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ORIGINAL RESEARCH PAPER

Spatial delineation on marine environmental characteristics using fuzzy c-means clustering method

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ABSTRACT

BACKGROUND AND OBJECTIVES: Conservation efforts are often prioritized on a large spatial scale because information about local ecosystems is frequently lacking. Therefore, comprehensive spatial classification of a region's environmental characteristics is essential for effective marine conservation. This study aimed to construct geophysical and chemical environmental delineation of the Lesser Sunda Islands which are located in Indonesia. This area is an ecoregion in the coral triangle that has been a primary concern of global biodiversity conservation strategies.

METHODS: This study utilized eleven global environmental variables that were accessed from global marine databases. After performing a principal component analysis, a fuzzy C-means clustering technique was used to classify the region into groups based on environmental characteristics in term of seasonal variability. It was expected that the areas within each group would have identical attributes and ecological processes.

FINDINGS: The results suggested that the marine environmental factors in Lesser Sunda can be simplified using a principal component analysis technique: 6 principal component factors explained 81.06 percent of the overall raw data variability for the wet season, and 7 principal component variables explained 84.51 percent of the overall raw data variability for the dry season. Then, the area can be delineated into 5 groups (wet season) and 10 groups (dry season) with different environmental characteristics. This method's classified groups principally inferred the Indian Ocean and Bali Sea, Savu Sea and Flores Sea, and Banda Sea as distinct clusters. In particular, the group that included the Indian Ocean had characteristics including lower nitrate and sea surface temperature concentrations, as well as higher potential hydrogen salinity and distance from the shore.

CONCLUSION: The findings of this study showed that the single marine conservation area in Lesser Sunda is not sufficient to adequately represent the physicochemical dynamics in the area. The proposed delineation result will supplement the existing bioregion classification of marine areas, such as the Marine Ecoregions of the World. Moreover, it is also consistent with existing conservation programs, including the notable national marine protected areas of the Savu Sea. Nevertheless, the acknowledged biogeographic group of the Indian Ocean indicates that countries must work together to successfully manage marine protected areas and achieve their conservation objectives. This work serves as a baseline for both academic research and ecological assessment, and it will contribute to marine protected areas strategies and conservation efforts in the Lesser Sunda Islands.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
47	6	2

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INTRODUCTION

In recent years, the marine environment, including its bio-physical and ecological functioning, has been facing potentially significant threats. Climate change is perceived as a major factor that contributes to the degradation of marine ecosystems and negatively impacts their perseverance, functionality, and related ecosystem services (Doney *et al.*, 2011; Smale *et al.*, 2019). Examples of climate change-induced stressors for ocean life include increased sea surface temperatures (SST), acidification, changing patterns of currents and productivity, a rise in sea levels, and decreased dissolved oxygen (IPCC, 2013). Heavy rainfall during the wet season can cause an influx of fresh water into the ocean, which alters salinity levels and disrupts the delicate balance of the environment. Some species' reproduction and survival may suffer as a result. Furthermore, an increase in precipitation can cause increased runoff, which can carry pollutants and excess nutrients into the water, causing problems like eutrophication and algal blooms (Ullah *et al.*, 2021). During the dry season, however, there may be less rainfall, resulting in decreased water levels in rivers and streams that drain into the ocean. This can also cause ecosystem disruption and changes in the distribution and behavior of some species (Doney *et al.*, 2011). Conservation of this environment is essential for preserving the earth's natural systems; it mitigates climate change, promotes adaptation, and ensures socioeconomic benefit (Marcos *et al.*, 2021). Currently, marine protected areas (MPAs) have emerged as a crucial component of efforts to conserve marine biodiversity. MPAs help to impede or lessen the effects of stressors (Sullivan-Stack *et al.*, 2022). MPAs are a type of area-based conservation strategy that are widely used to protect marine ecosystem services and biodiversity (Sullivan-Stack *et al.*, 2022). They are zones in which human activity is limited in order to properly manage and preserve marine and coastal resources from various threats, such as overfishing and habitat destruction. MPAs are widespread throughout the world, and research has shown that they preserve ecosystem services, halt the downturn of threatened ecosystems, and restore food systems (Gallacher *et al.*, 2016). To better plan marine conservation strategies, it is crucial to gain a comprehensive understanding of oceanographic processes and of the distribution of marine species (Lourie and Vincent, 2004). The Coral Triangle (CT) is a marine conservation area in the Western Pacific and parts of South-East Asia. Its sea area is larger than that of the Atlantic and Mediterranean combined in Europe (Asaad *et al.*, 2018; Linggi and Burhanuddin, 2019). Several initiatives have been launched to conserve this region's high levels of marine diversity (Estradivari *et al.*, 2022). The CT has been divided into a number of ecoregions, one of which is the Lesser Sunda region (Setyawan *et al.*, 2018). These areas are situated at a "crossroads" of major global climate forces, making them the most hostile tropical habitat in the Indonesian sea region (Mahrup *et al.*, 2021). The marine waters of the islands of Lesser Sunda form the habitats of 2631 reef fish species and 76 percent of coral reef species. The islands are also home to sea turtles and several marine mammal species such as the dugong and various species of dolphins and whales. Ultimately, the Lesser Sunda Islands are a significant biodiversity hotspot, and efforts are still being made to preserve the rare marine species that live there (Setyawan *et al,* 2018). However, the region has become increasingly affected by the environmental repercussions of human activities (Perdanahardja and Lionata, 2017). Physical and biological environments shape the structure and functioning of marine systems, act as surrogates for species and habitat distribution (data for which are hard to acquire at large scales), and aid in conservation planning. Conservation efforts are prioritized at a large spatial level because information about local ecosystems is frequently lacking (Wang *et al.*, 2015). These physical and biological environments must be classified using remote sensing techniques to gain a thorough knowledge of the area of interest, determine priority sites for quick assessments or monitoring, and construct ecologically representative MPA systems that integrate each habitat type in each of the environments (Chollett *et al.*, 2012). Therefore, a comprehensive spatial classification of the region's environmental characteristics is required to assist plans for marine conservation in the Lesser Sunda Island area. This goal can be met by employing the unsupervised classification method; the primary goal of this method is to generate classification identifiers instantaneously. Unsupervised methods look for similarities between data points to seeing if they can be classified by forming groups known as clusters. Unsupervised methods are commonly used in remote sensing include K-means, Fuzzy C-means (FCM), and neural network-based methods. FCM outperforms K-means when the data set cannot be clearly subdivided into underlying partitions (Perez-Ortega *et al.,* 2022). Previous research has attempted to delineate the biophysical conditions of the Lesser Sunda Islands by using the Self-Organizing Map (SOM) neural network approach (Wang *et al.*, 2015). However, the FCM clustering technique has been shown to perform better (Mingoti and Lima, 2006). As a result, in the sense of marine environments, FCM could be used to categorize various types of marine habitats based on a variety of input variables like water temperature, salinity, and dissolved oxygen levels. Such variables can be retrieved from remote sensing databases, resulting in a large amount of data that may impede the execution of FCM's algorithm (Lasram *et al.*, 2015). As a result, to improve the performance of FCM, principal component analysis (PCA) can be used to adequately reflect variable differences and improve algorithm speed (Sârbu and Pop, 2005). Therefore, the present study aims to divide the Lesser Sunda Island area into clusters based on globally accessible remote-sensing satellite environmental characteristics using FCM and PCA. This is to supply conservation efforts on a smaller spatial scale in the Lesser Sunda Islands, which is unavailable. The study will aid in the identification of conservation priorities. This study has been performed in the Lesser Sunda Islands of Indonesia in 2023.

MATERIALS AND METHODS

Study area

The Lesser Sunda Islands are located in Indonesia and divided into four administrative provinces, which include Bali, West Nusa Tenggara, East Nusa Tenggara, and Maluku, as well as territories within Timor Leste (Fig. 1). The area included information of marine species which were mostly from the families Labridae (122 species), Gobiidae (102 species), and Pomacentridae (85 species). This means that, among marine species, the Lesser Sunda Islands were dominated by the reef fish family. This is a logical conclusion, because the Lesser Sunda Islands area is a key region of marine biodiversity that is situated in the center of the Coral Triangle (Setyawan *et al*., 2018).

Data collection

The environmental variables used in this study were selected according to their relevance to marine species distribution and based on knowledge from previous

Fig. 1: Geographical location of study area in the Lesser Sunda Islands, Indonesia

studies. The details of each variable are presented in Table 1. These environmental data were obtained from the Marine Spatial Ecology (MARSPEC) and Bio-Oracle databases. This global database provides current, satellite-based information about the oceanic surface and seabed at a spatial resolution of 30 arc seconds (~ 1 km^2) (Sbrocco and Barber, 2013). The environmental data are divided in terms of the seasonal patterns (dry season and wet season) of the study area.

FCM clustering method

Clustering is a method that divides a given set of unidentified data into a series of clusters. Data in each cluster are highly similar, with distinct differences in characteristics among clusters. A clustering approach that includes the minimization of some objective function corresponds to the group's objective function algorithms. When an algorithm can minimize an error function, it is referred to as C-means. It is known as FCM if the number of classes or clusters utilized is c, and if the relevant classes utilize the fuzzy approach or simply fuzzy (Mingoti and Lima, 2006). The FCM method employs a fuzzy membership that assigns a degree of membership to each class. The importance of degree of membership in fuzzy clustering is analogous to the pixel probability assumption in mixture modeling. FCM has the advantage of forming new clusters from data points with similar membership values to current classes. The fuzzy membership function, partition matrix, and objective function are the three basic operators in the FCM approach (Deng, 2020). Table 2 describes various applications of the FCM clustering technique.

The FCM technique is the most extensively used and is one of the most effective fuzzy clustering algorithms (Deng, 2020). Based on the assumption that a set of data $D=\{x_i\}_{i=1}^{n}$ and k denotes the number of clusters, the objective function of FCM can be defined using Eqs. 1 and 2 (Deng, 2020).

$$J_m(U,C)=\sum_{i=1}^{n}\sum_{j=1}^{k}\mu_{ij}^{m} x_j - c_j^{\,2} \quad (1)$$

Restricted with

$$\sum_{j=1}^{k} u_{ij} = 1, \forall i \quad (2)$$

Where;

$D=\{x_i\}_{i=1}^{n}$ = dataset with a size of n

$U=\{\mu_{ij}\}_{i,j=1}^{n,k}$ = membership matrix

$C=\{c_j\}_{j=1}^{k}$ = centroids of each cluster

k = number of clusters

The Frobenius norm ||*|| is utilized to compute the differences between matrices. In addition, the fuzziness of the clustering algorithm is determined by the fuzzy coefficient $m\in[1,\infty)$. A higher m value results in more difficult clustering, with each data point strongly associated with a single cluster. A value m closer to infinity results in smoother clustering, with each data point belonging to multiple clusters to varying degrees. This can affect the accuracy of spatial delineation of marine environments because it determines how well the algorithm can distinguish between different types of habitats or regions (Perez-Ortega *et al.,* 2022). A higher level of fuzziness may result in habitats being

Table 1: Environmental variables used in the study

No.	Variable	Unit
1	Sea surface chlorophyll (SSC)	mg/m^3
2	SST	^0C
3	nitrate	$\mu mol/m^3$
4	salinity	PSS
5	Potential of hydrogen (pH)	-
6	depth	m
7	slope of the seabed	degree
8	distance to shore	km
9	current velocity	m/s
10	the eastness (aspect EW) of the slope	radians
11	the northness (aspect NS) of the slope.	radians

Table 2: Environmental variables used in the study

No.	Application	References
1	Water quality of Danube lake	Sârbu and Pop (2005)
2	Image processing	Lázaro *et al.* (2005)
3	The case of forest fires	Iliadis *et al.* (2010)
4	Optimization in Computer Forensics	Wang *et al.* (2012)
5	Modeling of beta diversity in Tunisian waters	Lasram *et al.* (2015)
6	Key performance indicator in business	Tokat *et al.* (2022)
	Hospital clustering	Setiawan *et al.* (2023)

grouped together that are actually distinct, while a lower level of fuzziness may result in habitats being separated that are actually similar. Therefore, the choice of membership degree as well as the number of the cluster (k) should be determined by using reliable criteria such as the Silhouette index. Optimal clustering results can be obtained by establishing the Lagrange equation, as shown in Eq. 3, for Eq. 1, under the restriction provided in Eq. 2 (Deng, 2020).

$$J_m(U,C)=\sum_{i=1}^{N}\sum_{j=1}^{K}\mu_{ij}^{m}x_j-c_j^{\,2}+\lambda\left(u_{ij}-1\right) \quad (3)$$

The partial derivative of Eq. 3 yields the membership equation, as shown in Eq. 4, as well as the centroid, as shown in Eq. 5 (Deng, 2020).

$$u_{ij}=\frac{1}{\sum_{k=1}^{c}\left(\frac{x_i-c_j}{x_i-c_k}\right)^{\frac{2}{m-1}}} \quad (4)$$

$$c_j=\frac{\sum_{i=1}^{n}\mu_{ij}^{m}x_i}{\sum_{i=1}^{n}\mu_{ij}^{m}} \quad (5)$$

The FCM algorithm can be presented as follows (Jaffar *et al.*, 2009):

Input dataset D and k

Output U and C *Process*

1. Randomly initialized U
2. Repeat 3 and 4 until $C_t-C_{t-1}<\varepsilon$
3. Compute c_j
4. Compute u_{ij}

Principal component analysis (PCA)

PCA is a class of multivariate analysis, which transforms the original set of the study variables into its principal components. In general, it is used to reduce the dimensionality of the variables of interest (Lusiana *et al.*, 2022). Because this analysis uses a large volume of data, the sampling adequacy criteria were tested by using the Kaiser-Meyer-Olkin (KMO) test (KMO > 0.50). Furthermore, a significant Bartlett test ($p < 0.05$) was also required to be fulfilled to support data homogeneity (Gañan-Cardenas and Correa-Morales, 2021).

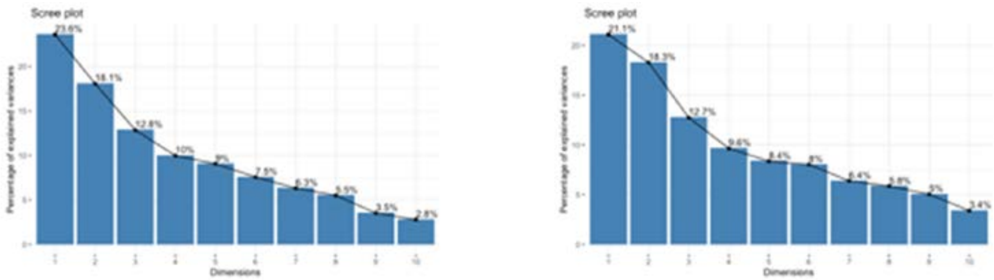
RESULTS AND DISCUSSION

PCA results

The prerequisite analyses for PCA, such as the KMO and Bartlett tests, showed that the data size of this study was adequate for both seasons (KMO > 0.50) and homogenous ($p < 0.05$). The cumulative data showed that the variance of the six principal components of the wet season was 81.06 percent (Fig. 2a), while the seven principal components of the dry season accounted for 84.51 percent (Fig. 2b). These principal components are sufficient to represent the complex original data as the input for further analysis on environmental data layers (Fitzpatrick *et al.*, 2013).

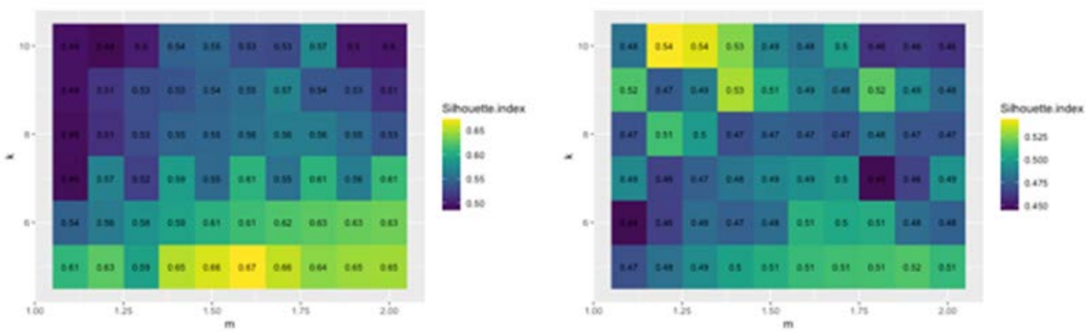
Spatial delineation groups

The analysis of FCM for spatial delineation started with by identifying the optimum number of clusters (k) and the fuzzy coefficient (m) based on the Silhouette index criterion for each season. As shown in Fig. 3a, the best clustering results for the wet season were achieved at $k=5$ and $m=1.6$. On the other hand, for the dry season, the optimum clusters were obtained with $k=10$ clusters and a fuzzy coefficient of $m=1.2$ (Fig. 3b). These results implied that the number of clusters is inversely proportional to the fuzzy coefficient value. As a result, the spatial delineation results during the wet and dry season are largely different, whereas the number of clusters formed in the dry season was double that of the wet season. This means that the environmental characteristics of the dry season are more variable than those of the wet season.



(a) (b)

Fig. 2: Scree plot of PCA result (a) wet season; (b) dry season

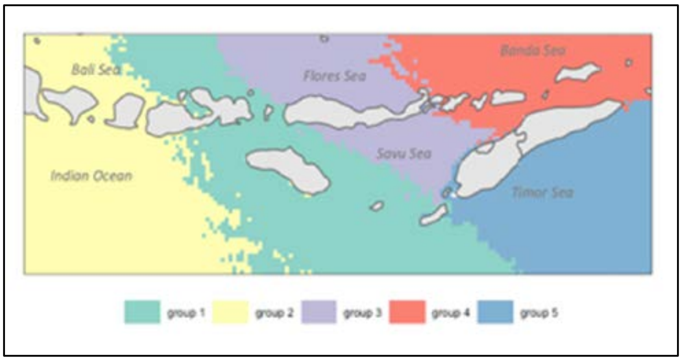


(a) (b)

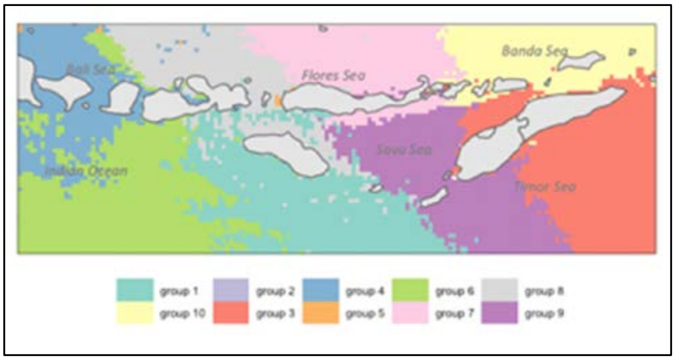
Fig. 3: Silhouette index plot of FCM (a) wet season; (b) dry season

FCM clustering of environmental characteristics in the Lesser Sunda Islands resulted in five groups. For the wet season (Fig. 4a), Groups 1 and 3 primarily cover the Savu Sea and Flores Sea. Group 2 represents the Bali Sea and Indian Ocean, while Group 4 denotes the Banda Sea. Finally, the Timor Sea is covered by Group 5. Meanwhile, a more diverse delineation or groups was obtained in the dry season, which resulted in 10 groups (Fig. 4b). Compared to the wet season, Group 1 in the wet season splits into Groups 4 and 6 in dry season, while Group 2 (wet season) becomes Groups 1 and 8. Meanwhile, Groups 3, 4, 5 in the wet season correspond with Groups 3, 7, 9, and 10 in the dry season. The dry season in Indonesia's Lesser Sunda Islands brings more steady weather and less rainfall, which could result in more distinct marine environmental features. There is commonly more cloud cover and precipitation during the wet seasons, which can heavily impact visibility and temperature, as well as the distribution and behavioral patterns of marine organisms (Ullah *et al*., 2021). Furthermore, during the dry season, human activities such as fishing and tourism may increase, which could further shift marine environmental attributes (Lincoln *et al.,* 2022). Specifically, during the wet season from November–January, many cetacean animals were found in areas of the Lesser Sunda Islands such as the Savu Sea and Flores Sea. It includes migratory bottlenecks for endangered whale species—such as sperm and blue whales—that are of regional conservation importance (Perdanahardja *et al.,* 2017).

Conservation efforts must include a complete sense of the scale at which they engage and the scale at which their objectives (biological units) act. Conservation priorities are frequently set at large geographic scales, but their execution occurs at small scales (Costanza *et al*., 1998). Broader scales of analysis may highlight important characteristics worldwide while overlooking significant regional ones, even if they may assist the globally significant ones (e.g., to benefit turtles, both feeding and nesting sites should be safeguarded). Linking conservation initiatives at the local, regional,



(a)



(b)

Fig. 4: Spatial delineation results of FCM clustering on the Lesser Sunda Islands (a) wet season; (b) dry season

and global scales would promote partnerships and collaboration (Mace *et al.*, 2000). Research on the geographical distribution functions of organisms, known as biogeography, could potentially play a major role in systematic marine conservation programs (Lourie and Vincent, 2004). Systematic planning entails a comprehensive view of the entire system, which includes defining conservation goals, gathering data, setting objectives, evaluating the contribution of existing areas to achieving goals, compiling a portfolio of regions for consideration, and defining focus areas for conservation action (Groves *et al.*, 2002). Marine conservationists have long recognized the need for holistic and detailed research on marine biogeography at a global scale. In recent years, the urgency of this need has increased due to the necessary approaches required for the designation of marine protected areas in various national, regional, and international planning agreements and legal frameworks (Costello and Chaudhary, 2017). The results obtained by spatially delineating the Lesser Sunda Islands in this study supplement the existing bioregion classification of marine areas, such as the Marine Ecoregions of the World (MEOW). MEOW is a classification of global coasts and shelves based on biogeography and was designed to be closely linked to existing regional systems. Ecoregions are subdivided into the larger biogeographic strata of realms and regions (Spalding *et al.*, 2007). According to MEOW, the area of the Lesser Sunda Islands (i.e., 30131) was solely classified as the Lesser Sunda Seascape (Spalding *et al.*, 2007).

Characteristics of spatial delineation groups

The study findings revealed different environmental characteristics throughout the study area during the wet season (Fig. 5) and the dry season (Fig. 6). In comparison to the other groups, groups that represent the Indian Ocean had the highest pH, salinity, and distance to shore, as well as lower nitrates and SST. This suggests that a single marine conservation area in the Lesser Sunda Islands is not sufficient to adequately represent the physicochemical dynamics in the area, which affect the distribution and diversity of marine species.

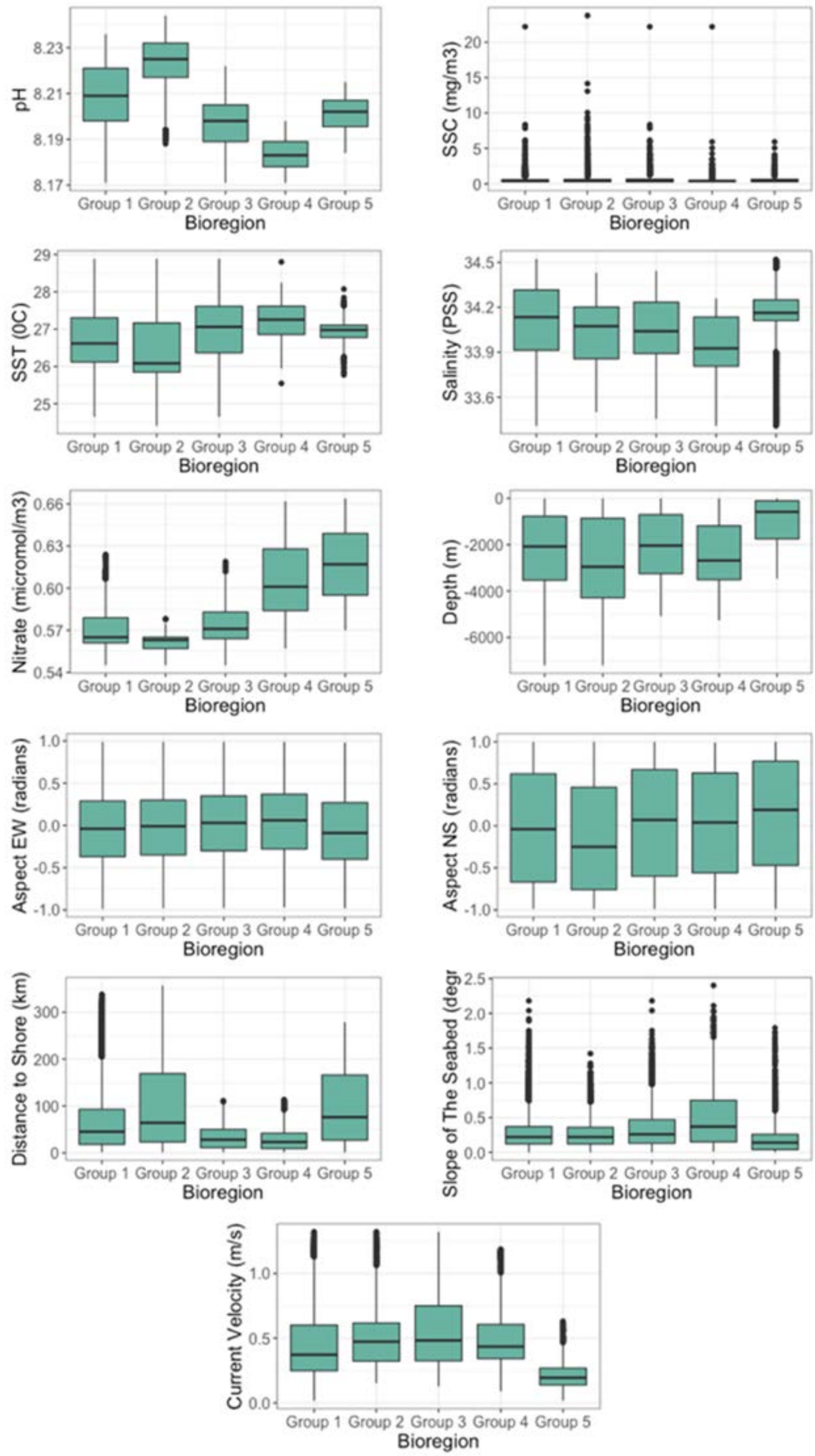


Fig. 5: Environmental characteristics of each FCM delineation group in the wet season

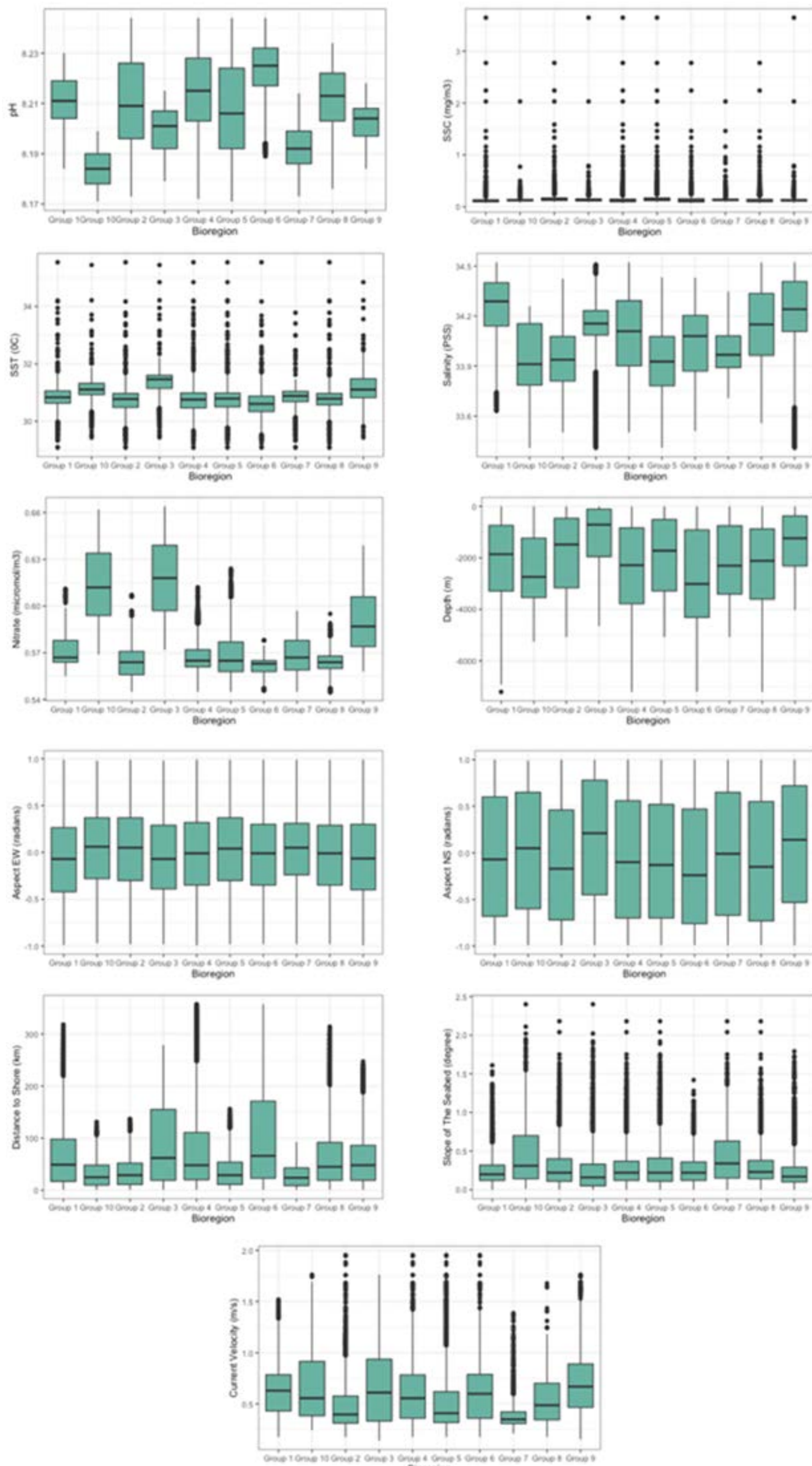


Fig. 6: Environmental characteristics of each FCM delineation group in the dry season

It is evident that the physicochemical conditions in Group 1 are affected by two main natural phenomena, namely, the Indian Ocean Dipole (IOD) and the El Nino-Southern Oscillation (ENSO). The Indian Ocean experiences significant interannual changes as a result of the frequent co-occurrence of these events (Sprintall and Révelard, 2014; Zhang *et al.*, 2022). Low-salinity tropical waters are transported from the Pacific to the Indian Ocean by way of the Indonesian Ocean via the Indonesian Throughflow (ITF). The ITF links ocean basins and is the only tropical oceanic route; therefore, it is crucial to sea circulation and to the earth's climate. Its interannual variability is primarily determined by ENSO-related air current forcing via the Pacific waveguide. However, the IOD may shift the impact of the Pacific ENSO via the wind fluctuation in the Indian Ocean, as well as the Indian Ocean waveguide (Sprintall and Révelard, 2014). Since the Indian Ocean is bounded by numerous countries, its various MPAs are managed individually. Research suggests that cooperation between these countries is essential to achieve the effective conservation of ecological systems and organisms across the islands and continental countries in the region (Levin *et al.*, 2018). Some ways that countries can coordinate to conserve marine ecosystems include regional cooperation through regional organizations, such as the United Nations Convention on the Law of the Sea (UNCLOS) or the Convention on Biological Diversity (CBD), to establish shared conservation goals and coordinate conservation efforts (Wartini, 2022). Moreover, countries can establish transboundary marine protected areas that span multiple countries and provide coordinated conservation efforts for the shared marine resources as well as collaborate on research and monitoring of marine ecosystems to improve understanding of shared resources and the impact of human activities (Gómez-Ballesteros *et al.*, 2021). In this study, the groups that covered the Savu Sea are characterized by high levels of nitrate and SST, low pH, and mild salinity. Further, the ITF that moves into the Savu Sea via the Ombai Strait contributes to a physical environment that both sustains sea life and supplies resources for the community. Due to its unique oceanographic features, such as deep trenches, oceanic currents, and upwelling areas, the Savu Sea is an important shelter and migratory pathway for cetaceans and turtles, a vital nursery ground, and an ideal location for coral reefs (Mujiyanto *et al.*, 2017). As a result, it contains extraordinary biodiversity and an abundance of marine species, particularly mammals (Mustika, 2006). It has incredibly diverse coral reefs that act as an essential ecosystem for a variety of marine organisms. Moreover, it is a fishing spot that acts as a major economic resource for coastal communities (Mustika, 2006). Finally, the finding in this study recommends that the conservation planning of the Lesser Sunda marine waters should be performed in smaller spatial scales rather than following that decided by MEOW in the form of MPA. Evidence suggests that conservation at smaller spatial scales ensures that, in comparison to large scales, important characteristics at the regional scale are accounted for. Furthermore, the results also do not conflict with the existing conservation strategy, but rather they complement it. For example, the area of Savu Sea has been designated as a national MPA in accordance with the Minister of Marine Affairs and Fisheries Decree No. 5/2014 (Djumanto *et al.*, 2021).

CONCLUSION

The impact of global climate change is undeniably threatening the bio-physical and chemical processes within marine ecosystem. Hence, an effective and efficient conservation strategy is needed to preserve the function of marine ecosystems. The spatial delineation of the Lesser Sunda Islands is essential for supporting the marine conservation planning efforts in this area. Since environmental characteristics are closely related to the distribution and existence of marine species, it is worth considering these characteristics when partitioning and developing marine conservation areas. The accessible global databases provide numerous marine environmental factors and can be simplified, using PCA techniques, into 6 principal component variables that explained 81.06 percent, and 7 principal components that represent 84.51 percent of the overall raw data variability for the wet and dry seasons, respectively. These components then become the input for the spatial delineation of Lesser Sunda by using FCM. The finding of the FCM analysis suggest that the Lesser Sunda Islands can be delineated into 5 groups during the wet season and 10 groups during the dry season, since it provides the best Silhouette index criterion. The delineated groups obtained from this approach primarily implied Indian Ocean and Bali Sea, Savu Sea and Flores Sea, as well as Banda Sea as distinct clusters. Notably, groups that represented the

Indian Ocean had the highest pH, salinity, and distance to shore, as well as lower nitrates and SST. This is an indication that a single marine conservation area in the Lesser Sunda Islands is not sufficient to adequately represent the physicochemical dynamics in the area, which affect the distribution and diversity of marine species. The delineation suggested in this study showed a certain level of conformity with existing conservation strategies, such as the national MPA of the Savu Sea. However, the identified biogeographic cluster of the Indian Ocean indicates the need for cooperation among countries to effectively manage the MPAs and achieve the various conservation goals. Despite of the used PCA prior to FCM analysis, the algorithm still needs a large amount of time to converge. Thus, modified data dimension reduction techniques and/or fuzzy methods should be considered to solve the issue. Furthermore, the present study only takes into account the environmental variables to delineate the study area to support conservation efforts, while its correlation with marine species distribution is also worth noting.

AUTHORS' CONTRIBUTIONS

E.D. Lusiana, as the corresponding author, contributed by shaping the study concept, data collection, and analysis as well as manuscript preparation. S. Astutik supervised the first author and helped the study design. N. Nurjannah provided a critical review of the manuscript. A.B. Sambah also supervised the first author and performed the study results' interpretation and literature study.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS

%	Percent
^0C	Degree Celsius
CBD	Convention on biological diversity
CT	Coral triangle
ENSO	El Nino-Southern Oscillation
et al.,	And others
e.g.	Exempli gratia or for example
EW	East west
FCM	Fuzzy c-means
Fig.	Figure
i.e.	Id est or that is
IOD	Indian ocean dipole
IPCC	The Intergovernmental Panel on Climate Change
ITF	Indonesian Throughflow
km	Kilo meter
KMO	Kaiser-Meyer-Olkin
m	Meter
m/s	Meter per second
MARSPEC	Marine spatial ecology
MEOW	Marine ecoregions of the world
mg/m^3	Milligram per cubic meter
MPA	Marine protected area
NS	North south
PCA	Principal component analysis
pH	Potential of hydrogen
PSS	Practical salinity scale

SOM	Self-Organizing Map
SSC	Sea surface chlorophyll
SST	Sea surface temperature
μmol/m³	Micromole per cubic meter
UNCLOS	United Nations Convention on the Law of the Sea

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