Towards Nationwide Mapping of Seagrasses in the Philippines: Empowering Students through Remote Sensing Education

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Abstract

Seagrasses are critical marine ecosystems facing numerous threats in the Philippines. This study aimed to develop a robust methodology for nationwide seagrass mapping using open-access satellite imagery and empower students to contribute through remote sensing education. We achieved this through a two-pronged approach: (1) developing a satellite-based mapping methodology and (2) training students to apply this method across the archipelago. Utilizing Sentinel-2 satellite images, we processed the data using SNAP and Google Earth Engine to identify seagrass beds. Before classification, the images underwent preprocessing steps including land masking, water column correction, and extraction of shallow water bathymetry. These processed layers were then stacked with Sentinel-2 bands 2, 3, 4, 8, and 11. Two classification methods, support vector machine, and random forest, were employed, and their results were compared with existing seagrass maps. Students achieved overall accuracies ranging from 70 to 90 percent. Prior to mapping activities, students received training on remote sensing techniques and seagrass ecology. This project demonstrates the potential of remote sensing for large-scale seagrass mapping and highlights the value of student engagement in marine conservation.

1. Introduction

Seagrasses, as marine flowering plants, constitute essential components of healthy coastal ecosystems worldwide (Bach et al., 1998, Green and Short, 2004, Orth et al., 2006, Tamondong et al., 2021). These marine angiosperms (Vermaat et al., 1997) provide crucial habitat for a diverse array of fish, invertebrates, and other marine life (Fortes, 2012, Micallef et al., 2012). They also act as natural water filters, trap and stabilize sediments, and play a vital role in nutrient cycling (de Boer, 2007, Miyajima and Hamaguchi, 2019, Tamondong et al., 2020, Yamamoto et al., 2019).

The Philippines, a Southeast Asian archipelago recognized as a global biodiversity hotspot, is fortunate to have diverse seagrass meadows flourishing along its extensive coastline (Fortes, 2012, Fortes et al., 2018). However, these vital ecosystems face increasing threats from human activities, including habitat destruction, pollution, and overexploitation (Short and Wyllie-Echeverria, 1996, Green and Short, 2004, Short et al., 2016). Compounding these challenges is the lack of comprehensive data on the distribution and extent of seagrass beds across the Philippine archipelago (Fortes et al., 2018, Sudo et al., 2021). Such knowledge gaps hinder effective conservation and management efforts, particularly in a nation where a significant portion of the population resides in coastal communities and depends on marine resources for sustenance and livelihoods.

Recognizing the imperative to safeguard these critical ecosystems, the importance of mapping seagrasses cannot be overstated. Accurate and comprehensive mapping of seagrass beds is essential for informing coastal resource planning, conservation strategies, and sustainable management practices. However, achieving such objectives requires robust methodologies and innovative approaches, particularly in a vast and geographically complex region like the Philippines.

Remote sensing technology has been established as an effective tool for mapping and monitoring seagrass habitats over large spatial scales (Hossain et al., 2015, Phinn et al., 2018, Roelfsema et al., 2009, Tamondong et al., 2013). By harnessing data from satellite and airborne sensors, remote sensing enables the rapid and cost-effective assessment of seagrass distribution, health, and dynamics. Numerous studies have demonstrated the efficacy of remote sensing techniques in mapping seagrasses across diverse coastal environments globally. While remote sensing technology has been known as an effective tool for mapping seagrass habitats over large spatial scales, seagrasses in the Philippines are not as extensively mapped compared to other coastal habitats such as mangroves, particularly at the nationwide scale.

Efforts from government agencies such as NAMRIA (National Mapping and Resource Information Authority), along with other projects like the Allen Coral Atlas, have contributed to seagrass mapping in the Philippines. However, concerns persist regarding the accuracy and level of detail of existing maps. Therefore, there is a pressing need for improved mapping methodologies and increased efforts to address these concerns and expand on our knowledge of the nation's seagrass distribution.

Building upon this foundation, the present study aims to advance the field of seagrass mapping in the Philippines through a comprehensive approach. Our primary objective is twofold: firstly, to develop a robust methodology for mapping seagrasses using satellite images, and secondly, to engage and empower the next generation of scientists and engineers through online lecture sessions and hands-on processing exercises.

To achieve these objectives, our initial focus was on method development. Recognizing the enormity of the task of nationwide seagrass mapping, we prioritized the creation of a reliable and scalable methodology. Through a collaborative effort under the Comprehensive Assessment and Conservation of Blue Carbon Ecosystems and their Services in the Coral Triangle, or the BlueCARES Project, we devised a systematic approach to identify and map seagrass beds using satellite imagery.

Once the methodology was established, our attention turned to implementation. Rather than attempting to map the entire coastline ourselves, we adopted a decentralized approach. We provided training to secondary and tertiary students, equipping them with the necessary knowledge and skills to apply the methodology to different regions across the Philippines. By distributing the workload among multiple participants, we aimed to maximize efficiency and coverage, ultimately facilitating the creation of a nationwide seagrass map.

In this paper, we detail the methodology developed for seagrass mapping using satellite images and present the results of our nationwide mapping efforts. Leveraging a combination of remote sensing techniques and secondary datasets sourced from the BlueCares Project for field data, we have gained valuable insights into the distribution and extent of seagrass habitats in the Philippines. We then explore the implications of our findings for marine conservation and management, while also discussing the potential for future research and monitoring initiatives.

2. Materials and Methods

2.1 Study Area

The Philippines, an island nation in Southeast Asia, is recognized as a global biodiversity hotspot (Licuanan et al., 2019). It comprises over 7,000 islands, creating a complex geography with a vast coastline stretching approximately 36,000 kilometers (Antoinette and Parras, 2001). This extensive coastline provides habitat for diverse marine ecosystems, including seagrass meadows, coral reefs, and mangroves. The tropical climate features distinct wet and dry seasons. The surrounding seas (Philippine Sea to the east, West Philippine Sea to the west, and Pacific Ocean to the north) create complex current patterns and nutrient-rich waters that contribute to the rich marine life.

Seagrasses are a crucial part of the shallow coastal waters in the Philippines. These marine flowering plants form vital habitats for diverse marine organisms and play a critical role in maintaining the health of the ecosystem. Seagrass meadows filter water, stabilize sediments, store carbon, and serve as nursery grounds for fish species that are commercially significant.

Despite their ecological and economic importance, seagrasses face numerous threats, including coastal development, pollution, overfishing, and climate change (Orth et al., 2006, Sudo et al., 2021). Furthermore, a lack of comprehensive data on the distribution and extent of seagrass beds in the Philippines hinders effective conservation and management efforts.

2.2 Development of Seagrass Mapping Methodology

The development of the seagrass mapping methodology involved a systematic and multi-step approach, integrating various remote sensing techniques and data processing methods to ensure accuracy and reliability. Figure 1 provides a visual representation of the methodology flowchart.

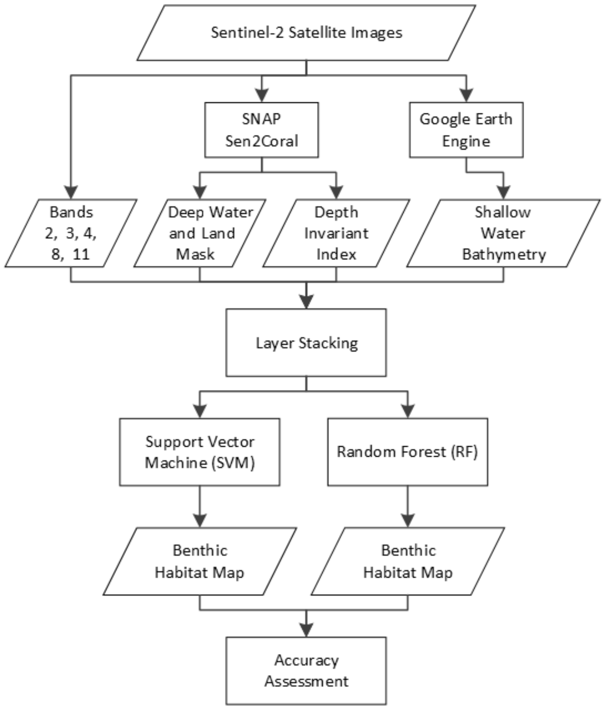

Figure 1. Flowchart of Seagrass Mapping Methodology

Initially, high-resolution Sentinel-2 satellite images covering the entire extent of the Philippines were acquired. These images served as the primary data source for the seagrass mapping process. Subsequently, the Sen2Coral tool, integrated within the Sentinel Application Platform (SNAP), was utilized to preprocess the satellite imagery. This preprocessing step involved resampling of selected bands, masking land areas to exclude terrestrial features from the analysis and creating a depth invariant index to correct for variations in water column properties.

Following land masking and water column correction, a custom Google Earth Engine code was employed to further refine the imagery by masking deep water areas. This step was crucial for ensuring accurate analysis by excluding areas beyond the suitable depth range for seagrass habitat.

The processed satellite imagery, comprising selected bands (2, 3, 4, 8, and 11) along with the depth invariant index, underwent additional processing to remove any remaining land and deep water areas, thereby focusing the analysis exclusively on the shallow coastal regions where seagrass habitats are typically found.

Supervised classification algorithms, including support vector machine (SVM) and random forest (RF), were employed to categorize the composite satellite image into distinct benthic habitat classes, such as corals, seagrass, rocks, rubbles, and sand. Macroalgae was excluded in the habitat classes as they were seasonal and not present in majority of the areas in the Philippines. These algorithms utilize spectral signatures and spatial patterns present in the satellite imagery to differentiate between various habitat types accurately.

Support Vector Machine (SVM) operates by finding the optimal hyperplane that best separates different classes within the feature space (Pal and Mather, 2005). It achieves this by maximizing the margin between classes, aiming to identify the most suitable decision boundary. SVM works well with high-dimensional data and is especially useful when dealing with complex, nonlinear classification problems. It works well with relatively small training datasets and is less prone to overfitting.

Random Forest (RF), on the other hand, is an ensemble learning technique that builds several decision trees in the training stage. (Belgiu and Drăguţ, 2016). Every decision tree chooses the best split among a random subset of features at each node after being trained on a random subset of the training data. RF then aggregates the predictions of all individual trees to make the final classification decision. RF works well with large datasets, is robust to overfitting, and can handle both categorical and continuous input variables effectively.

While both SVM and RF are powerful classification algorithms, they have distinct characteristics and are suited to different types of datasets and classification tasks. SVM excels in identifying complex decision boundaries in high-dimensional feature spaces, making it suitable for datasets with fewer training samples. On the other hand, RF is well-suited for handling large datasets with diverse features and is less sensitive to noisy data. The choice between SVM and RF depends on factors, including the type of data, the difficulty of the classification task, and the amount of computing power available for training and assessing the model.

To validate the classification results, an accuracy assessment was conducted using both secondary data and image interpretation techniques. Ground-truth data collected through field surveys, existing seagrass maps, and high-resolution satellite imagery were utilized for comparison and validation purposes. This validation process ensured the reliability and validity of the mapped seagrass habitats.

Overall, this comprehensive methodology facilitated the mapping of seagrass habitats across the Philippines, providing valuable insights into their distribution and extent. These insights are essential for informing effective marine conservation and management strategies aimed at preserving and protecting these critical ecosystems.

2.3 Implementation of the Student Training Program

The implementation of the training program was pivotal in equipping students with the requisite skills for seagrass mapping using remote sensing techniques. The program comprised a series of lectures and practical exercises aimed at providing a comprehensive understanding of remote sensing processing and its application in benthic habitat mapping. These lectures covered diverse topics including remote sensing processing techniques, the ecological significance of seagrasses, and their role in providing ecosystem services. Furthermore, students were introduced to the principles of benthic habitat mapping using remote sensing technologies, emphasizing the importance of accurate data analysis.

To ensure focused processing and analysis, the entire Philippines was divided into distinct study areas, with each area assigned to individual interns. Figure 2 shows the Sentinel-2 footprints covering the Philippines. This approach facilitated hands-on experience for students in processing satellite imagery and conducting seagrass mapping within their designated regions. Practical tutorials were provided on utilizing the Sentinel Application Platform (SNAP) for preprocessing satellite imagery, with special emphasis on tasks such as land and cloud masking, and water column correction. Students also conducted visual analysis of the NAMRIA Coastal Resources Map (CRM) using Google Earth to identify potential misclassifications.

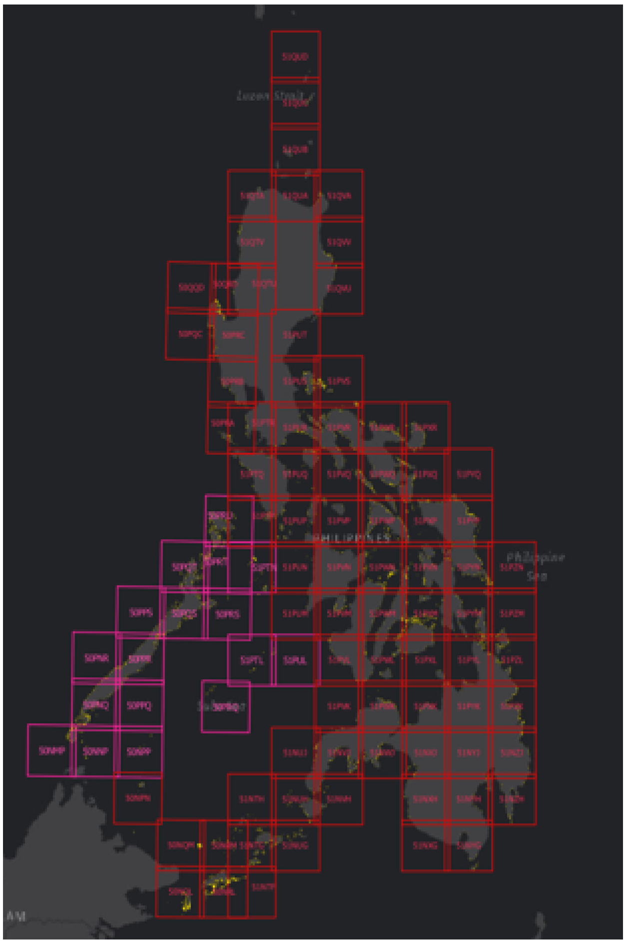

Figure 2. Sentinel-2 satellite image footprints covering the Philippines

Furthermore, students downloaded and preprocessed Sentinel-2A data for their assigned areas, focusing on acquiring images from the dry season in 2022 with minimal cloud cover. They used high-resolution satellite images from Google Earth to conduct habitat identification and applied image interpretation techniques to delineate various benthic habitat classes, including seagrass beds. To ensure consistency, interpretation keys were created. Field data from certain areas were provided to assist students in identifying different habitats. Spectral profile analysis of various benthic habitats was used to refine classification methods, with students plotting the spectral profiles to enhance their identification of habitat classes.

Supervised classification techniques were then employed to classify the satellite imagery. Finally, students conducted accuracy assessments using secondary datasets and another set of image interpretation points to validate the classification results, ensuring the reliability and validity of the mapped seagrass habitats.

3. Results and Discussion

3.1 Results from the Student Training Program

The students demonstrated proficiency in applying the seagrass mapping techniques learned during the training program. They effectively utilized remote sensing processing methods to map seagrass habitats across various study areas. Figure 3 provides a comparison of the seagrass maps generated from three different sources: the Allen Coral Atlas, the NAMRIA Coastal Resource Map (CRM), and the output of one student's mapping efforts.

The student outputs showed promising accuracies ranging from 70 to 90 percent while the NAMRIA CRM appeared to be generalized, combining seagrass and seaweed into a single class without providing any accuracy assessment. Similarly, the Allen Coral Atlas presented some limitations that align with the challenges faced in this research project. The overall accuracy of the Allen Coral Map ranges from 60 to 90 percent, varying across different mapped regions (Roelfsema and Phinn, 2013). These variabilities in accuracy in both datasets are influenced by environmental factors such as habitat complexity, water depth, and turbidity, as well as the quality of the analytical image mosaic, satellite-derived water depth, and reference dataset used for training and validation.

Moreover, several students went beyond the basic techniques taught in the program, employing advanced methods to enhance their seagrass mapping efforts. This initiative showcased their adaptability and innovation in utilizing remote sensing technologies for marine conservation applications. Sample maps generated by students across different study areas visually depict the progress of seagrass mapping efforts, providing insights into the variability and diversity of seagrass habitats across the Philippine archipelago. Figure 4 displays some output maps generated by the students.

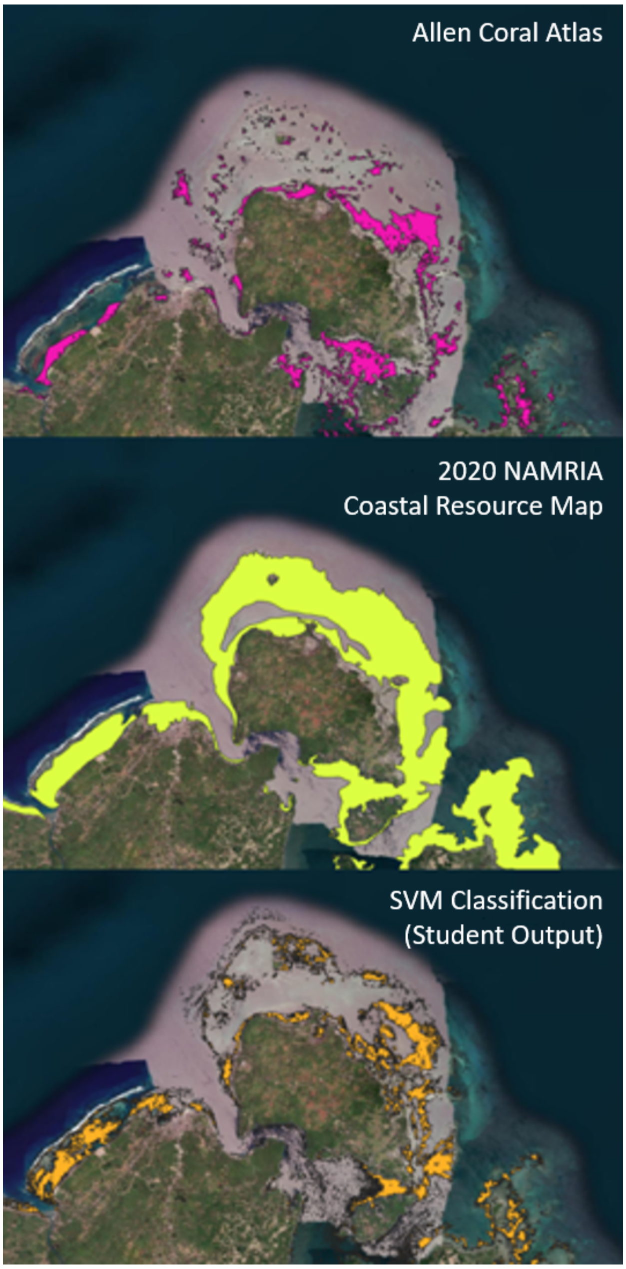

Figure 3. Comparison of seagrass area from Allen Coral Atlas, 2020 NAMRIA CRM and classification results using SVM processed by one of the students as output of the training program

3.2 Challenges in Seagrass Remote Sensing

The assessment of seagrass habitats using remote sensing encountered several challenges. These included the availability of satellite images with suitable quality and minimal cloud cover, the morphological diversity of seagrass species, and the spatial and seasonal variability of seagrass beds. Additional challenges arose from water attenuation due to turbidity and depth, as well as the presence of sun glint and waves in the images.

To address the challenge of image quality and cloud cover, each student selected datasets with the least cloud cover and the highest quality, even if they were not obtained during the dry season of 2022. Regarding the morphological diversity of seagrass species, we chose not to differentiate between seagrass species but instead classified seagrasses in general, although this approach may have introduced classification errors into the data.

To tackle the spatial and seasonal variability of seagrasses, students were initially instructed to prioritize downloading the best images captured during the dry season of the same year (2022). If such images were unavailable, they were instructed to select the best cloud-free image from the dry season of the previous year (2021).

To mitigate misclassification due to water turbidity, students were trained to identify turbid water areas, particularly those near rivers. These areas were masked out and excluded from the classified areas. In addressing depth-related issues, depth-invariant indices were derived to correct the image. Furthermore, students were educated on identifying the presence of sun glint in the images and were instructed on sun glint correction techniques. However, instances of sun glint were rarely observed by students.

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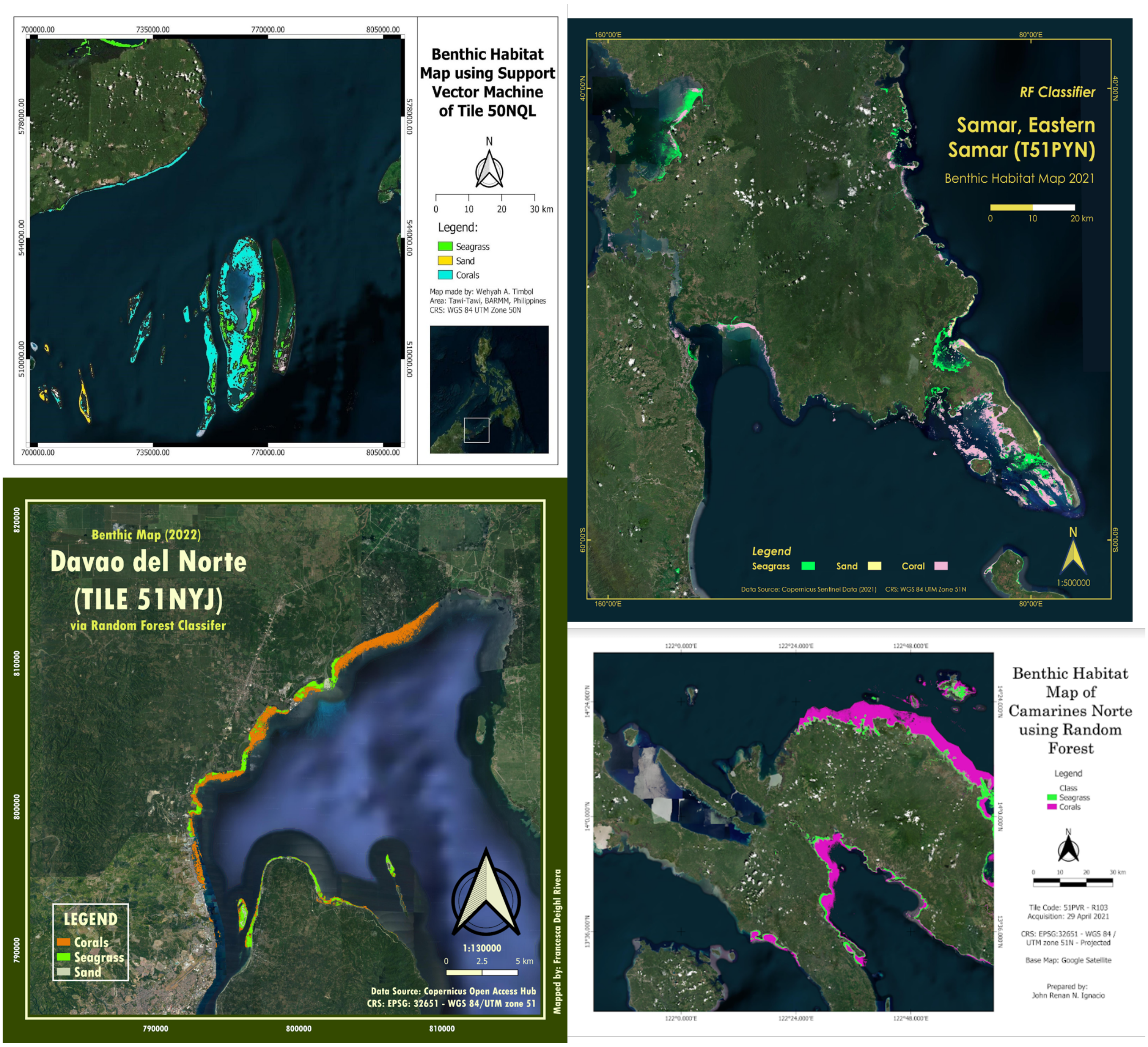

Figure 4. Four (4) sample outputs of seagrass maps produced by students

3.3 Successes and Challenges of the Student Training Program

Although the training program successfully facilitated the mapping of seagrasses across the Philippines, the varying accuracies observed among student-generated maps emphasized the necessity for thorough data validation and stringent quality control measures. Challenges emerged during the collation and reconciliation of datasets from different students, underscoring the critical importance of standardization and consistency in both data collection and processing protocols. Despite these hurdles, the training program offered students invaluable practical experience in seagrass mapping using remote sensing techniques.

This immersive learning opportunity not only played a pivotal role in enhancing the professional growth of participating students but also made substantial strides in bolstering marine conservation endeavors across the Philippines. By providing hands-on experience in seagrass mapping using remote sensing techniques, the training program empowered students with practical skills and knowledge essential for addressing intricate environmental issues. As these newly skilled individuals join the workforce, they bring with them the capability to contribute meaningfully to ongoing conservation initiatives, thereby broadening the collective expertise available to tackle the multifaceted challenges confronting marine ecosystems. In essence, the program’s impact extends beyond individual skill development, serving as a catalyst for building a stronger and more adept community of conservationists dedicated to safeguarding marine biodiversity in the Philippines and beyond.

3.4 Implications for Seagrass Conservation and Management

The ongoing efforts to advance the seagrass mapping project in the Philippines have profound implications for the conservation and management of seagrass ecosystems throughout the region. Access to detailed spatial data on seagrass distribution provides conservationists and policymakers with a crucial tool for devising targeted strategies aimed at preserving these vital marine habitats. By pinpointing areas of high seagrass

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abundance and identifying vulnerable regions, conservation efforts can be optimized to maximize effectiveness and resource allocation.

Furthermore, the methodology developed in this study serves as a blueprint for future educational endeavors focused on seagrass mapping and conservation. Its success demonstrates the feasibility of integrating remote sensing education into academic curricula, offering students a hands-on approach to environmental stewardship. By engaging students in practical exercises and real-world applications of remote sensing technology, educational initiatives can cultivate a new generation of conservation-minded individuals equipped with the skills and knowledge needed to address pressing environmental challenges.

Moreover, the scalability of this educational model means that similar initiatives can be replicated and expanded to reach a broader audience. By leveraging open-access satellite imagery and freely available software tools, educational institutions can introduce remote sensing techniques into a wide range of academic disciplines, fostering interdisciplinary collaboration and nurturing a deeper understanding of marine ecosystems. Ultimately, by empowering students to become active participants in marine conservation efforts, these initiatives play a pivotal role in fostering environmental awareness and promoting the sustainable management of natural resources.

3.5 Role of Students in Research and Conservation Efforts

Students have the potential to play a significant role in research and conservation efforts related to seagrasses. Their involvement in seagrass mapping initiatives extends beyond academic settings, with some students continuing their efforts through thesis projects or securing employment as researchers in research and government institutions. By actively participating in seagrass mapping and conservation projects, students contribute to ongoing research efforts and conservation initiatives aimed at protecting and preserving seagrass ecosystems. Their contributions underscore the importance of student engagement in environmental conservation and highlight the role of education in fostering environmental stewardship.

4. Conclusion

This study represents a significant step toward nationwide mapping of seagrasses in the Philippines, achieved through the development of a robust mapping methodology and the empowerment of students through remote sensing education. By combining remote sensing techniques with student engagement, we have made substantial progress in understanding and conserving seagrass ecosystems across the Philippine archipelago.

Our results demonstrate the effectiveness of remote sensing technology in mapping seagrass habitats on a large scale. Through the systematic processing of Sentinel-2 satellite imagery and the application of advanced classification algorithms, we have been able to accurately delineate seagrass beds in diverse coastal environments. Moreover, the involvement of students in this endeavor has not only expanded our mapping coverage but has also fostered a new generation of scientists and engineers passionate about conservation.

Despite the challenges encountered, including image availability and classification difficulties, our methodology has provided valuable insights into the distribution and extent of seagrass habitats in the Philippines. These insights have significant implications for marine conservation and management, enabling targeted strategies for the protection and preservation of seagrass ecosystems.

Moving forward, our study lays the foundation for future research and monitoring initiatives focused on seagrass conservation. By replicating our approach and scaling up educational initiatives, we can continue to engage students in marine conservation efforts and promote environmental stewardship. Through their active participation, students will play a vital role in advancing our understanding of seagrass ecosystems and ensuring their long-term sustainability.

In conclusion, this research not only contributes to the broader understanding of seagrass ecosystems but also highlights the importance of collaboration between academia, government, and local communities in marine conservation. By working together, we can protect and preserve the invaluable seagrass habitats of the Philippines for future generations.

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