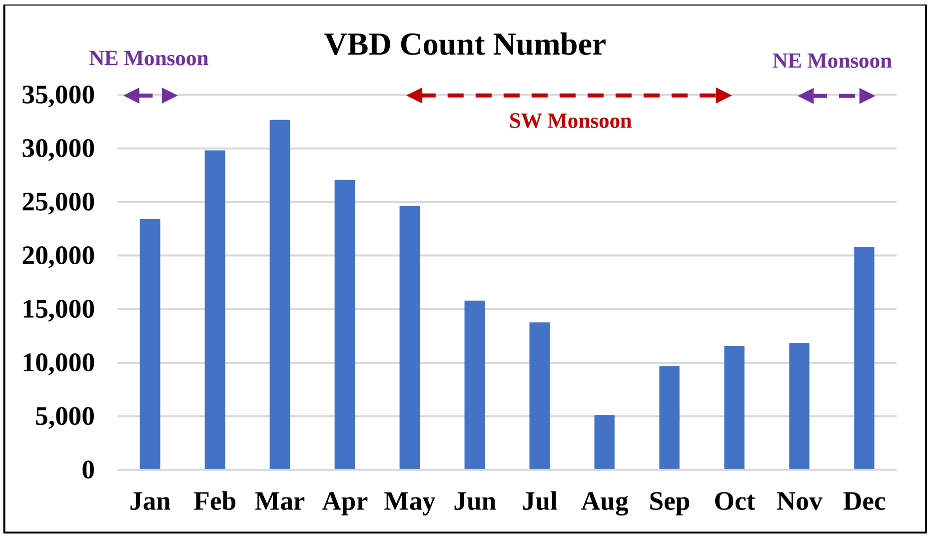


Figure 4. Monthly VBD count numbers in the year 2021.

A comprehensive visualization of composite annual maps that elucidate regions characterized by a notable concentration of maritime activities involving vessels employing nighttime lighting. Within the coastal expanse of the Gulf of Thailand, these activities are prominently concentrated in specific locales, including Trat Province's Khlong Yai District, Koh Chang District, and Koh Kood District; Chanthaburi Province's Tha Mai District; Rayong Province's Mueang District; Chonburi Province's Sriracha District and Bang Lamung District; Chumphon Province's Pathio District, Mueang District, and Sawi District; Surat Thani Province's Koh Phangan District; and Songkhla Province's Mueang District, Chana District, and Thepha District. Similarly, along the coastal zone of the Andaman Sea, maritime activities with nighttime lighting are notably observed in Phang Nga Province's Surin Islands and Phang Nga Bay, Krabi Province's Ao Luek District and Mueang District, as well as Satun Province's Tarutao Islands (refer to Figure 5).

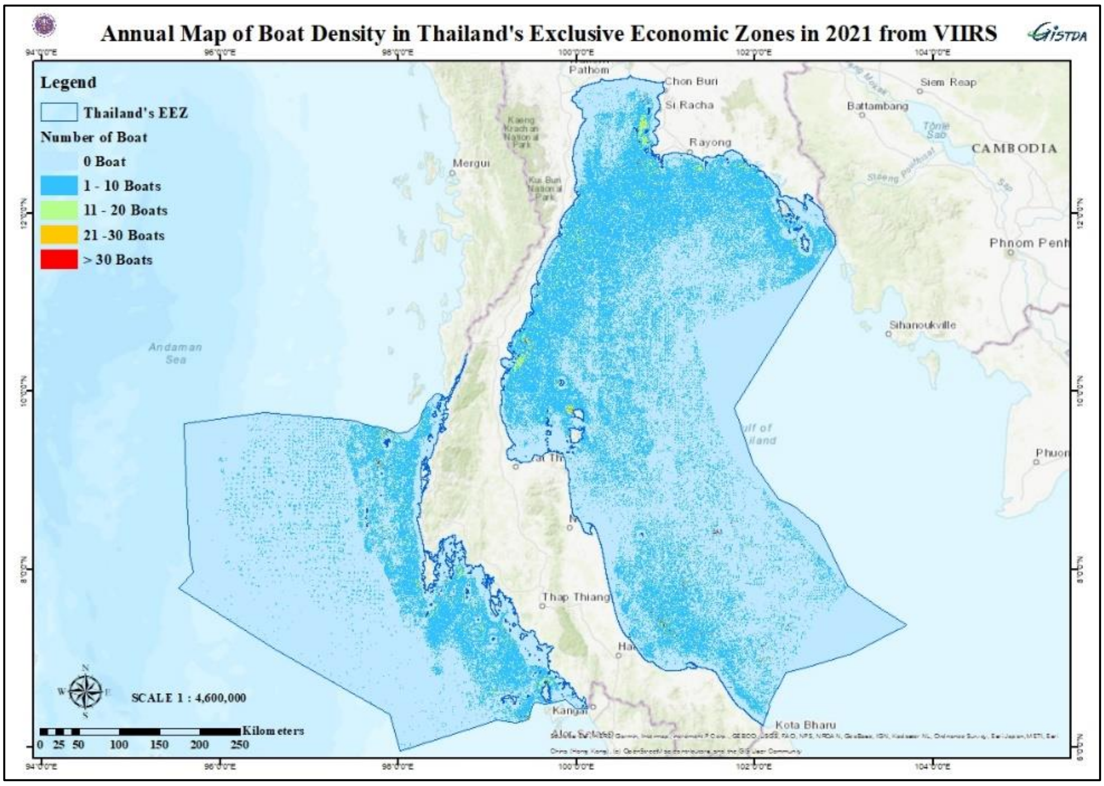


Figure 5. Annual map of boat density in Thailand's Exclusive Economic Zones in 2021.

The outcomes are predicated upon an analysis of boat detections during a fishing closure period, juxtaposed with boat detections during a standard operational period spanning from January 1, 2021, to December 31, 2021, specifically within the western sector of the Gulf of Thailand, extending from Prachuap Khiri Khan's Mueang district to Prachuap Khiri Khan's Hua Hin (referred to as "zone 1"). The VIIRS Closure Index (VCI) is calculated at -27.67%, signifying that the count of boat detections during the closure period exceeds that of the standard period. This VCI outcome suggests an ineffective implementation of the designated closure period, which spans from February 15 to May 15. In light of these findings, it is conceivable that bolstered enforcement measures may be requisite to enhance the efficacy of the closure period, as illustrated in (refer to Figure 6).

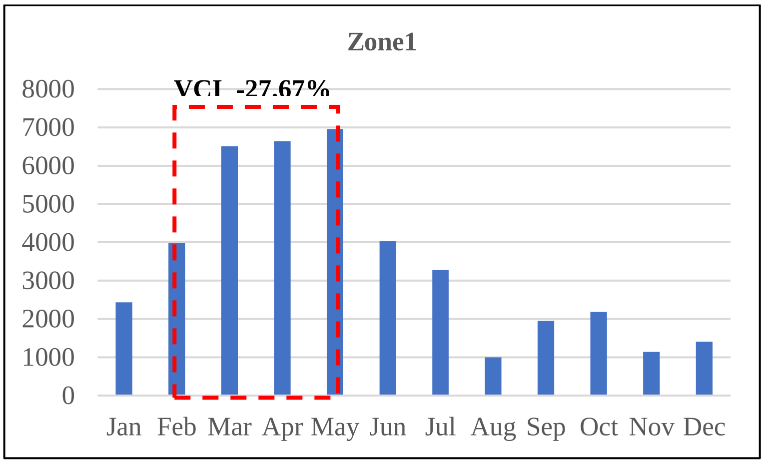


Figure 6. The sum of VBD detections in zone 1 in 2021 and the VCI values.

A comparable analysis of boat detections during a fishing closure period juxtaposed with those during a typical operational period, covering the time frame from January 1, 2021, to December 31, 2021, specifically within the southwestern segment of the Gulf of Thailand, extending from Surat Thani to Prachuap Khiri Khan's Mueang district (referred to as "zone 2"). In this instance, the VIIRS Closure Index (VCI) is calculated at 70.88%, signifying a lower count of boat detections during the closure period in relation to the standard period. This VCI outcome suggests an effective implementation of the closure period, spanning from May 16 to June 14, possibly attributable to effective adherence to notifications regarding the fishing closure period (refer to Figure 7).

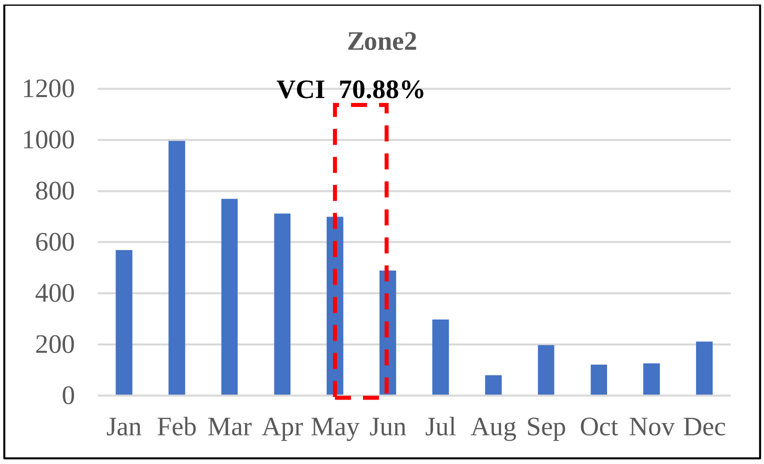


Figure 7. The sum of VBD detections in zone 2 in 2021 and the VCI values.

Similarly offers insights gleaned from an analysis of boat detections during a fishing closure period, juxtaposed with those during a typical operational period, spanning from January 1, 2021, to December 31, 2021, within the northwestern region of the inner Gulf of Thailand, encompassing Prachuap Khiri Khan's Hua Hin district to Samut Sakhon's Mueang district (referred to as "zone 3"). In this context, the VIIRS Closure Index (VCI) is computed at 81.64%, indicating a lower count of boat detections during the closure period in relation to the standard period. This VCI outcome suggests an effective implementation of the closure period, extending from June 15 to August 15, potentially resulting from successful collaboration in adhering to notifications pertaining to the fishing closure period (refer to Figure 8).

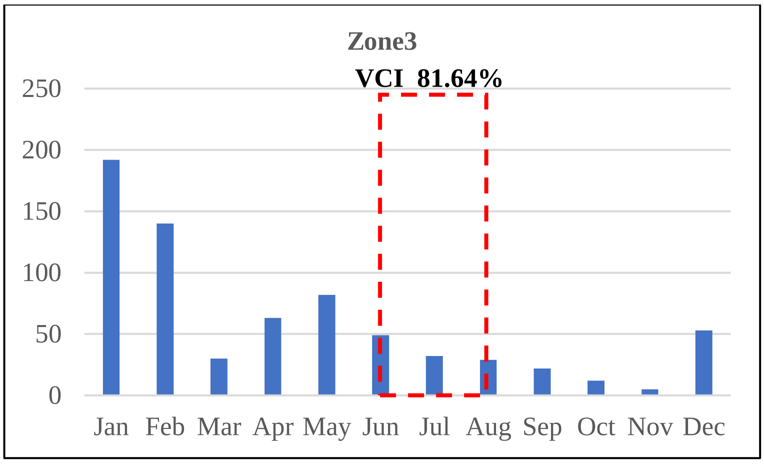


Figure 8. The sum of VBD detections in zone 3 in 2021 and the VCI values.

The findings derived from an analysis of boat detections during a fishing closure period contrasted with those during a typical operational period spanning from January 1, 2021, to December 31, 2021, within the northeastern segment of the inner Gulf of Thailand, from Samut Sakhon's Mueang district to Si Racha district in Chon Buri (referred to as "zone 4"). In this instance, the VIIRS Closure Index (VCI) is calculated at 98.29%, indicating a lower count of boat detections during the closure period in relation to the standard period. This VCI outcome suggests an effective implementation of the closure period, extending from August 1 to September 30, potentially resulting from effective collaboration in adhering to notifications concerning the fishing closure period (refer to Figure 9).

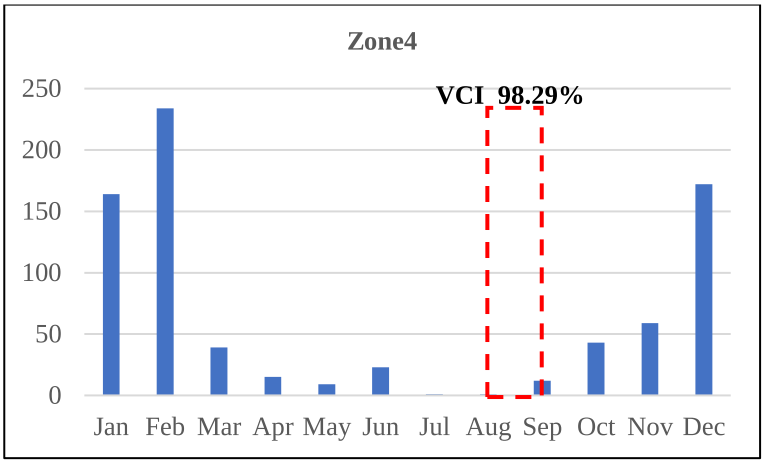


Figure 9. The sum of VBD detections in zone 4 in 2021 and the VCI values.

4. CONCLUSION

This study demonstrates the potential of the Visible Infrared Imaging Radiometer Suite (VIIRS): Day/Night band (DNB) to monitor marine activity by VIIRS boat detection (VBD) based on nighttime fishing lights within Thailand's Exclusive Economic Zones. The findings from the density analysis indicate that the regions where nighttime fishery light activities demonstrate obvious patterns or boundaries in accordance with the monsoon seasons in Thailand, encompassing both the northeast and southwest monsoon periods. Assessment of the utilization of measures for announcing the closure of fisheries area utilizing the VIIRS Closure Index (VCI). The analysis results indicate that the utilization of effective measures for the closure of fisheries areas in Zones 2, 3, and 4 is evident from the lower count of vessels during the closure periods in comparison to regular periods. Conversely, within Zone 1, it becomes apparent that more strong measures may be necessary, as there is an observable increase in the number of fisheries boats during the bay closure period compared to the regular period. This information can serve as a valuable instrument for the strategic planning and organizing of marine area utilization, aimed at optimizing their potential and sustainability while minimizing any adverse impact on marine resources. This encompasses the resolution of conflicts among diverse user groups, such as marine zoning, the establishment of marine protected areas, and the delineation of fisheries management zones. This tool is commonly known as Marine Spatial Planning (MSP). The future plan will involve the validation and comprehensive analysis of boat information using Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data to enhance accuracy and completeness. The study's findings will also be consulted with the Department of Fisheries for the purpose of incorporating the study results into the formulation of tangible strategies for the management of fishing zones.

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