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Spatial planning model for optimization of conservation priority for local community utilization in Marine Protected Area: A case study of the Raja Ampat Marine Protected Area (MPA) on Arefi Island, West Papua, Indonesia

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This study addresses the critical role of spatial planning in marine conservation, particularly within the Raja Ampat Marine Protected Area (MPA) located on Arefi Island, West Papua, Indonesia. Despite the recognized ecological significance of this region, characterized by diverse ecosystems such as mangroves, seagrass beds, and coral reefs, a gap exists in effectively integrating these natural assets into conservation strategies that empower local and indigenous communities. To bridge this gap, we applied Marine Reserve Design Using Spatially Explicit Annealing (Marxan) Models as a zonation tool in spatial planning to delineate conservation zones within the MPA. Our approach centers on leveraging the area's biodiversity to achieve conservation goals that are synergistic with the socioeconomic needs of the indigenous population. Through analyzing three Ecological Value-based scenarios, each scenario aiming to quantify and prioritize conservation features, we explored the potential for sustainable ecosystem utilization while ensuring the protection of critical habitats. The outcomes reveal that among the scenarios tested, the one denominated Ecological Value III aligns most closely with international conservation standards, saving 34.37 ha (6.32% of the total area) as a core conservation zone. However, Ecological Scenario II presented a balanced approach, offering more significant areas for local community use while maintaining conservation integrity. This scenario emphasizes the necessity of incorporating traditional knowledge and community involvement in conservation efforts. The findings advocate for an adaptive management strategy, highlighting the vital role of geospatial technology in safeguarding marine biodiversity and supporting sustainable resource use in Indonesia's coastal ecosystems

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Abstract

This study addresses the critical role of spatial planning in marine conservation, particularly within the Raja Ampat Marine Protected Area (MPA) located on Arefi Island, West Papua, Indonesia. Despite the recognized ecological significance of this region, characterized by diverse ecosystems such as mangroves, seagrass beds, and coral reefs, a gap exists in effectively integrating these natural assets into conservation strategies that empower local and indigenous communities. To bridge this gap, we applied Marine Reserve Design Using Spatially Explicit Annealing (Marxan) Models as a zonation tool in spatial planning to delineate conservation zones within the MPA. Our approach centers on leveraging the area's biodiversity to achieve conservation goals that are synergistic with the socioeconomic needs of the indigenous population. Through analyzing three Ecological Value-based scenarios, each scenario aiming to quantify and prioritize conservation features, we explored the potential for sustainable ecosystem utilization while ensuring the protection of critical habitats. The outcomes reveal that among the scenarios tested, the one denominated Ecological Value III aligns most closely with international conservation standards, saving 34.37 ha (6.32% of the total area) as a core conservation zone.

However, Ecological Scenario II presented a balanced approach, offering more significant areas for local community use while maintaining conservation integrity. This scenario emphasizes the necessity of incorporating traditional knowledge and community involvement in conservation efforts. The findings advocate for an adaptive management strategy, highlighting the vital role of geospatial technology in safeguarding marine biodiversity and supporting sustainable resource use in Indonesia's coastal ecosystems.

Keywords: Marine Protected Area, conservation zones, biodiversity conservation, Marxan Models, spatial zoning.

Introduction

Indonesia boasts some of the world's richest marine biodiversity. Indonesia contains an estimated 16% of the world's coral reefs and over 5% of seagrass beds and has the most extensive mangroves on Earth, accounting for 23% of the world's total (Amkieltiela et al. 2022). These productive ecosystems provide many benefits, such as filtering pollutants, nutrition, coastal protection, livelihoods, and carbon storage. Due to these benefits, Indonesia has a high priority for conservation, particularly in Raja Ampat Marine Protected Area Regency of Arefi Island West Papua Province. Conservation of the marine environment is critical for upholding the Earth's natural processes, overseeing its reactions to substantial forthcoming challenges like addressing climate change impacts, and ensuring the well-being and advantages of society (Marcos et al. 2021).

Indonesia's government has established protected areas (PAs) to implement biodiversity conservation and sustainability management. Indonesia has established 411 ~~MPAs~~ marine protected areas (MPAs) across its archipelago, covering approximately 9% of its territorial waters, which amounts to over 28 million hectares (Estradivari et al. 2022). One of these areas is the Raja Ampat Islands in the Raja Ampat Regency, West Papua Province (Kepmen KP, 2014). This MPA is divided into five areas with a total area of approximately 1,026,540 hectares. Each area has specific zones that play a crucial role in managing and conserving natural resources, providing a framework for effective planning and sustainable development. In this context, the term "zone" refers to a defined area with specific characteristics or purposes, often demarcated for conservation, resource management, or other regulatory objectives (Permen KP, 2016). The zones in this conservation area include the core, utilization, fisheries, and other zones. The other zones are divided into two subzones: the traditional use and seasonal closure subzone and the other utilization subzone.

For marine biodiversity conservation, MPAs are defined as marine, coastal, or small island areas that are protected and managed by a zoning system to achieve sustainable management of fish resources and biodiversity conservation (Green et al. 2009). MPAs are essential tools for conserving marine biodiversity and sustaining ecosystem services (Claudet et al. 2020). In particular, MPAs with well-designed spatial planning strategies are more effective in achieving conservation goals (Edgar et al. 2014). With the increasing threats posed by human activities such as overfishing, habitat destruction, and climate change, effective spatial planning within MPAs becomes essential for sustainable management. (Mora, et al. 2019).

Raja Ampat Regency, located in West Papua, Indonesia, has a variety of natural tourism charms, both land, and sea and has socio-cultural riches for its exceptional marine biodiversity. In recent years, the MPA area distributed in Raja Ampat, encompassing Arefi Island, has faced mounting pressures from anthropogenic activities, necessitating comprehensive conservation strategies to ensure its long-term sustainability. Spatial planning, utilizing advanced modeling techniques, emerges as a valuable tool for optimizing conservation efforts within MPAs. However, increasing anthropogenic pressures, such as overfishing and habitat destruction, threaten the ecological integrity of the Raja Ampat MPA and the sustainability of Arefi Island's marine ecosystems (Cinner et al. 2018). To address these challenges, effective spatial planning within MPAs is essential (White et al. 2018). Spatial planning involves systematically allocating marine areas for different uses, considering ecological, social, and economic objectives (Agardy et al. 2011).

This extensive conservation area certainly has shortcomings in certain areas, as exemplified by Arefi Island. Arefi Island and its surroundings are located within other zones in the marine conservation area in Raja Ampat (Kepmen KP, 2014). The decree, while acknowledging the significance of Arefi within the broader context of marine conservation, lacks the necessary specificity to harness its full potential. Specifically, the decree falls short in delineating the subzone's boundaries. It fails to address the diverse ecosystems and biodiversity present and optimize the use of these marine resources by indigenous communities, hindering the realization of its conservation objectives. For an MPA to be effective and beneficial to the surrounding communities, determining its location must consider four main principles: Connectedness, Adequacy, Representativeness, and Effectiveness (CARE) (Ban et al. 2011). Based on numerous studies, the ideal proportion of coastal areas that should be protected is 20-30% of the total coastal area. Furthermore, the minimum core zone area within a ~~Marine Protected Area~~ MPA is 20-30% to ensure the sustainability of the targeted biota stocks (Krueck et al. 2017).

This gap in applying the CARE principles within the context of Arefi Island's designation underlines a critical issue in marine conservation efforts in Indonesia and similar biodiverse regions globally. While establishing MPAs is a significant step towards conservation, the lack of precise boundary delineation, coupled with inadequate consideration for the complex mosaic of ecosystems, impedes the strategic planning necessary for effective conservation. The existing decree's broad strokes approach fails to account for the ecological and socio-economic nuances of Arefi Island, leading to a mismatch between conservation objectives and on-ground realities. This oversight not only compromises the ecological integrity of the protected area but also the livelihoods and cultural heritage of the indigenous communities dependent on these marine resources. Moreover, the shortfall in aligning with the recommended coverage and core zone area for MPAs further exacerbates the challenges faced in achieving sustainable conservation outcomes. Addressing these gaps requires a comprehensive, data-driven approach to MPA management that emphasizes spatial planning and community involvement, ensuring biodiversity conservation and socio-economic resilience.

Thus, effective maritime planning is required to design marine conservation areas. In maritime planning, processing, and analyzing information with spatial dimensions is crucial. Therefore, implementing maritime planning within the Geographic Information System (GIS) framework provides significant benefits. The effective maritime planning process includes evaluating various objectives, identifying conflicts or synergies in marine use, the risk of human activities, spatial zone management, and scenario testing. Stelzenmüller et al. (2013) stated that the assessment of conservation area planning can be quickly done using practical tools. These tools encompass risk assessment, forecasting, modeling, and other decision support tools, such as simulation models, to address 'what if' questions or scenarios for developing planning options.

This study aims to explore the complexities of the Arefi subzone's conservation by leveraging existing biodiversity elements so that the community can optimally utilize them. This study aims to redesign zoning within the MPA to protect biodiversity and support the sustainable management of marine resources by the community. Through this research, we aspire to contribute valuable insights to marine conservation planning to develop a robust and sustainable spatial unit plan for the Arefi subzones.

Materials & Methods

Study Area

This research was conducted in Area III of MPA, Dampier Strait, Arefi Island, Raja Ampat Regency, West Papua (Fig. 1). The Raja Ampat MPA in West Papua, Indonesia, encompasses a vast and diverse marine ecosystem, including Arefi Island. This region is recognized for its exceptional biodiversity and ecological importance (Allen and Erdmann, 2012). Arefi Island, situated within the Raja Ampat MPA, harbors significant marine biodiversity and provides critical habitats for various species, including corals, fish, and endangered marine mammals (Trip et al. 2019).

The Dampier Strait is renowned for its ecological richness, making it a popular tourist destination. As an area with a well-functioning aquatic ecosystem and fisheries, this region is also strategically important for those looking to exploit the benefits of fisheries resources. Despite being categorized under 'other zones,' satellite data reveals the rich bio-physical potential of Arefi Island (McKenna et al. 2002; RPZ Raja Ampat 2018). The island exhibits characteristics that make it a suitable candidate for various conservation zones, including core, fisheries, and sustainable utilization. This potential underscore the need for a comprehensive and nuanced zoning strategy to fully harness and protect the diverse ecosystems found on and around Arefi Island.

Figure 1. Study area map in Arefi Island, Raja Ampat District

The Arefi region, enriched with indigenous cultures, practices the "sasi" tradition, deeply rooted in their rich cultural heritage. This customary resource management system, involving periodic closures, is designed to allow ecosystem recovery, ensuring resource sustainability (Sairiltiata, 2023). The "sasi" tradition offers an avenue for eco-tourism, presenting visitors with an authentic and culturally immersive experience. Specifically, the communities of Arefi and Yansaway on Batanta Island are revisiting "sasi gereja," a localized traditional conservation method that harmonizes traditional laws with church teachings, in response to the marked decline in marine resources and environmental degradation. "Sasi gereja" is set for reintroduction on Way Island, known for its rich marine biodiversity, including fish, sea cucumbers, clams, and lobsters. This initiative involves a unique ceremonial process where a church service marks the beginning of the "Sasi" period, ceasing fishing activities to give nature a rest period for rejuvenation. A concluding service signifies the end of the closure period, following the belief that the marine resources have adequately recovered. Non-compliance with the "sasi gereja" commands penalties, underscoring the community's commitment to this eco-culturally integrated conservation strategy (McKenna et al. 2002).

Biophysics Parameters

Biophysical parameters were obtained from the classification of high-resolution Worldview 3 satellite images in 2021 provided by the Center for Data and Information (Pusdatin) BRIN. The spatial resolution of these satellite images is approximately 0.6 meters, enabling detailed analysis and mapping of terrestrial and aquatic ecosystems. The WorldView 3 satellite imagery, as detailed by Choudhury et al. (2021), encompasses a broad spectrum of multispectral bands, each targeting specific wavelengths that are instrumental in distinguishing various surface materials and conditions. The Coastal band (400-450 nm) is designed to penetrate aquatic environments, offering insights into water clarity and sediment levels. The Blue band (450-510 nm) and the Green band (510-580 nm) are critical for assessing water body depths and the health of aquatic vegetation. The Yellow band (585-625 nm) helps differentiate soil and vegetation types. Given its sensitivity to chlorophyll absorption, the Red band (630-690 nm) is particularly effective in identifying vegetation. The Red edge band (705-715 nm) marks the transition between the red and near-infrared parts of the spectrum, providing valuable information on vegetation health and stress. Furthermore, the Near-Infrared one band (770-895 nm) and Near-Infrared two band (860-1040 nm) are paramount for analyzing biomass content and water body delineations. These bands are essential for identifying and quantifying vegetation types and densities, soil moisture levels, and other critical environmental variables (Table 2).

Due to the high resolution of the satellite images, a thorough image analysis is required. At this stage, classification methods based solely on pixel information are minimal due to spectral similarities. To overcome this limitation, object-based image analysis (OBIA) can be a valuable tool to differentiate cover classes. OBIA is a distinct option from pixel-based methods, using image objects as the basic unit of analysis rather than individual pixels (Hossain and Chen, 2019). OBIA is an iterative process that starts by dividing satellite images into cohesive and contiguous image segments. The resulting image objects are then assigned to the intended classes through the use of supervised or unsupervised classification approaches (Belgiu and Csillik, 2018). According to Ventura et al. (2018), the OBIA workflow initially involves image segmentation (a series of segmentation processes based on parameters of pixels with the same spectral values). In this study, we utilized the Multi-resolution Segmentation (MRS) algorithm, a process for image objects aimed at minimizing average heterogeneity and maximizing homogeneity. Three crucial parameters in implementing the MRS algorithm are shape, compactness, and scale (Darmawan et al. 2022). OBIA analysis was done using the eCognition Developer 64 software.

The segmentation results were then classified using Support Vector Machines (SVM) algorithms, a sophisticated non-parametric classifier widely employed in hyperspectral image classification, which operates based on statistical learning theory (Tan et al. 2018). It is designed to seek an optimal decision hyperplane within a high-dimensional space, ensuring an optimal separation of classes. SVM consistently performs well in challenging classification scenarios with high-dimensional features, demonstrating effectiveness even when dealing with a limited number of training samples (Cao et al. 2018). The fundamental concept behind SVM is to identify a hyperplane that maximizes the margin between distinct classes. This hyperplane is expressed through the following equation:

$$f(x) = \sum_{i=1}^{n} \alpha_i y_i K(x,x_i) + b$$

where, $f(x)$: decision function

α_i : coefficients obtained during the training process

y_i : class label of the training sample x_i

$K(x,x_i)$: kernel function

b : bias term

The predicted class of the input data point x is the determined by $f(x)$. If $f(x) > 0$ then the data point is classified as belonging to one class. If $f(x) < 0$ then the data point is classified as belonging to another class. The classified data, field, and secondary observations, are then input into the Marxan software.

Marxan Models

Marine Reserve Design Using Spatially Explicit Annealing (Marxan) is software that provides decision support for the systematic design of conservation areas (Ball et al. 2009). The Marxan analysis is based on specific principles that aid in identifying conservation areas with high value in terms of sustainability and relatively low management costs. Marxan operates using a simulated annealing algorithm developed to achieve optimal results quickly through optimization within its algorithm (Anggraeni et al. 2017). Many random changes to the protected area system are attempted, typically one million or more. At the beginning of the annealing process, every change in the score is accepted. As the process unfolds, the probability of accepting unfavorable changes gradually decreases until only beneficial changes are accepted. Unfavorable changes are those that increase the objective function score, while beneficial changes are those that decrease the score (Moilanen and Ball, 2009). This process allows the algorithm to find a solution approximating the exact solution (Watts et al. 2017). The optimal results indicate the lowest total cost that operates with the following equation (Watts et al. 2017):

$$Total\ Cost = \sum_{i=1}^{n} Cost + \left(BLM\ x \sum Boundary\right) + \sum_{i=1}^{n} (SPF\ x\ Penalty)$$

Cost : The combination of socio-economic values in each planning unit within the selected solution.
BLM : Values set by the user and related to the level of connectivity between planning units. The higher the Boundary Length value, the denser the solution area.
Boundary: The boundary of the selected area.
SPF : Values set by the user and related to the importance of biodiversity target objectives. The higher the SPF assigned to a feature, Marxan will prioritize that feature in the solution.
Penalty : Penalty value assigned if biodiversity protection targets are not achieved (optional).
i : Unit ID in the shapefile.
n : Last Unit ID in the shapefile.

Boundary length in the protected area system is measured as the number of planning units that border planning units outside the protected area system. Therefore, a fragmented protected area system will have a considerable boundary length. Modifying the boundary length or Boundary Length Modifier (BLM) aims to address connectivity issues by assigning a value to the importance of a denser protected area system. BLM is crucial because a fragmented system will likely be difficult (and expensive) to manage (Watts et al. 2017). The Species Penalty Factor (SPF) is assigned for each conservation target and represents additional costs added to the total portfolio cost if conservation target objectives are unmet. Setting a high species penalty factor helps ensure that Marxan will achieve conservation target objectives (Geselbracht et al. 2009). see Kim et al 2021) ~~In Kim et al. (2021), SPF for bird species targets was set up to 100% to prioritize species conservation and minimize the number of unmet targets~~

Data and Scenario

The data used in this research is mainly from remote sensing as primary data and supported by available secondary data (Table 1) and specification of multispectral bands of worldViews 3 image shows at Table 2. In the conservation planning process, targets denote the minimum quantity or proportion of elements (such as vital habitats, species, processes, activities, and distinct areas considered during the planning phase) within the planning region that should be encompassed in the final plan. For instance, a target might be set to ensure 30% coverage of each habitat type in the conservation system. Targets can be specified as a specific quantity (e.g., hectares of a particular habitat) or the number of occurrences (number of individuals) for each feature emphasized in the reserve system. Biophysical parameters, including mangroves, seagrass, and coral reefs, function as breeding grounds for numerous fish species that possess both commercial value and ecological significance (Weeks 2017; Sutrisno, D et al. 2021). These parameters are incorporated as integral conservation components.

Table 1 Types and Sources of Data

Table 2 The multispectral bands of the WorldView-3 satellite imagery (Source : Choudhury et al. 2021)

Figure 2 Research Framework

This research employs three different scenarios. Each scenario with conservation features will be called "Ecological Value." The conservation features on Arefi Island consist of several ecosystems, namely mangroves, seagrass, and coral reefs. Each of these features will be protected and serve as the primary consideration in the spatial zoning design of the conservation area according to the weight of each scenario parameter. The percentage weights for each conservation feature in Ecological Value I, II, and III are 30%, 40%, and 50%, respectively (Table 3). The International Union for Conservation of Nature (IUCN) considers these percentages to be the best for sustainability. The cost characteristics found in Marxan inputs signify the social, political, and operational challenges that hindered the selection of protected zones. Allocating planning units for conservation actions is a part of the cost feature, and this process relies on social data, which encompasses population figures, resource utilization patterns, and area usage. Recognizing regions with distinctive local characteristics beyond conventional policies is instrumental in shaping the spatial layout of marine conservation areas (Table 4). The scenario with a combination of other percentage weights can be utilized; however, in this research, only three scenarios are used.

Table 3 Ecological Value of Conservation Zoning

Table 4 Cost Features

This study considers the cost features of various human spatial utilization activities within the conservation area. Penalty scores for each cost feature are assigned based on the level of importance of the activity. The higher the penalty score assigned, the more difficult it is to consider the activity area as a core zone. A penalty score of one represents activities such as docks, floating net cages, and residential areas. Higher penalty scores are assigned to land use activities. These scores are based on the difficulty of considering or releasing the area as a core zone (Wijayanto, 2021).

Results

Satellite Image Analysis Results

The satellite image analysis using the OBIA method revealed three main coastal ecosystems in Arefi Island. These coastal ecosystems are mangroves, seagrasses, and coral reefs (Fig. 3). These three ecosystems are crucial coastal ecosystem components that contribute to conservation sustainability. ~~Mangrove, seagrass, and coral ecosystems play a significant role in coastal protection against climate change, provide food, and serve as habitats for shelter, nursing, and breeding~~ (Carlson et al. 2021; Unsworth et al. 2019). The three ecosystems have interrelationships that support each other. Mangroves and seagrasses control the release of sediment from the land, reducing the impact of excessive sediment flows that could potentially suffocate coral reefs (Golbuu et al. 2008). In return, mangroves are shielded from wave impact and establish mutually beneficial biological connections with coral reefs. Therefore, the existence of these three ecosystems must be preserved, and efforts should be made to minimize degradation from anthropogenic activities.

Figure 3 OBIA analysis of coastal ecosystems of Arefi Island, Raja Ampat, West Papua

The total area of coastal ecosystems on Arefi Island is approximately 64.78 hectares (Table 5). This area is predominantly covered by coral reefs, accounting for 45.41% of the total coverage. Mangrove, seagrass, and coral reefs are scattered around Arefi Island, while mangroves are densely distributed southeast of Arefi Island. ~~Mangroves~~ mangroves are scarce in residential areas. Seagrass beds coverage, making up 36.35% of the total, dominates the northern part of Arefi Island. The presence of a port and floating fish cages indicates shipping, fishing, and tourism activities by the local community.

Table 5 Percentage coverage of coastal ecosystems using OBIA analysis.

Conservation Priority Area Recommendations on Arefi Island

In three main scenarios, the buffer area is around 600 meters. This is based on the geographical location of Arefi Island, where the farthest ecosystem extends to approximately 500 meters from the island's coastline. To avoid bias in the study, the entire area of shallow marine habitats must be included. From the analysis of the maps captured in Figure 4, three main areas emerge with higher selection percentages, even in lower target scenarios. These areas are observed in the northern, southeastern, and southwestern waters of Arefi Island. The lack of selected areas for conservation in the eastern part of Arefi Island's waters is evident. This may be due to a lower level of biodiversity compared to other regions, justifying the absence of this area in the solutions generated by Marxan. Another factor contributing to the absence of high-priority areas is the scarcity of data and cumulative impacts resulting from high anthropogenic activities in a specific region (Fernandes et al. 2018). This factor occurs in the western and southern waters of Arefi Island. Suspected tourism activities, shipping routes, and aquaculture practices, specifically floating net systems, contribute to the scarcity of high-priority areas.

Figure 4 Conservation zones in Arefi Island with (a) Ecological Value I, (b) Ecological Value II, (c) Ecological Value III

The analysis of the zoning arrangements for the Arefi Island conservation area under three distinct Ecological Value scenarios reveals significant differences in spatial allocation aimed at optimizing conservation priorities, as seen in Table 6. Under Ecological Value I, the Core Zone, designated for the most stringent protection, covers 12.33 hectares or 2.27% of the total conservation area. Adjacent zones, including the Utilization Zone and Sustainable Fisheries Zone, constitute 1.62% and 3.68% of the area, respectively, indicating a prioritization strategy that leans towards a more inclusive use of the space while reserving the majority, 92.43%, for Other Zone, which may include general use areas with minimal restrictions. This arrangement totals 544.03 hectares, emphasizing a conservative approach to spatial designation.

Moving to Ecological Value II and III scenarios, there is a noticeable shift towards increased allocation for core conservation efforts. The Core Zone expands to 19.53 hectares (3.60%) and 34.37 hectares (6.32%) in scenarios II and III, respectively, reflecting a progressive enhancement in dedicated conservation spaces. Correspondingly, the Utilization and Sustainable Fisheries Zones undergo adjustments in their spatial allocations, with scenario III demonstrating a strategic reduction in these zones to bolster core conservation areas. This shift indicates a heightened emphasis on conservation, with the Other Zone area proportionately decreasing to accommodate the expanded Core Zone.

Table 6 Zoning arrangements for the Arefi Island conservation area

Discussion

This study carried out an overview of remote sensing techniques for biodiversity monitoring in marine protected areas. It explores high-resolution satellite sensors and image analysis methods used to assess habitat types, species distributions, and ecological changes. The review highlights the potential of satellite imagery for biodiversity assessment and emphasizes the importance of

results?

integrating remote sensing data with ground-based observations for accurate monitoring~~, as explained by~~ Petrou, Z.I. et al. (2015).

The parameters used vary depending on the geographic conditions of the existing region. Some research commonly utilizes parameters such as coral reefs, seagrass beds, mangroves, biota migration routes, protected biota areas, turtle farming, shipping lanes, etc (Fernandes et al. 2018). The distribution descriptions of each parameter are provided in the study area. From this research, it is evident that coral reefs, seagrass beds, and mangroves show significant results in depicting the conservation area. Ecological Value: I use a target proportion (prop) of 30%. In the Marxan setting, the prop will be adjusted to 0.3, meaning the conservation feature area within the planning units will be determined at 30%. The result of this scenario has a core zone area of 12.33 hectares or 2.27% of the total planned conservation area. This area does not yet meet the ideal target for biota protection in the conservation area. According to Krueck et al. (2017), the ideal area of coastal regions to be protected is 20-30% of the total coastal area.

The Marxan model was utilized to design conservation and utilization zone areas on Arefi Island. Marxan models operate systematically and are specifically designed to identify locations, plan, and manage conservation areas comprehensively (Anggraeni et al. 2017). This model relies on the static distribution of selected features, such as habitats, species distribution, or landscape types, to choose candidate features to achieve the desired conservation targets (Henriques et al. 2017). Marxan employs a more detailed and practical planning unit approach that optimally integrates biodiversity considerations for sustainable conservation (Cheok et al. 2016). ~~This~~ Our (or the current) study found that employing a spatial planning model can identify optimal conservation priority zones within Arefi Island for local community use in the Marine Protected Area. Spatial planning modeling integrates ecological data, habitat suitability assessments, and stakeholder input to identify areas of high conservation value and vulnerability (Halpern et al. 2019). Employing this approach would enhance the effectiveness of conservation measures and ensure the long-term sustainability of marine ecosystems in the Raja Ampat MPA.

Scenario Ecological Value II indicates that the protection target or conservation features will be simulated to receive 40% protection for all ecosystems. The result of this scenario has a core zone area of 19.53 hectares or 3.60% of the total planned conservation area. This area does not yet meet the ideal target for biota protection in the conservation area. According to Krueck et al. (2017), the ideal area of coastal regions to be protected is 20-30% of the total coastal area.

~~Scenario Ecological Value III indicates that the protection target or conservation features will be simulated to receive 50% protection for all ecosystems. The result of this scenario has a core zone area of 34.37 hectares or 6.32% of the total planned conservation area. This area does not yet meet the ideal target for biota protection in the conservation area. According to Krueck et al. (2017), the ideal area of coastal regions to be protected is 20-30% of the total coastal area.~~

Of the three Ecological Values, the one that comes closest to the ideal scenario is Ecological Value III, which has a core zone percentage of 6.32%. This requirement is part of the IUCN conservation standards, aiming to safeguard 30% of crucial habitats within the region. It can safeguard 20-30% of significant fish species at various trophic levels and disperse 30% of larvae generated by these sites beyond the designated area. Based on Regulation of the Minister of Marine Affairs and Fisheries No. 30 of 2010 Article 9 paragraph 3 concerning the zoning management plan of conservation areas, it is stipulated that a core zone must be established for each marine conservation area, coastal area, and small islands covering at least 2% (two percent) of the total area. The establishment of this regulation indicates that all three scenarios of Ecological Value meet the standard where the core zone area in each scenario exceeds 2% of the total area. In other words, designing a conservation area requires scenario designs that consider various conservation features and incorporate prop values (protection portions) into Marxan according to management objectives.

The outcomes of our analysis, particularly under Ecological Value Scenario II, highlight the optimal balance between conservation imperatives and the potential for sustainable utilization. This scenario, which allows for a higher degree of human activity within the designated areas without compromising the overarching conservation goals, mirrors the findings of similar studies that have sought to identify the sweet spot between ecological preservation and socioeconomic development. For instance, a study by Nguyen et al. (2018) on the optimization of MPA design for fisheries and biodiversity indicated that careful zoning could enhance marine resource stocks while supporting local livelihoods. This resonance between our findings and Nguyen et al. 's work underscores the efficacy of adaptive spatial planning in achieving multifaceted conservation objectives.

Moreover, the preferential outcomes associated with Ecological Value Scenario II, when compared with other scenarios, corroborate the theory that not all conservation efforts need to limit human activities to be strictly effective. This aligns with the principles outlined in the study by Harris et al. (2019), which suggested that MPAs with mixed-use areas, when properly managed, could contribute significantly to biodiversity conservation while simultaneously providing economic benefits to local communities. This perspective challenges the traditional conservation paradigm that often advocates for strict no-take zones, suggesting that a nuanced approach, as demonstrated in our scenario II, can yield significant ecological and socioeconomic benefits.

The juxtaposition of our scenario II results with these studies not only validates our methodology but also contributes to the ongoing dialogue on sustainable conservation practices. It highlights the necessity of incorporating local socio-economic realities into conservation planning, ensuring that MPAs serve both as bastions of biodiversity and as sources of sustainable development.

Such comparisons are invaluable for refining future conservation strategies, suggesting that further research should explore the integration of ecological and socio-economic data more deeply. This approach will enhance the understanding of the complex interplay between conservation areas and human communities, paving the way for more inclusive and effective conservation solutions.

Comparing the results of this study with previous research highlights both advancements in conservation planning methodologies and the critical need for refined spatial analysis in marine protected areas (MPAs). For instance, a study by Jones et al. (2016) on MPA design and effectiveness pointed out the crucial role of incorporating ecological and social data to achieve both biodiversity conservation and community benefits. While Jones et al. emphasized the integration of socio-economic factors, our study primarily focused on Ecological Values and their spatial distribution. This difference underscores the importance of a holistic approach that balances ecological integrity with human well-being, suggesting that future studies should include more comprehensive socio-economic analyses to align conservation efforts with community needs and aspirations.

A notable limitation of this research is the reliance on static ecological data, which may not fully capture the dynamic nature of marine ecosystems and their responses to climate change and human activities. The spatial resolution and temporal scope of the data, while sufficient for initial zoning and scenario planning, might not reflect subtle but significant ecological shifts over time. Additionally, the Marxan tool, despite its robustness in conservation planning, has constraints in modeling complex human-environment interactions, highlighting the need for integrating more adaptive and participatory planning tools that can accommodate changing ecological and social landscapes.

Future studies should aim to address these limitations by incorporating dynamic environmental modeling that accounts for climate change scenarios, habitat migration, and other ecological shifts. The inclusion of longitudinal community engagement and socio-economic data will enrich the conservation planning process, making it more responsive to the needs and values of local populations. Moreover, the exploration of innovative technologies, such as machine learning and artificial intelligence, could offer new insights into optimizing MPA design and management. These advancements will not only enhance the effectiveness of conservation zones but also contribute to the global knowledge base on sustainable marine resource management, ensuring the protection of biodiversity while supporting the livelihoods of dependent communities.

Conclusions

The outcomes of our analysis, particularly under Ecological Value Scenario II, highlight the optimal balance between conservation imperatives and the potential for sustainable utilization. This scenario, which allows for a higher degree of human activity within the designated areas without compromising the overarching conservation goals, mirrors the findings of similar studies that have sought to identify the sweet spot between ecological preservation and socioeconomic development. For instance, a study by Nguyen et al. (2018) on optimizing MPA design for fisheries and biodiversity indicated that careful zoning could enhance marine resource stocks while supporting local livelihoods. This resonance between our findings and Nguyen et al. 's work underscores the efficacy of adaptive spatial planning in achieving multifaceted conservation objectives.

Moreover, the preferential outcomes associated with Ecological Value Scenario II, when compared with other scenarios, corroborate the theory that not all conservation efforts need to limit human activities to be strictly effective. This aligns with the principles outlined in the study by Harris et al. (2019), which suggested that MPAs with mixed-use areas, when properly managed, could contribute significantly to biodiversity conservation while simultaneously providing economic benefits to local communities. This perspective challenges the traditional conservation paradigm that often advocates for strict no-take zones, suggesting that a nuanced approach, as demonstrated in our scenario II, can yield significant ecological and socioeconomic benefits.

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Figure 1

Study area map in Arefi Island, Raja Ampat District

This research was conducted in Area III of marine Protected Area (MPA), Dampier Strait, Arefi Island, Raja Ampat 146 Regency, West Papua (Fig. 1). The Raja Ampat MPA in West Papua, Indonesia, encompasses a 147 vast and diverse marine ecosystem, including Arefi Island.

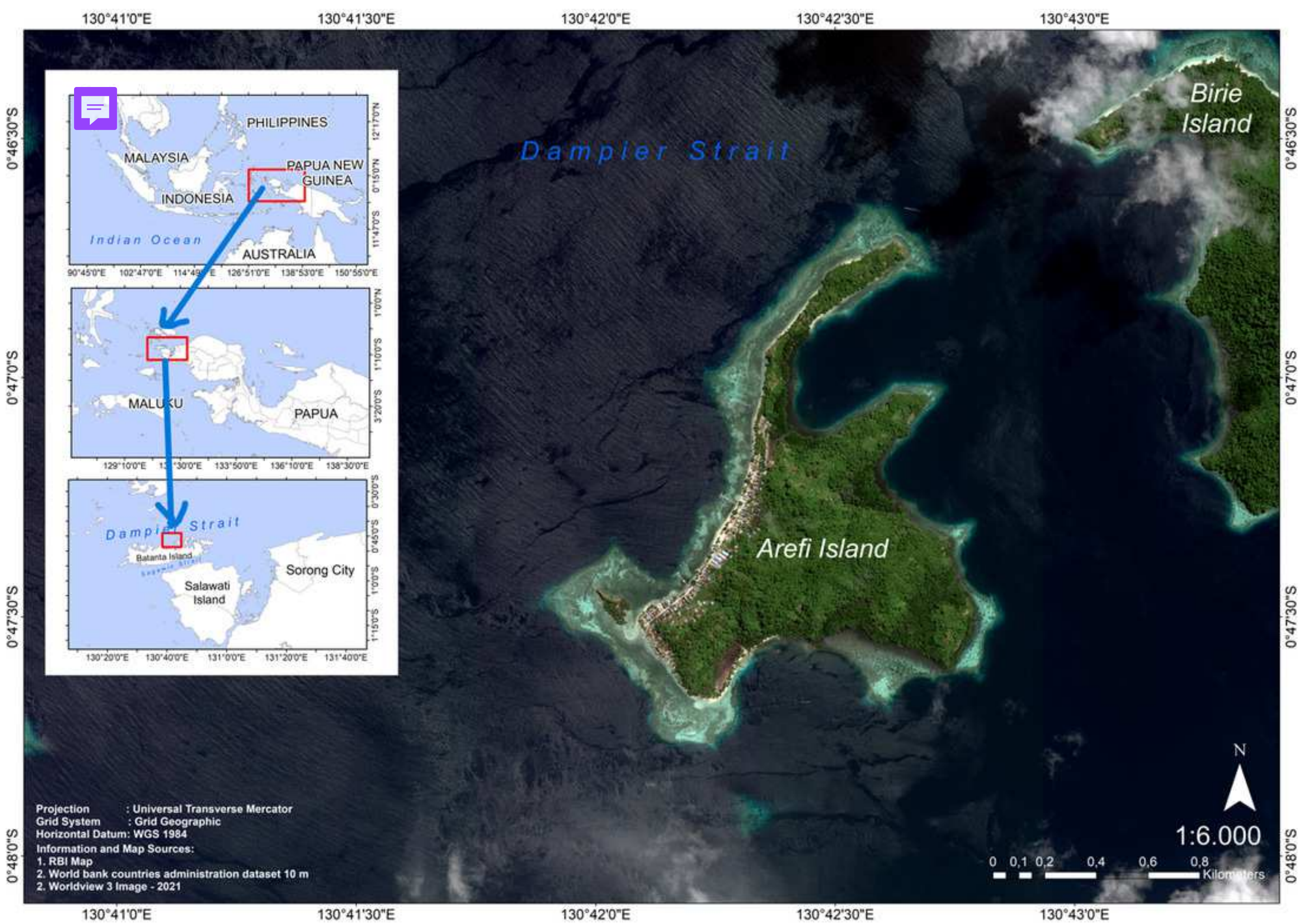

Figure 2

Research Framework

Figure 2 illustrates the flow of research carried out involving biophysical analysis of high-resolution satellite data, spatial analysis using GIS applications, and Marxan models for zoning planning units and discussions.

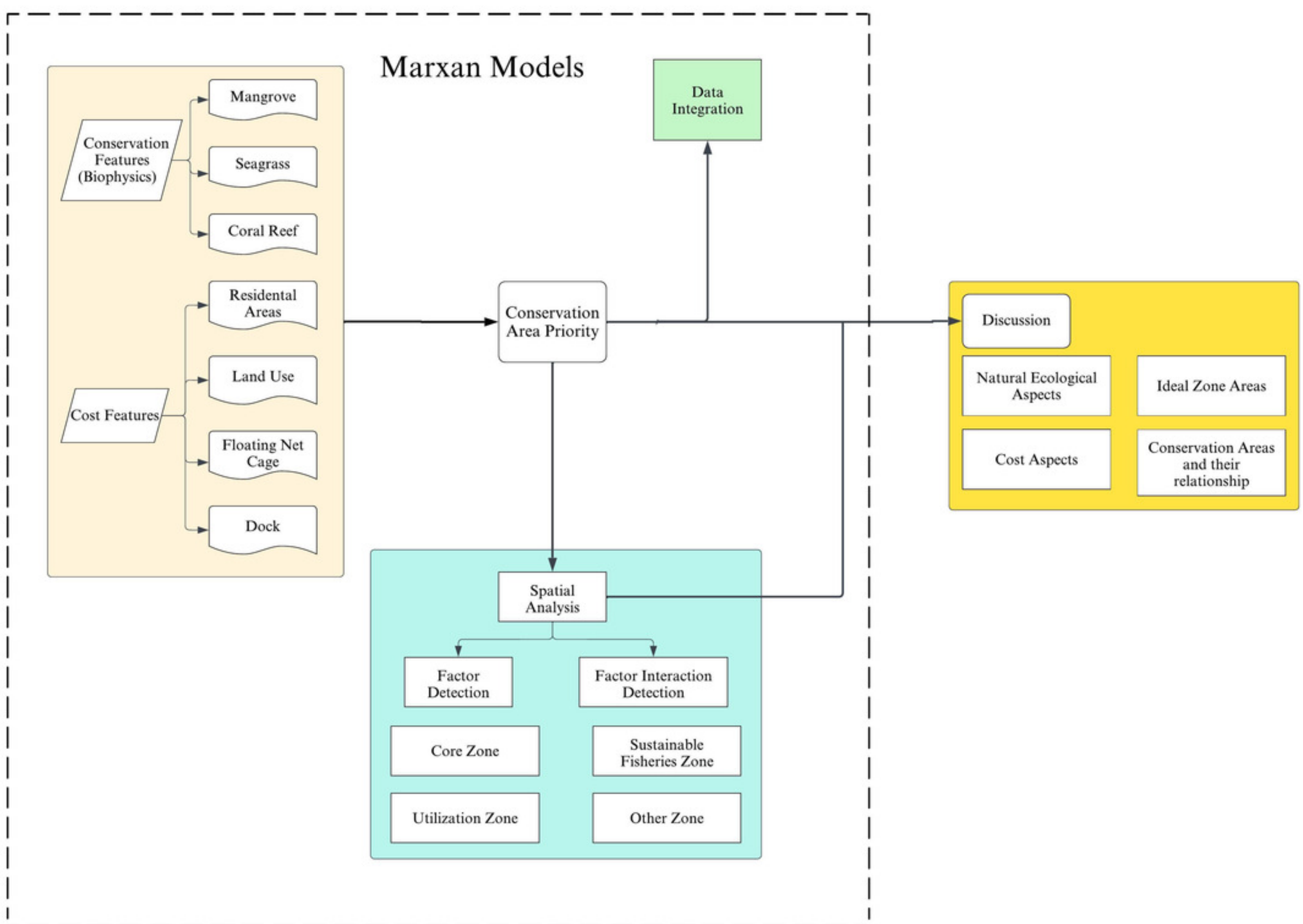

Figure 3

OBIA analysis of coastal ecosystems of Arefi Island, Raja Ampat, West Papua

OBIA analysis of coastal ecosystems of Arefi Island, Raja Ampat, West Papua from satellite worldview 3 data for mangroves, sea grass and coral reefs

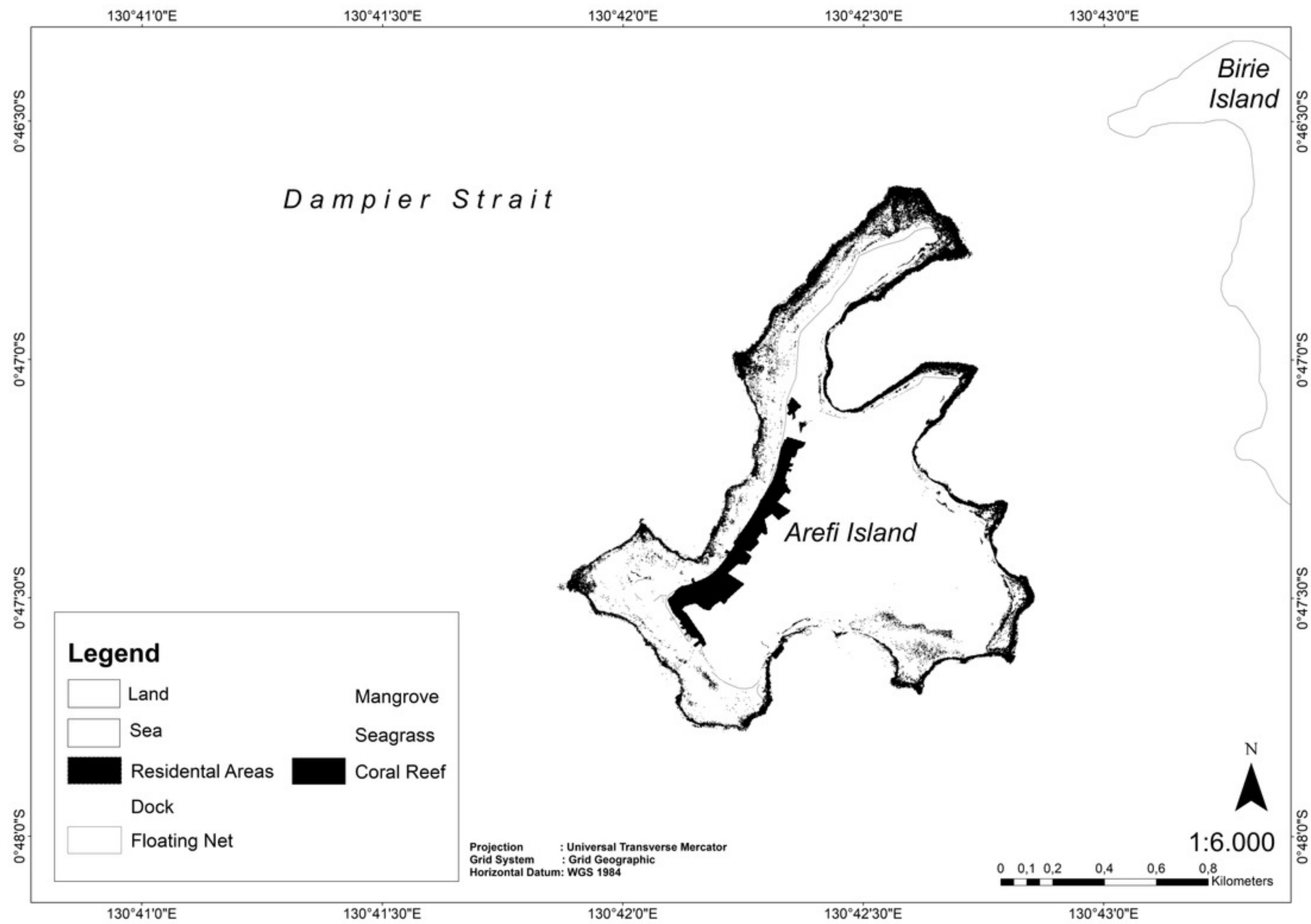

Figure 4

Conservation zones in Arefi Island with Ecological Value I

results of spatial analysis and zoning models for conservation zones in Arefi Island with (a) Ecological Value I, (b) Ecological Value II, (c) Ecological Value III

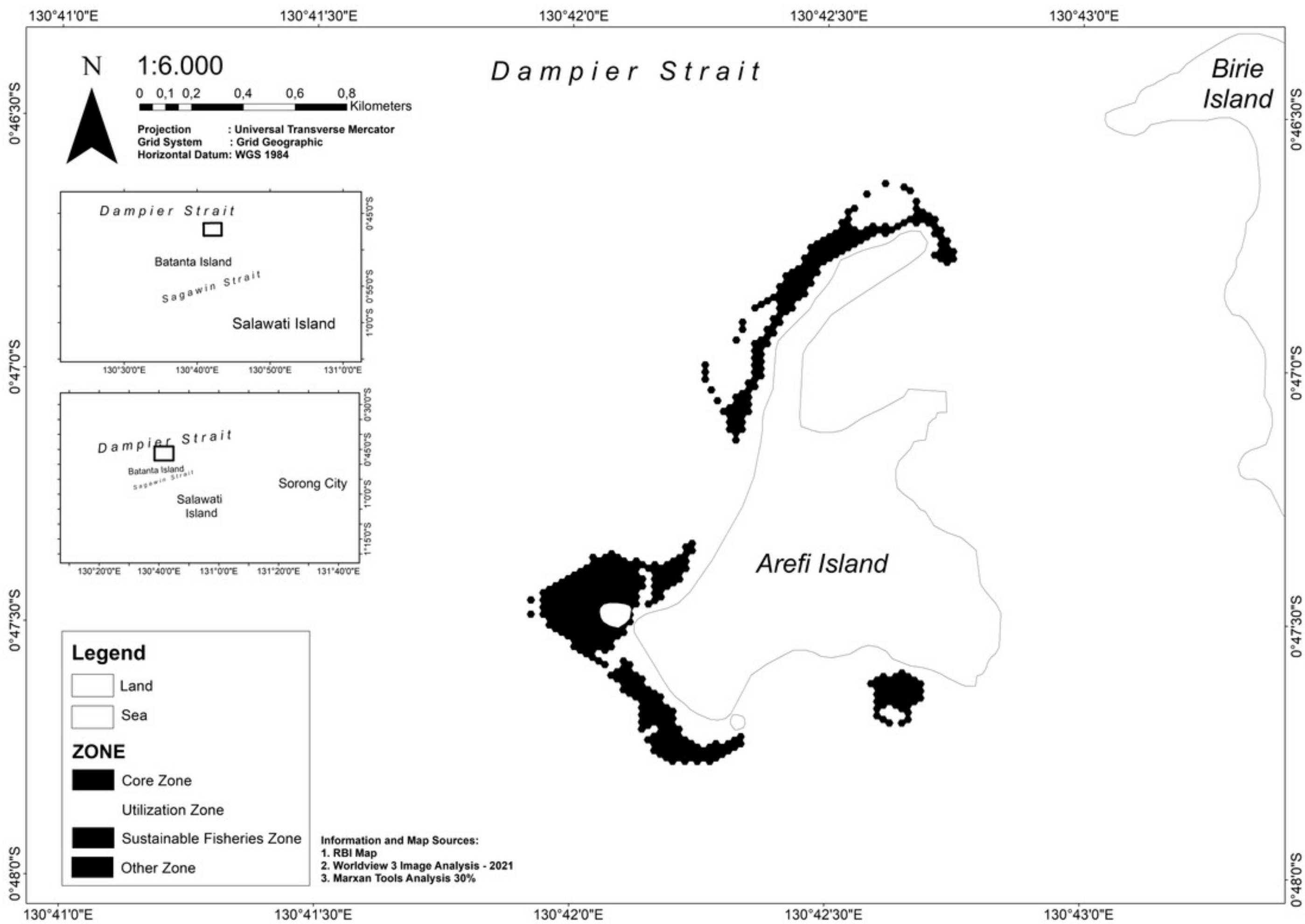

Figure 5

Conservation zones in Arefi Island with Ecological Value II

results of spatial analysis and zoning models for conservation zones in Arefi Island with (a) Ecological Value I, (b) Ecological Value II, (c) Ecological Value III

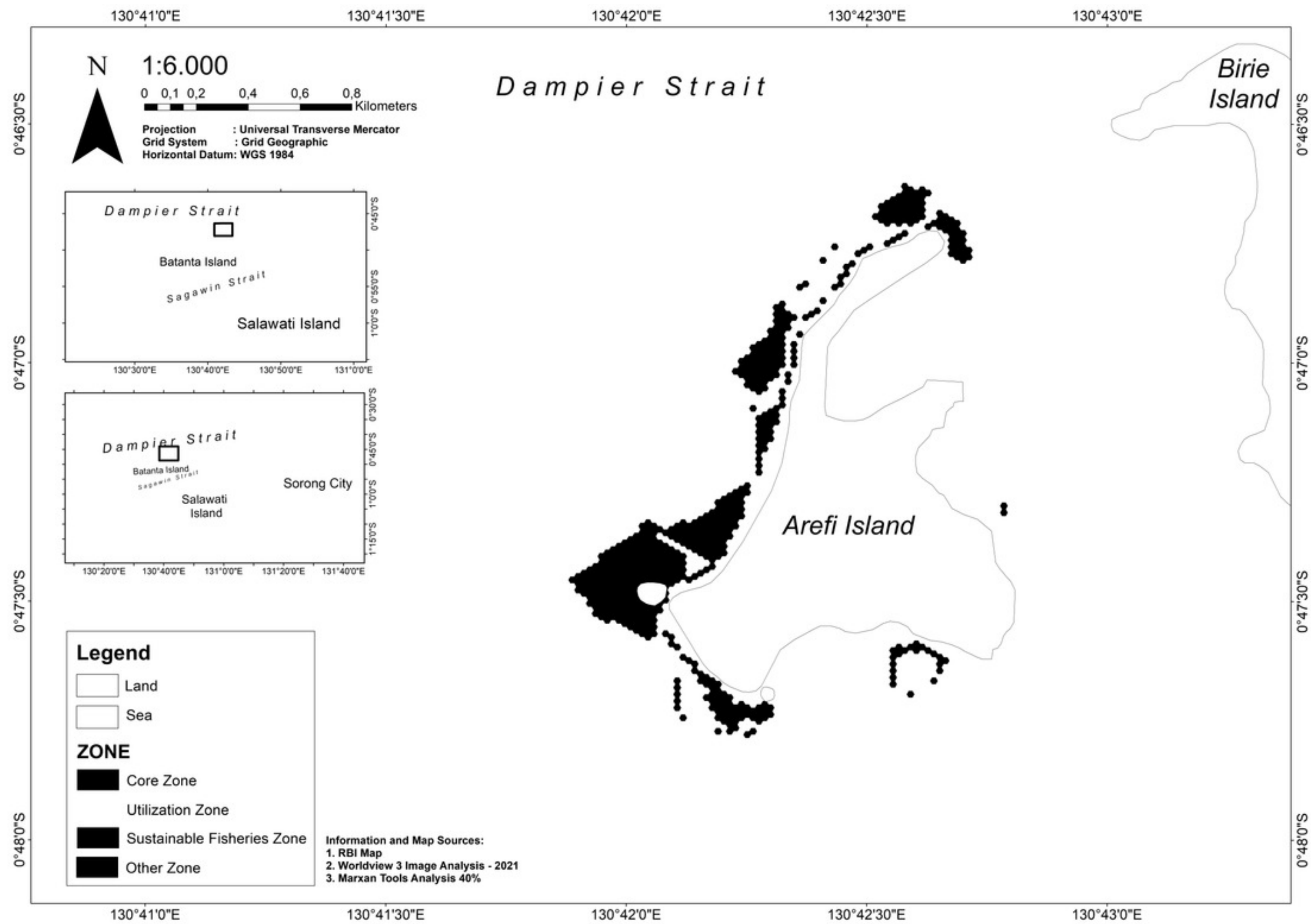

Figure 6

Conservation zones in Arefi Island with Ecological Value III

Results of spatial analysis and zoning models for conservation zones in Arefi Island with (a) Ecological Value I, (b) Ecological Value II, (c) Ecological Value III

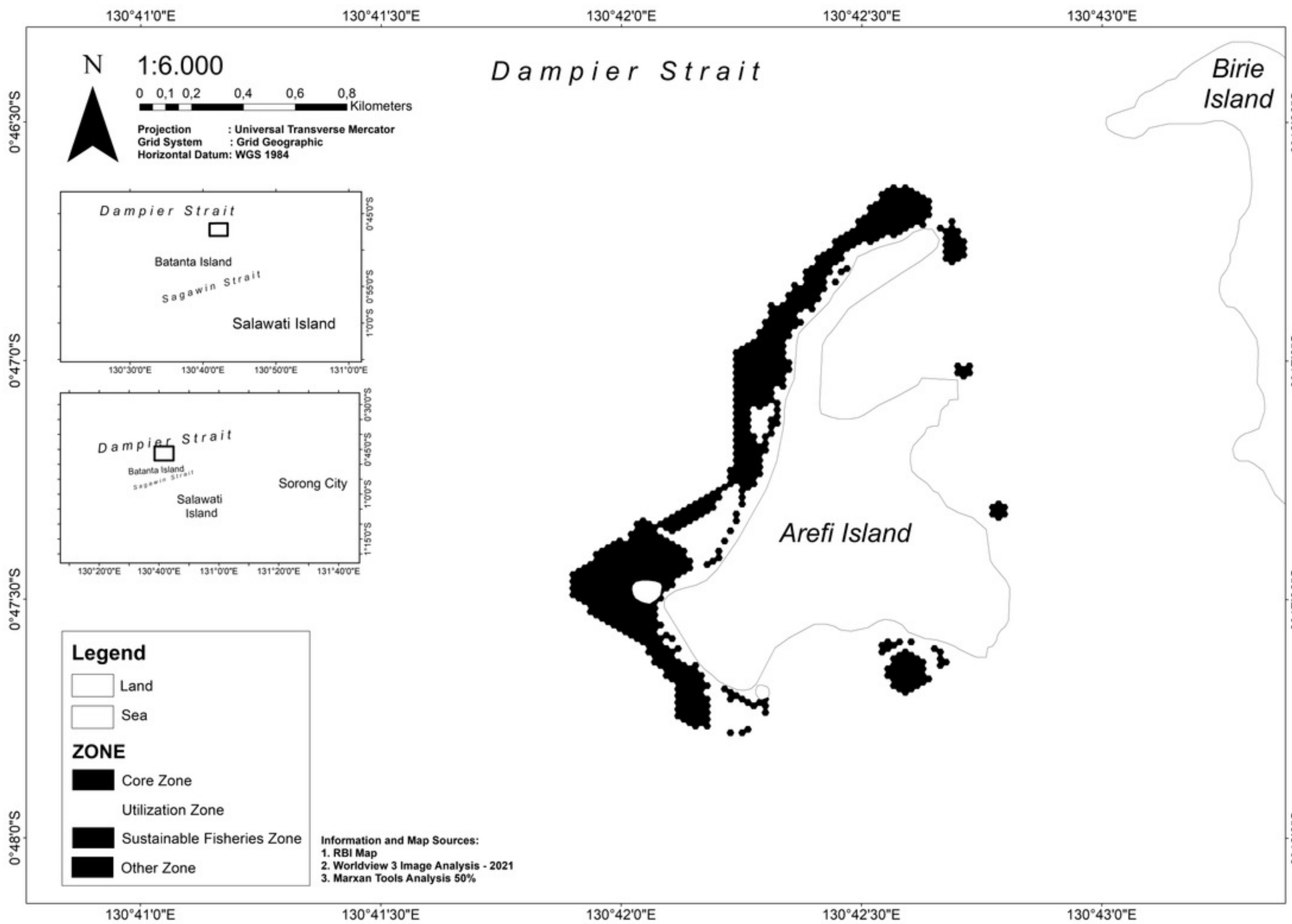

Table 1(on next page)

The multispectral bands of the WorldView-3 satellite imagery

The multispectral bands of the WorldView-3 satellite imagery (source: Choudhury et al. 2021)

1 **Table 1** Types and Sources of Data

Type of Data	Data	Resolution	Source
Primary Data	Worldview 3 Image	0.6 meter	BRIN
	Base Map	1: 10.000	BIG
Secondary Data	Mangrove Map	1: 25.000	BIG
	MPA Map	-	Kepmen KP 2016

2

Table 2 (on next page)

The multispectral bands of the WorldView-3 satellite imagery

The multispectral bands of the WorldView-3 satellite imagery (Source : Choudhury et al. 2021)

1 **Table 2** The multispectral bands of the WorldView-3 satellite imagery

Bands	**Wavelength [nm]**
Coastal band	400-450
Blue band	450-510
Green band	510-580
Yellow band	585-625
Red band	630-690
Red edge band	705-715
Near-Infrared one band	770-895
Near-Infrared two band	860-1040

2 Source : (Choudhury et al. 2021)

Table 3(on next page)

Ecological Value of Conservation Zoning

This research employs three different scenarios. Each scenario with conservation zone features will be called "Ecological Value."

Table 3 Ecological Value of Conservation Zoning

Features	Ecological Value		
	I	II	III
Coral Reef			
Seagrass	30%	40%	50%
Mangrove			

Table 4 (on next page)

Cost Feature

This study considers the cost features of various human spatial utilization activities within the conservation area. Penalty scores for each cost feature are assigned based on the level of importance of the activity.

Table 4 Cost Features

Cost Features	
Feature	Score
Residential Areas	1
Land use	3
Floating Net Cage	1
Dock	1

Table 5(on next page)

Percentage coverage of coastal ecosystems using OBIA analysis

Table 5 shows the percentage of a coastal ecosystem from OBIA analysis. The total area of coastal ecosystems on Arefi Island is approximately 64.78 hectares (Table 5). This area is predominantly covered by coral reefs, accounting for 45.41% of the total coverage. Mangrove, seagrass, and coral reefs are scattered around Arefi Island

Table 5 Percentage coverage of coastal ecosystems using OBIA analysis.

Classification	Areas (ha)	Percent to the area (%)
Coral reefs	23.55	45.41
Seagrass	29.42	36.35
Mangrove	11.81	18.24
Total	64.78	100

Table 6(on next page)

Zoning arrangements for the Arefi Island conservation area

Tabel 6 shows the analysis result of the zoning arrangements for the Arefi Island conservation area under three distinct ecological value scenarios for optimizing conservation priorities

Table 6 Zoning arrangements for the Arefi Island conservation area

Conservation Area	**Zone**	**Areas (ha)**	**Percent to Area (%)**
Ecological Value I	Core Zone	12.33	2.27
	Utilization Zone	8.83	1.62
	Sustainable Fisheries Zone	20.05	3.68
	Other Zone	502.82	92.43
	Total Per Area	**544.03**	**100**
Ecological Value II	Core Zone	19.53	3.60
	Utilization Zone	15.96	2.93
	Sustainable Fisheries Zone	15.67	2.88
	Other Zone	492.89	90.59
	Total Per Area	**544.05**	**100**
Ecological Value III	Core Zone	34.37	6.32
	Utilization Zone	11.92	2.19
	Sustainable Fisheries Zone	11.87	2.18
	Other Zone	485.87	89.31
	Total Per Area	**544.03**	**100**