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Research Article

Optimising Marine Basic Spatial Units (MBSU) for Ocean Accounting using empirical data from Saleh Bay, Indonesia

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Abstract

Ocean Accounts, aligned with the UN System of Environmental Economic Accounting – Environmental Accounting (SEEA EA), bring together economic, social and environmental information in a coherent and standardised manner. Ecosystem extent is a structure to understand environmental assets and uses a basic spatial unit to facilitate the classification and measurement of ecosystems by type. This study tested the impact of grid size and method of designation per grid cell for Marine Basic Spatial Units (MBSU), using Saleh Bay, Indonesia as a case study. The extent of mangrove, seagrass and coral reefs were previously delineated in 2021 for ocean accounting activities. This study tested grids with two different cell sizes (10 x 10 m^2 and 25 x 25 m^2) and two different methods of designation, namely: (i) dominance (extent-based) and (ii) hierarchy (criteria-based) methods. The results indicated that a larger grid size is related to higher error in estimating both total area per ecosystem and spatial configuration within the study area. The dominance method produced more accurate results than the hierarchy method, although, when considering computational trade-offs, a larger grid size and the hierarchy method observed a much lower computational cost. These results demonstrate the need to carefully consider grid size and method when designating basic spatial units for accounting activities, as they impact linked accounting tables and, in turn, have implications when providing information for management and policy.

Keywords

coastal ecosystems, ecosystem extent, spatial analysis, grid optimisation, natural capital

Introduction

Coastal ecosystems, such as coral reefs, mangroves and seagrass, are vital for supporting the livelihoods and well-being of coastal communities through their services. Ecosystem services are the contribution to the benefits provided by the ecosystems, which are utilised in human activities and the economy. These services have been broadly classified into three groups, namely provisioning (e.g. biomass for human consumption, raw materials and energy), regulation and maintenance (e.g. maintaining biological, chemical and physical processes) and cultural services (e.g. intellectual and symbolic interactions with the ecosystems) (Potschin and Haines-Young 2016, UNSD 2021). These services underpin economic activities. For example, the global coral reef ecosystem generates US$2.7 trillion annually, of which US$36 billion comes from tourism (ICRI et al. 2021). In Indonesia alone, mangroves and seagrass are estimated to contribute IDR165.7 trillion and IDR13.2 trillion into the fisheries sector, respectively (MMAF 2023). However, these ecosystems are in decline due to anthropogenic impacts (Halpern et al. 2015), which could be addressed through management efforts. The need to balance economic and environmental considerations could be achieved by embedding concepts, such as natural capital accounting into these efforts.

Natural capital conceptualises natural resources and ecosystems as a stock that generates flows (ecosystem services) (Daly and Farley 2011), which supports the health and livelihood of communities (UNEP 2011). The conceptualisation of nature as “stocks” and “flows” aligns with existing accounting frameworks, such as the System of National Accounts (SNA) that describe a nation’s economic activity. The System of Environmental-Economic Accounting (SEEA) was developed as an international accounting standard to align with and extend the SNA. Specifically, the SEEA – Ecosystem Accounting (SEEA EA) standard provides methods for the physical and monetary measurement of ecosystems*[1] using a spatial approach. The standard provides guidance for several accounts, including ecosystem extent, ecosystem condition, ecosystem services supply and use (physical and monetary) and ecosystem asset accounts in monetary terms (UNSD 2021). However, many of the concepts within the SEEA EA are more suitable for the terrestrial environment, as they are difficult to align with complex biophysical flows in the ocean (Findlay et al. 2022). There is also a need to better link the SNA and SEEA EA to the ocean context, especially through disaggregating ocean-related sectors from the broader economy (Fenichel et al. 2020).

Ocean Accounts (OA) is an emergent framework that provides further guidance for the implementation of accounts aligned with the SNA and SEEA EA within the coastal and marine domain. The OA Framework extends both the SNA and SEEA EA by testing and defining concepts in collaboration with a global community of practice. The emergence of OA has been driven by the need to centralise, standardise and integrate data for marine information systems and provide a streamlined process to provide scientific evidence to achieve the implementation of marine management frameworks, such as marine spatial planning, fisheries management and marine protected area (Gacutan et al. 2022a, Gacutan et al. 2022b, Yulianto et al. 2022).

As OA is spatial, a key challenge in accounting is the need to harmonise data and derive statistics from a variety of sources (Bordt 2015). Thus, a spatial frame of reference, acting as the core statistical unit, is crucial, where social and economic data are commonly reported through administrative and statistical areas. These areas, however, may not align with natural systems (e.g. forests, coral reefs) and a common spatial unit is needed to represent the highly contextual environmental data. The Basic Spatial Unit (BSU), drawn from the SEEA EA, describes a spatial reporting unit that could be used to facilitate the harmonisation of several domains of data (e.g. ecology, economy, social aspects and governance) for the compilation of accounts. Practitioners have tested several forms of BSU, at various shapes (e.g. square, hexagonal*[2]) and sizes for accounting purposes. The choice of BSU characteristics may depend on computing capacity and current data resolution and, thus, could vary from a pixel in a remote sensing image to the reference system grid of the national territory (UNSD 2021).

There are several considerations for selecting the size of a BSU. A larger BSU may be cost-effective, but increases the need for aggregation and simplification of complex data, which may lead to edge effects and increase errors in estimation (Tulloch et al. 2017). In contrast, a finer resolution could lead to higher accuracy, but at exponentially higher computing costs. The implications of BSU sizes are evident in Ecosystem Accounting applications, where each cell in a grid (i.e. BSU) is assigned to a specific ecosystem type. Two common methods for assigning BSUs to an ecosystem include proportional extent-based assignments (e.g. assignment to ecosystem with largest coverage) or using criteria (e.g. assigning by order of management priority). The challenge of spatial unit grid designation shows parallels in other fields. In ecology, computer modelling can be used to overcome challenges in transforming species distribution vectors into grid cells of presence-absence matrix (Vilela and Villalobos 2015). In remote sensing, the existence of multiple classes within a homogenised pixel would cause the mixed pixel problem (Fisher 2010).

Tailoring the BSUs specifically for marine and coastal areas (henceforth, “Marine Basic Spatial Unit,” MBSU) is imperative due to the complexities of the ecosystems and data availability. Not only does it address the unique requirements of coastal and marine settings, but it also distinguishes the spatial infrastructure from its terrestrial counterpart.

In OA, the application of MBSU could underpin multiple accounting for multiple accounts, such as ecosystem extent, condition, services and asset accounts (GOAP 2021). Several MBSU shapes have been used and tested globally, such as hexagonal and rectangular. In this case, Indonesia has utilised rectangular-shaped grids in its OA pilot project (MMAF 2022a). Few countries have explored the effects of different grid sizes on ecosystem accounts and a standardised grid has yet to be established. Thus, testing various MBSU grid sizes is needed.

This study aims to determine the optimal MBSU for the implementation in the Indonesian coastal region through employing a case study using empirical data from Saleh Bay, West Nusa Tenggara, a pilot testing of OA within Indonesia. Here, we present:

1. an overview of the OA concepts and MBSU;
2. the approaches for ecosystem asset consolidation into the MBSU;
3. the study area;
4. the performance comparison between different MBSU grid sizes and gridding methods.

Materials and Methods

OA concepts and the MBSU

The framework of OA consists of seven structures — environmental asset accounts, flows to the economy, flows to the environment, ocean economy, ocean governance, combined presentation and ocean wealth (GOAP 2021). The accounting of environmental assets is performed spatially using a series of spatial units with differing scales and types (Fig. 1). The SEEA EA (UNSD 2021) defines an Ecosystem Accounting Area (EAA) as "*the geographical territory of which an ecosystem account is compiled".* As the largest spatial unit, the EAA determines the types of contiguous Ecosystem Assets, each of which is assigned to an ecosystem type. The MBSU is then applied to implement Ecosystem Assets, providing a means for harmonisation across data types, projection, scales and temporal changes.

The MBSU, as a grid-based approach for ecosystem accounting, divide the EEA into a statistical unit using arbitrary grid cells. This method is commonly applied to remotely-sensed data, in which the grid size is contingent upon the resolution of the data source and each cell is designated to a specific Ecosystem Asset type. For extent accounting, cells with the same classification within a boundary are counted and summed (Vardon et al. 2011). In this study, the tested MBSUs were 2-dimensional square grid cells projected to WGS 1984 UTM 50S. The grid sizes tested were 10 x 10 m^2 and 25 x 25 m^2. Considerations regarding the chosen sizes are presented in Table 1.

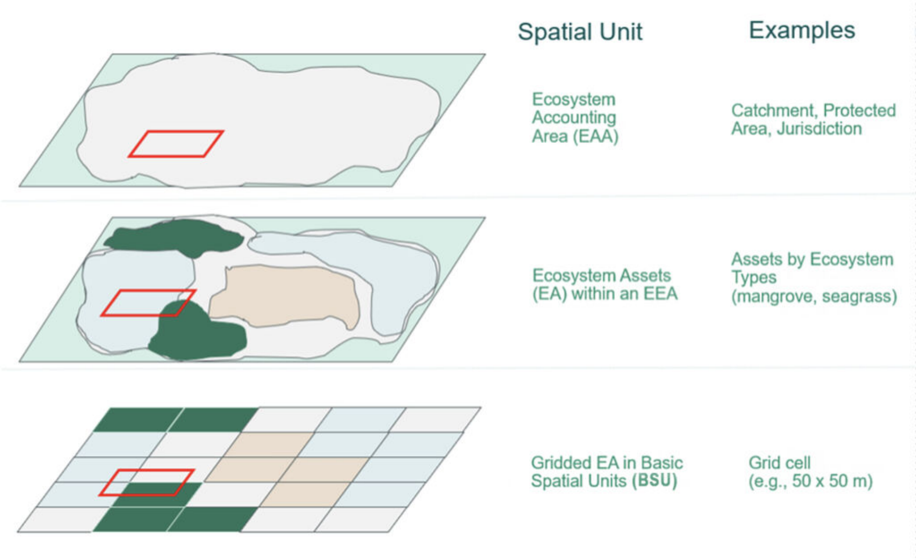

Figure 1.

The types of spatial units within ecosystem accounting, represented in a hierarchal manner.

Table 1.

The MBSU grid sizes compared in this study and the basis for their selection.

MBSU size	**Basis for selection**	**Description**	**Reference**
10 x 10 m^2	Spatial resolution of remote sensing data	The pixel size (visible and NIR bands) of Sentinel-2, as the satellite used in this study.	Vardon et al. (2011)
25 x 25 m^2	Mapping scale	The mapping unit (smallest polygon area) of coastal and shallow water habitats for producing 1:50,000 scale spatial accounts map in Indonesia.	BIG (2023)
	Precedence	The trialled MBSU size in OA pilot in Indonesia.	MMAF (2022a)

Approaches for joining data to MBSU

For this study, we proposed two viable approaches in assigning Ecosystem Assets to MBSU grid cells, namely the hierarchy method and the dominance method. The hierarchy method uses a criteria-based approach, aligned with the objectives for marine spatial management. For the case study, ecosystem classes were sorted by economic importance, in which the grid cell assignment was prioritised to ecosystems in the following order: mangroves, coral reefs, seagrasses, in accordance with the flows to the economy module (MMAF 2022a). The dominance method was performed with an extent-based approach as described by Findlay et al. (2022). For this study, the ecosystem type with the largest coverage was assigned to a grid cell, regardless of their type and their extent relative to the grid size. Thus, we compared 4 (four) MBSU schemes, namely: 1) 10 x 10 m^2 grid with hierarchy method (10H); 2) 10 x 10 m^2 grid with dominance method (10D); 3) 25 x 25 m^2 grid with hierarchy method (25H); and 4) 25 x 25 m^2 grid with dominance method (25D).

Case study: Saleh Bay, West Nusa Tenggara

The Government of Indonesia began testing of OA in 2020. As the largest archipelagic nation with approximately 17,508 islands and more than 91,300 km of coastline (Sui et al. 2020), Indonesia's sustainable use of marine resources is mandated by Law No. 32/2014 on the Sea*[3], forming the basis for a sustainable management framework supported by OA. Furthermore, the implementation of OA in Indonesia is driven by the nation's international commitments as a member of the High-Level Panel for a Sustainable Ocean Economy*[4].

This paper focuses on Saleh Bay, a semi-enclosed bay located in West Nusa Tenggara Province and an established case study for OA within Indonesia, chosen for its importance to the fisheries sector (Fig. 2). The Bay lies within the Fisheries Management Area (FMA) of the Republic of Indonesia (Code FMA 713). Saleh Bay supports over 5,800 fishers (Yulianto et al. 2016) and encompasses several Marine Protected Areas (MPAs). The Liang Ngali MPA was established through the Ministerial Regulation of the Minister of Marine Affairs and Fisheries No. 20/2020*[5], covering an area of 32,644.43 ha, while the second MPA is under development for Lipan Rakit, established through the West Nusa Tenggara Governor's Decree No. 523-222/2019. Ongoing efforts in OA and its importance in fisheries and conservation make it a suitable case study to test various approaches for MBSU.

Saleh Bay possesses three types of coastal ecosystems. Coral reefs are found in nearly all parts of Saleh Bay, with geomorphology ranging from fringing reefs with steep contours in the east of Saleh Bay, sloping in the west and patch reefs in the western and central parts of the Bay (Edrus et al. 2010). Seagrasses and mangroves are located along the western part of Saleh Bay, with the largest mangrove forest in the Santong Bay area, Plampang District, Sumbawa Regency.

In this study, the EAA included the waters of Saleh Bay and the land up to the last mangrove vegetation boundary. This area encompassed the coastal area of Saleh Bay within the Sumbawa and Dompu Districts, Moyo Island and the Liang Ngali MPA and Lipan Rakit MPA.

This study tested the impact of different MBSU approaches for ecosystem extent for a single year (i.e. 2021). The data were compiled from multiple sources, covering remotely-sensed satellite imagery, field data and pre-existing official maps issued by the Indonesian government (see Suppl. material 1). The EAA in this study was representative of the existing coastal habitats in Saleh Bay. The area was divided into five ecosystem types, focusing on three coastal ecosystems (mangrove, coral reef, seagrass) and two additional classes (bottom substrate and land). The bottom substrate type included all other subtidal ecosystem types (e.g. sand, mud, macroalgae, rocky reef). The land type contained all terrestrial habitats, excluding mangroves. The coastline used in this study was in accordance with the coastline and regency administration borders issued by the Indonesian Geospatial Information Agency (BIG) for the year 2021.

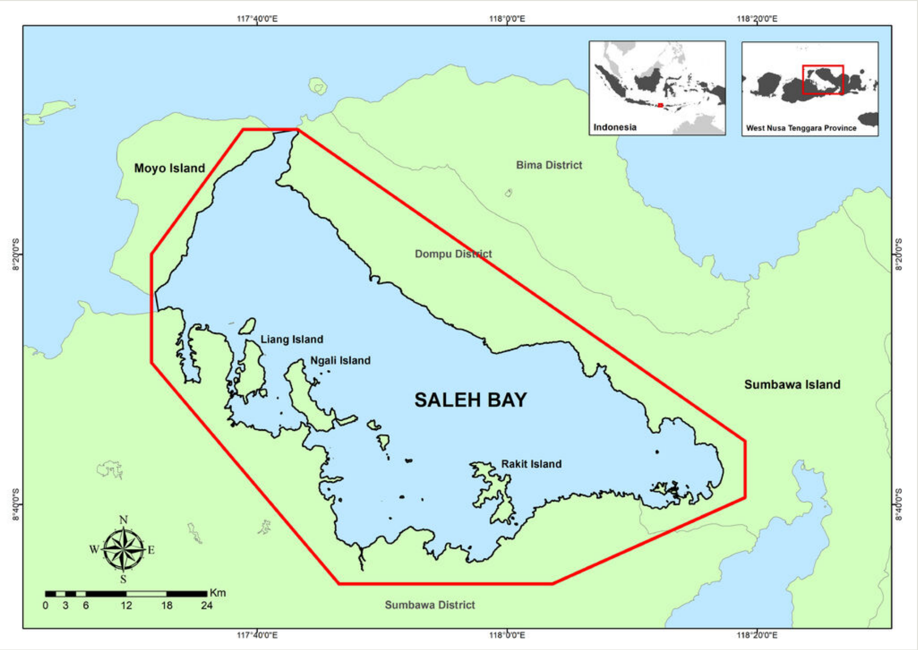

Figure 2.

Map of Saleh Bay, West Nusa Tenggara, the EAA of this study (demarcated with red), as well as their location in Indonesia inset.

The seagrass and coral reef ecosystem extent was obtained from Sentinel-2 imagery and ground-truthing. Similarly, mangrove extent was supplied from the Indonesian Mangrove Map 2021, updated using ground information and Sentinel-2 imagery. In this paper, the vector data for all Ecosystem Assets would hereinafter be referred to as the 'Source' layers. The Ecosystem Asset delineation was carried out on remotely-sensed images following the guidelines by the Geospatial Information Agency of Indonesia (BIG 2023). The details for remote sensing image processing methods, as well as ecosystem delineation, are presented in Suppl. material 1.

The GIS analysis was performed using ArcMap 10.8. The MBSU grids were generated, based on the EAA using the Grid Index Features tool, producing 36,346,207 grids sized 10 x 10 m^2 and 5,818,612 grids of 25 x 25 m^2. The area of grids outside the EAA was removed from analysis. The Source and MBSU grids were joined according to each scheme's grid size and gridding method. For the hierarchy method, the grids that intersected with a specific Ecosystem Asset were selected and assigned to the said Asset. The assignment was performed with an ascending order, so that the ecosystem with a higher level of importance would overwrite the previous assignment. For the dominance method, the Source was joined to the grids using the Union geoprocessing tool. Each Ecosystem Asset within a grid became its own polygon; however, different polygons from the same grid would share the same grid index. The area of each polygon was calculated, then the data were exported and pivoted in RStudio to identify the Ecosystem Asset with the dominant area within a grid. The pivoted data were imported back into ArcMap and joined with the initial MBSU using the grid index as base.

Statistical analysis was then carried out by calculating the percentage error of each gridding scheme, in comparison to the Source. Next, an accuracy test was carried out using an error matrix analysis wherein the ground-truth data were used for validation, employing the approach of Congalton and Green (2019). Additionally, the computation time of the process, which included data processing, starting from grid generation, overlaying grids with source, pivoting data tables for grid processing and total area summation, was calculated to determine the trade-off between performance and computation cost. In this study, the entire operation was performed with the following hardware: an Intel Xeon CPU E5-2670 (2.60GHz, dual processor), with 8 cores, 16 threads and 10 GB RAM. Further details on the accuracy test and computation time calculations are presented in Suppl. material 1.

Results

Ecosystem extent

Based on the satellite image analysis presented in the Source (Fig. 3), the extent of coral reef, seagrass and mangrove ecosystems in Saleh Bay are 4,809.01 ha, 1,625.00 ha and 2,172.95 ha, respectively. The ecosystem extent account covered 357,539.96 ha (Table 2), with extent differences found in all gridding schemes for every ecosystem type. A visual comparison of the results of each gridding scheme was produced, based on the core zone of the Liang Ngali MPA, which represented all ecosystem types (Fig. 4). Gridding of the Source data to MBSUs led to a general trend of increasing extent in all coastal ecosystem types, of which the mangrove type in the hierarchy method increased the most. However, the land type decreased in extent in all gridding schemes.

Table 2.

The estimated area (ha) of each ecosystem type within the accounting extent boundary. "Source" denotes the pre-gridded vector data for all Ecosystem Asset. The numbers denote grid sizes (10 = 10 x 10 m^2 grids, 25 = 25 x 25 m^2 grids), whereas the letters denote the treatment for designating the ecosystem (H = hierarchy method, D = dominance method).

Grid	**Ecosystem extent (ha)**					**Total (ha)**
	Mangrove	**Seagrass**	**Coral reef**	**Land**	**Bottom substrate**	
Source	2172.95	1625.00	4809.01	145847.14	203085.85	357539.96
10H	2598.97	1757.44	5387.07	142479.78	205316.69	357539.96

Grid	Ecosystem extent (ha)					Total (ha)
	Mangrove	Seagrass	Coral reef	Land	Bottom substrate	
10D	2206.97	1655.06	4884.40	142498.46	206295.06	357539.96
25H	3130.25	1827.69	5773.63	142788.01	204020.38	357539.96
25D	2207.50	1660.81	4879.44	142384.57	206407.63	357539.96

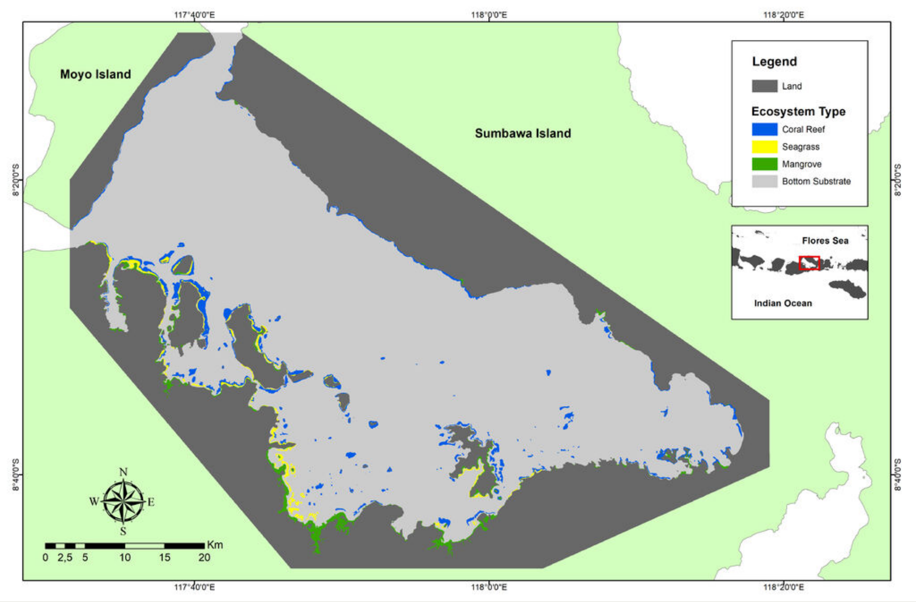

Figure 3.

The ecosystem assets of Saleh Bay in year 2021 (Source) within the accounting extent boundary.

Statistical analysis

Each MBSU processing scheme was subjected to statistical analysis. The highest percentage errors relative to the Source are found in the 25H followed by 10H, while the 10D and 25D errors yield similar error values (Table 3).

Accuracy tests

Accuracy tests were carried out using a confusion matrix on the Source and on each MBSU gridding scheme (Table 4). The tests resulted in several accuracy measures. Overall accuracy is the percentage denoting the comparison between accurately classified sample units on the gridding results and the reference data. User's accuracy denotes how well the results reflect reality to indicate a map's reliability to a user. Producer's accuracy shows how well the process was performed by the producer (Congalton and Green 2019). The accuracy measures also include the KHAT score (also

Ƙ), which denotes the degree to which image interpretation agrees with ground-verified reference data (Congalton and Mead 1983). The Source produced the highest accuracy, with an overall accuracy value of 92.568% and a KHAT of 0.888. After gridding, a decrease in accuracy was observed for all schemes, of which the scheme with the lowest accuracy was 25H, followed by 10H.

Table 3.

The percentage error of each MBSU gridding scheme. The numbers denote grid sizes (10 = 10 x 10 m^2 grids, 25 = 25 x 25 m^2 grids), whereas the letters denote the treatments (H = hierarchy method, D = dominance method).

Ecosystem	% **Error (relative to the Source)**			
	10H	**10D**	**25H**	**25D**
Mangrove	19.61	1.57	44.06	1.59
Seagrass	7.54	1.85	16.54	2.20
Coral Reef	12.02	1.57	27.54	1.46

Computation Time

In executing the gridding process, 10H required 941 minutes, 10D required 1,604 minutes, 25H required 286 minutes and 25D required 459 minutes.

Discussion

In testing different grid sizes and allocation treatments for ecosystems into the MBSU, we found clear differences between the ecosystem extent of all grids and the Source data. When assigning Ecosystem Assets on to each grid, the total extent increased for all coastal ecosystem types (coral, seagrass and mangrove), whilst the area classified as “land” decreased by an average of 2.1% relative to the Source. The decrease in land could be attributable to boundary effects during gridding, where land was the most prominent class at the EEA boundary. In contrast, bottom substrate showed the highest total increase in area across classes. The increased area could be linked to the higher number of cells classified as “bottom substrate” due to its long perimeter.

In assessing the relative error due to grid size, the differing grid sizes produced vastly different extents across both hierarchy and dominance methods. In general, the 25 x 25 m^2 grids yielded a higher percentage error and lower accuracy compared to the 10 x 10 m^2 grids, which could be linked to the effect of upscaling to a coarser resolution grid (i.e. reducing the resolution of the data through aggregation). A higher error was most noticeable in the grid 25H, relative to the Source (percentage error = 16.54 - 44.06%, overall accuracy = 73.56%, Ƙ = 0.59). The upscaling exacerbated existing errors in total area as well as the spatial distribution of how grids were classified (Sun et al. 2017, Lu et al. 2022). Therefore, using larger MBSU sizes would introduce additional errors and unreliability. Careful consideration needs to be made before upscaling or downscaling operations are conducted, to understand the impact on the data to ensure that the outputs remain representative (UNSD 2015).

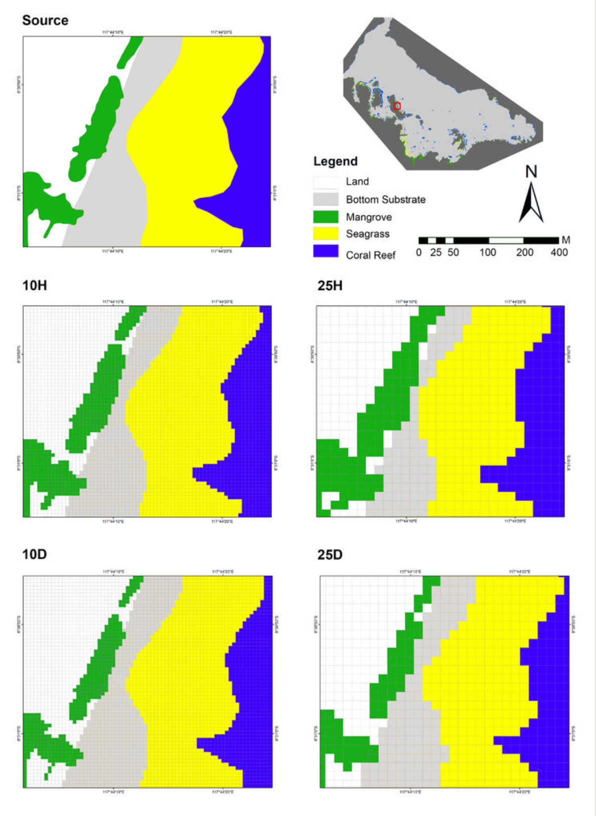

Figure 4.

Spatial distribution comparison of the gridding schemes using the sample area from the core zone of Liang Ngali MPA and its location in the EAA inset. Source = Ecosystem Asset (un-gridded). The compared gridding schemes include: 10H = 10 x 10 m^2 grids with hierarchy method, 10D = 10 x 10 m^2 grids with dominance method, 25H = 25 x 25 m^2 grids with hierarchy method, 25D = 25 x 25 m^2 grids with dominance method.

Table 4.

Accuracy test results. The numbers denote grid sizes (10 = 10 x 10 m^2 grids, 25 = 25 x 25 m^2 grids), whereas the letters denote the treatments (H = hierarchy method, D = dominance method).

Accuracy	**Source**	**10H**	**10D**	**25H**	**25D**
Overall Accuracy (%)	92.57	80.41	89.86	73.65	86.49
KHAT (K)	0.89	0.70	0.85	0.59	0.79
User's Accuracy (%)					

Accuracy	**Source**	**10H**	**10D**	**25H**	**25D**
Mangrove	85.71	85.71	85.71	75.00	83.33
Coral Reef	98.36	77.78	95.08	71.59	85.92
Seagrass	100.00	81.82	100.00	80.00	100.00
Bottom Substrate	85.96	87.18	83.05	86.21	84.00
Land	88.89	70.00	88.89	53.85	88.89
Producer's Accuracy (%)					
Mangrove	85.71	85.71	71.43	85.71	85.71
Coral Reef	89.55	94.03	91.04	94.03	86.57
Seagrass	93.33	53.33	80.00	60.00	80.00
Bottom Substrate	96.08	49.02	82.35	66.67	96.08
Land	100.00	87.50	100.00	87.50	100.00

The total extent of each Ecosystem Asset was similar between both the hierarchy and dominance method. The differences were more apparent, however, when assessing the spatial distribution of Ecosystem Assets at the local scale, which could introduce errors for local analyses and accounting activities. Changes in the distribution of Ecosystem Assets, relative to the Source, were most prominent in the hierarchy method (Fig. 4). Changes between ecosystem types occurred in the boundary area between Assets, with similar findings identified by Lu et al. (2022). Changes could be observed, particularly around the mangrove ecosystem which has finer features than others, while more homogeneous areas (e.g. land, bottom substrate) remained mostly unaffected. These changes occurred because the hierarchy method prioritised mangrove as the most important ecosystem; hence, a grid would be classified into mangrove even though the mangrove Source layer only slightly intersects the grid.

In comparing the two approaches, the hierarchy method for both the 10H and 25H grids produced the largest percentage error (Table 3). As only the ecosystems' level of importance was considered instead of area extent, errors were introduced. In the hierarchy method, percentage error increased (in order) for seagrass, coral reef and mangrove, which is parallel to the order of importance imposed by MMAF (2022a). This indicates that the larger error and biases of the hierarchy method would be inclined towards ecosystems considered more important, as seen within the mangroves in this study.

Meanwhile, the dominance method's percentage errors were minor compared to the Source (Table 3). This is thought to occur because this method considers the area across ecosystem types within a grid cell. Adjacent or nearby grids at the boundary of Ecosystem Assets may be offset when the grids are classified to a specific ecosystem type, where the type not dominant in one grid cell (i.e. Cell A) tends to be dominant in an adjacent cell (i.e. Cell B). Hence, the area of that specific ecosystem type which was lost in Cell A would be compensated in Cell B. The observed offset may lead to a relatively small error when comparing the dominance method results to the Source (Fig. 5). However, should the grid size be increased even larger than the ones tested in this study, upscaling effects would be more apparent, which might result in a noticeable decrease in area for smaller, non-dominant ecosystem types, similar to the findings of Lu et al. (2022).

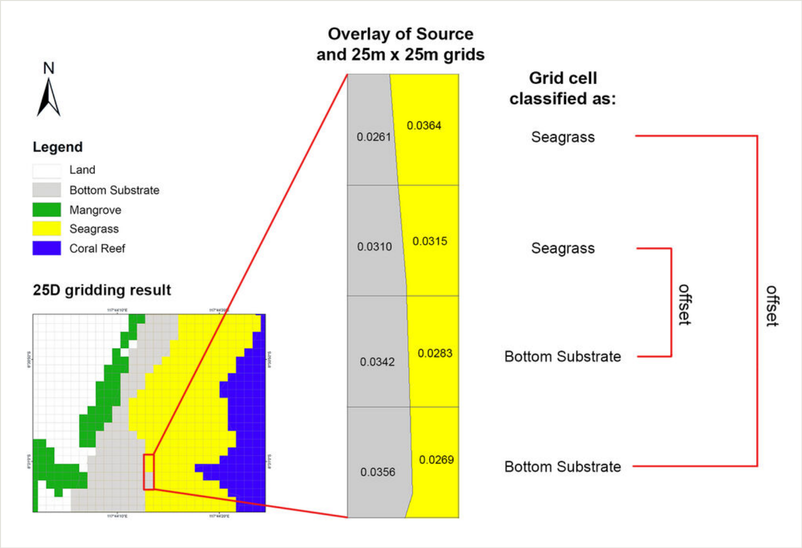

Figure 5.

Four vertically adjacent grids representing a boundary of Ecosystem Assets, sampled from 25D (25 x 25 m^2 grids with dominance method) result. The overlay of Source and 25 x 25 m^2 grids are labelled with numbers denoting the area (ha) of the Source's Ecosystem Assets (i.e. seagrass and bottom substrate) contained within each grid.

A criterion for overall accuracy within remote sensing data is approximately 85% (Anderson et al. 1976), although such a value is dependent on management aims. While overall accuracy decreased across all grids, relative to the Source, both grids using the dominance method (10D and 25D) were above this benchmark (Table 4). A KHAT value provides an additional metric to assess accuracy, where the KHAT value is considered poor below 0.4, moderate in the range of 0.41–0.60, good in the range of 0.61–0.75, very good in the range of 0.76–0.80 and almost perfect if it has a value above 0.81 (Shivakumar and Rajashekararadhya 2018). Based on this range of values, the Source and 10D were considered almost perfect, 25D was considered very good, 10H was considered good and 25H was considered moderate.

This study represents a novel approach in optimising MBSUs for OA purposes, utilising the most rudimentary approaches to MBSU gridding. Follow-up studies are important to address factors such as land/seascape, geomorphology, natural patterns and ecosystem types and their extent in testing and determining the optimal shapes and sizes of MBSUs. Additionally, future research is needed for a more robust mechanism for calculating and assigning Ecosystem Assets to MBSU grid cells, employing techniques such as weighted scoring methods which take multiple environmental and management factors into consideration.

Computing trade-offs

As shown in this study, several methods and grid sizes could provide comparable results in terms of errors and accuracy, but vary significantly in computational costs. Hence, considering the length of processing time, the 25D was the more efficient computationally than its 10D counterpart. Intuitively, 10 x 10 m^2 took substantially longer than 25 x 25 m^2 grids for both methods, at approximately 400% longer for grid generation alone. Grid processing time also differed between methods, where the dominance method required more time than its same-sized hierarchy counterpart (120–250% more allotted time), due to additional running time in RStudio for ecosystem type assignment.

Computational time is an important, albeit unreported aspect of modelling, with implications for performing environmental economic accounting globally. Practitioners should be aware of the balance between management and reporting needs and the methods used, as there are trade-offs between the performance of the methods and the length of computation time (Valavi et al. 2021). These trade-offs will be increasingly important as countries implement accounts. For example, Indonesia is one of seventeen countries that have committed to national scale accounts as a member of the High-Level Panel for a Sustainable Ocean Economy*[4]. Technological capacity varies across countries and detailed, high-resolution analysis over a wide scope EAA may be limited by computing capacity.

A potential solution is leveraging the increasing accessibility of cloud-computing for GIS and OA analysis. GIS Cloud-Computing offers a viable solution to address computing limitations and other challenges. This approach enables a diverse range of services to users worldwide, while also diminishing implementation costs and eliminating constraints related to computing power, band width utilisation and storage capacity (Bhat et al. 2011).

Implications for policy and management

Ecosystem extent accounts are a foundation for the compilation of other accounts, such as Ecosystem Condition and Ecosystem Services Accounts (GOAP 2021). Hence, the selection of MBSU may have implications for estimates across several other linked accounts by propagating errors in extent (in both total area and Ecosystem Asset spatial distribution). For example, the economic valuation of ecosystem services may be impacted, as the monetary valuation may be displayed in terms of units of area and ecosystem extent is normally included in ecosystem services calculations. To illustrate, the provisioning service of the coral reef ecosystem in Gili Matra, Indonesia in 2021 was calculated to be 2,060,949 IDR/ha/year, totalling to 510,084,881 IDR/year flowing from the coral reef ecosystem to the economy (MMAF 2022a). Another example can be seen in carbon stock accounting, where the total carbon sequestration potential of an area is dependent on the extent of the blue carbon ecosystems, such as seagrasses and mangroves (Kauffman and Donato 2012, Rustam et al. 2019).

Errors or inaccuracies in extent could also have implications for management and decision-making. For example, the overestimation of an ecosystem prioritised for conservation could lead to excessive and misplaced costs, while underestimation due to omission errors (false absence) could result in ineffective conservation measures and failures in achieving conservation goals (Rondinini et al. 2005, Rondinini et al. 2011). In Indonesia, OA is linked to marine and coastal management frameworks, for use as a baseline for granting permits, a spatial use evaluation tool for assessing the Suitability of Marine Space Use (Bahasa Indonesia abbr. PKKPRL) for marine spatial planning, conservation and MPA management, as well as a tool for monitoring the impacts of marine ecosystem services and resources utilisation (MMAF 2022b), all of which would be impacted.

Since errors are unavoidable in implementing MBSU, we strongly recommend that practitioners carefully select the optimal MBSU grid size and processing method according to the country's aims, specific ecosystems present and computational capacity. If the hierarchy method and larger grid sizes must be used, practitioners should be cognizant that such choices could introduce errors and misclassify grids for specific areas, with implications for linked accounts and, subsequently, for management and decision-making. This fact should be brought into attention by clearly stating the amount of error and the accuracy value in the reporting of ecosystem extent, as well as adding disclaimers to other linked accounts.

Conclusions

This study compared grid sizes (10 x 10 m^2 and 25 x 25 m^2) and processing methods (hierarchy and dominance) for optimising MBSU, using a case study of OA implementation within Saleh Bay, Indonesia. We observed that a larger grid size increases the error in the estimate of area, the inaccuracies and the spatial configuration of Ecosystem Assets due to reduced data resolution. Between the two tested methods, taking the ecosystem type with the largest coverage per grid cell (dominance method) produced a more accurate result, relative to a criteria-based method for classification (hierarchy method). However, when considering computing cost, a larger grid size and the hierarchy method reduced computing costs, which may prove advantageous for cases of limited computational capacity. The error introduced via MBSUs should be carefully considered for ecosystem extent accounts, as errors may propagate to other linked accounts in OA. These errors could subsequently impact management policies through ineffective budget placement and conservation measures. Practitioners should consider trade-offs of each scheme for choosing the most optimal MBSU in line with their country's management goals, environment and computational capacity.

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Author contributions

A.K. Rahayu — Conceptualisation, Data Curation, Investigation, Methodology, Writing - Original Draft, Writing - Review & Editing

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Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary material

Suppl. material 1: Methodology and Data

Authors: Agavia Kori Rahayu
Data type: Word
Brief description: Methodology for Ecosystem Assets delineation, accuracy testing and computation time calculation, as well as the data used in this study and their sources.

Endnotes

*1 The SEEA EA follows the Convention on Biological Diversity (CBD), which defines ecosystems as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".

*2 Canada hexagonal grid, Innovation, Science and Economic Development (ISED), Government of Canada: https://open.canada.ca/data/en/dataset/4129e42c-bfa6-40f1-9b2a-19dc04136bb4 (accessed January 2024)

*3 Law of the Republic of Indonesia No. 32 of 2014 about the Sea: https://www.kemhan.go.id/ppid/wp-content/uploads/sites/2/2016/11/UU-32-Tahun-2014.pdf (accessed January 2024)

*4 High Level Panel for a Sustainable Ocean Economy: https://oceanpanel.org/ (accessed January 2024)

*5 Ministerial Regulation of MMAF No. 20/2020 concerning Zoning Plans for National Strategic Areas for the Outermost Small Islands of Rusa Island and Raya Island: https://peraturan.bpk.go.id/Details/159378/permen-kkp-no-20permen-kp2020-tahun-2020 (accessed January 2024)