30 Years National Scale Seagrass Mapping in Vietnam with Landsat and Sentinel Imagery on Google Earth Engine

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ABSTRACT: Seagrass beds, one of the blue carbon ecosystems are crucial for mitigating climate change. However, their distribution is decreasing at an alarming rate. An estimated 168,817 km2, or 52% of seagrasses in the world are in the Tropical Indo-Pacific region, but most of those distribution is documented as point data, but not mapped as polygons. To quantify this distribution, previous studies have shown that remote sensing is a cost-effective approach for seagrass mapping. However, benthic mapping for tropical coastal waters remains a challenge. It is because the clarity of tropical coastal waters is frequently changing, and frequent cloud coverage limit the number of images available. However, the continuous archives of images are still an invaluable resource for monitoring the changes in seagrass distribution. The objective of this research is to utilize all the data available to monitor changes in seagrass distribution in a tropical coastal area. Due to the rapidly changing nature of tropical coastal waters, the surface reflectance over water pixels changes constantly. Vietnam was chosen as the study site because the country exemplifies a diversity of coastal environment. By carefully select images and masking out turbid water pixels, we estimate the changes in seagrass distribution over a 30-year period in Vietnam. All documented seagrass beds in Vietnam were analyzed in this framework. Some major seagrass beds in Vietnam, such as in Cam Ranh Bay, Van Phong Bay, and Tam Giang Lagoon, as much as 40-85% of seagrass beds were lost between 1989 and 2019. Most change happens due to the direct impacts of land use conversion for aquaculture use. Some seagrass beds appear unchanged. However, the degraded water quality suggests that the productivity of these seagrass beds may have decreased. These trends are common in places where pressure on coastal development are high. This research gives a spatially explicit estimate for the inventory of seagrass in Vietnam. Hence, it contributes to the understanding of seagrass distribution in the Tropical Indo-pacific region and provides the foundation for the conservation of these valuable ecosystems.

1. INTRODUCTION

Seagrasses are marine flowering plants, usually found in shallow, sandy or muddy flats. Seagrass beds play crucial roles in preventing coastal erosion, supporting fisheries, improving water quality, and mitigating climate change. Per hectare, the carbon burial rate of seagrass beds is 35 times higher than those of terrestrial forests. (Duarte et al., 2010; Fourqurean et al., 2012; McLeod et al., 2011).

Despite their important role for the environment, seagrass distribution is decreasing rapidly. An estimated 7% of seagrass is lost annually worldwide. (Waycott, 2009) When lost, not only do we lose their potential to capture carbon, but also, the sequestered carbon would be released to the atmosphere, making it a carbon source. It is therefore crucial to monitor the distribution of seagrass and prevent further losses.

However, our knowledge on seagrass distribution is still limited. The best estimates of global seagrass distribution is 325 178 km^2 (Unsworth et al., 2019), and the data has not been updated for 20 years in many places. A significant number of countries, especially those with a major contribution to seagrass distribution, do not have a spatially explicit database of seagrass distribution. At the same time, coastal development is happening in these countries, for the purpose of expanding aquaculture production or construction of infrastructure.

Vietnam is an example of such countries. The estimation of seagrass distribution in Vietnam is 17,000 ha (Cao et al., 2012). However, this information not spatially explicit, nor is currently updated. Meanwhile, rapid coastal development is causing major loss for seagrass distribution. About 60% of seagrass beds in Vietnam had been lost in between the pre-1995 level compared to that of the 2003's survey. (Nguyen, 2008). Rapid changes to the coastal zones require frequent, thorough monitoring, which is costly if only field surveys are done. In Vietnam, the ecosystems service value of seagrass is 4000 USD/ha/year on average (23 - 14,346 USD/ha/year). This is less than the world's average 26,226 or 28,916 (Costanza, 2014), and is small compared to the expected annual profit compared to aquaculture farms, which is 97,000 USD/ha for medium farms to 177,000 USD/ha for large farms of pangasius (Pham et al., 2016).

Remote sensing could be the key to monitor the seagrass beds in this case. Changes to coastal waters could be inferred from images since 1984 with the Landsat 5 mission, and have been continuously recorded. Recently, we have abundant data, ranging from the freely available Landsat and Sentinel missions, to the commercial high resolution missions such as SPOT, Worldview, or Planet Doves. Computing platforms have also enabled processing of petabytes of images, exemplified by Traganos' research on mapping seagrass beds in the entire Greek waters (Traganos et al., 2018) with Sentinel-2 images on Google Earth Engine.

In this research, we propose to monitor the changes in seagrass distribution in the entire nation of Vietnam using Landsat and Sentinel image over the last thirty years. This will reveal the temporal and spatial patterns of changes in seagrass distribution in a tropical country with rapid coastal development. The results will update the inventory of seagrass distribution, highlight areas for seagrass conservation, and be the foundation for predicting future changes.

2. METHODOLOGY

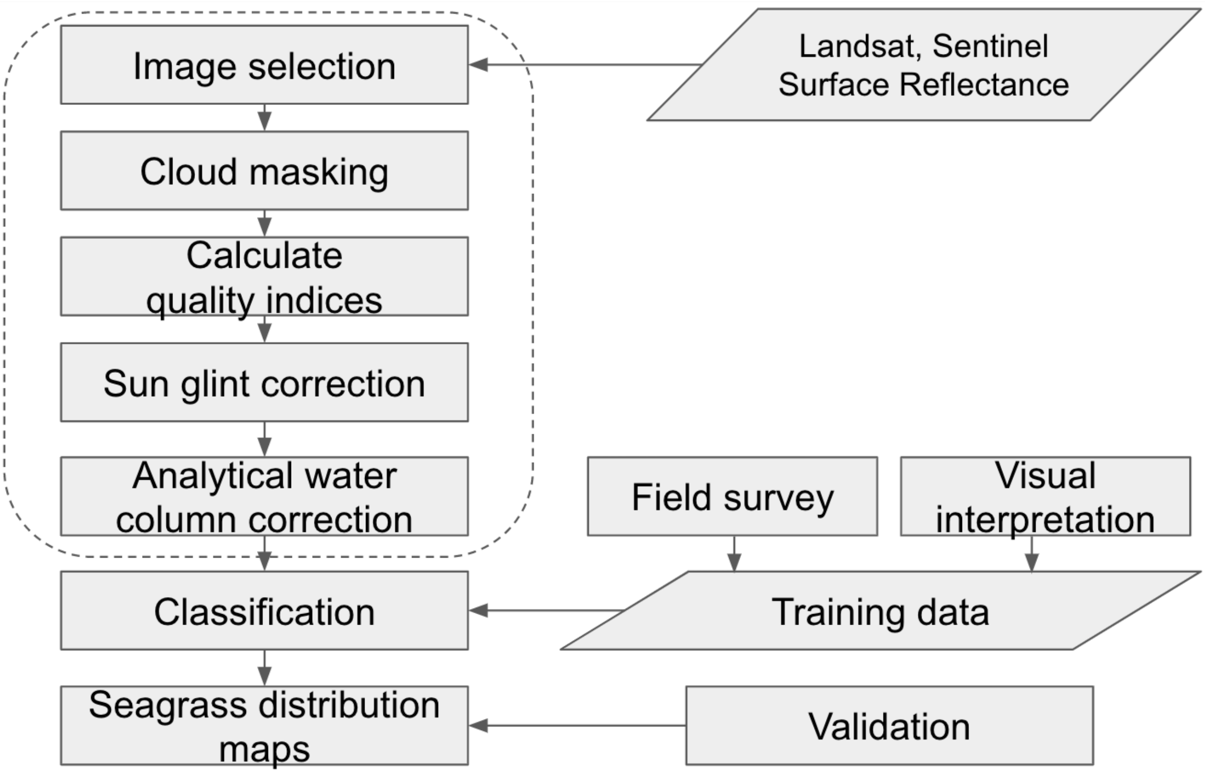

Figure 1: Flow chart of data analysis for monitoring seagrass distribution

2.1 Datasets and image selection

Surface Reflectance images from Landsat 5 TM, Landsat 8 OLI, and Sentinel-2 MSI were used. Based on cloud cover metadata on the images, all cloud free or almost cloud free images over the coastal area.

As seagrass distribution in Vietnam has seasonality. Seagrass in lagoons are affected by seasonal variation in salinity. Thus, images in the dry seasons were chosen for analysis to ensure consistency. There were two seasonal patterns in Vietnam, due to different climatic zones, where the dry months are between March-September for Central Coasts, and between November-April for the rest of the country. Rarely, exceptions were made due to data availability.

2.2 Preprocessing

Preprocessing followed a standard procedure. As the surface reflectance products have been corrected atmospherically and geometrically, these steps were skipped. Clouds were masked out based on the quality flags on the images. The Normalized Difference Water Index (Xu, 2006) was calculated to help separating water and land pixels.

Sun glint contaminates water leaving reflectance, therefore minor sun glint was corrected by Hedley's equation (Hedley et al., 2005). Images with major sun glint was discarded.

Water column correction was done following Matsunaga's Bottom Index method (Matsunaga et al., 2000), for its simplicity and analytical approach. Transects over homogenous sandy floor over varying depths were manually chosen to calculate the attenuation coefficients.

2.3 Classification

Training data was created with visual interpretation, references to high resolution images from Google Earth, and knowledge from field surveys. Considerations were made not to overfit the classifier, and make sure the training data were balanced amongst classes.

Classification was done with a Random Forest classifier (Pal, 2005). This classifier is non-linear, therefore it can handle classes that cannot be distinguished with linear equations. The Support Vector Machine classifier was also considered. Both classifiers yielded similar accuracy, but Random Forest is more efficient in terms of memory, it was preferred.

As tropical coastal water usually contains plumes of suspended sediments and high chlorophyll contents, accuracy is generally low. To minimize this issue, classified images in each five years period were composed, and the mode of the classes were used as a representative. Each resulting pixel would represent the most frequent class at the pixel during the given period. (Lyons et al., 2013)

Accuracy assessment was done by splitting the training data set into two portions. 70% of the training data was used for classification and the remaining 30% were reserved for validation.

3. RESULTS AND DISCUSSION

3.1 Seagrass distribution changes in Vietnam

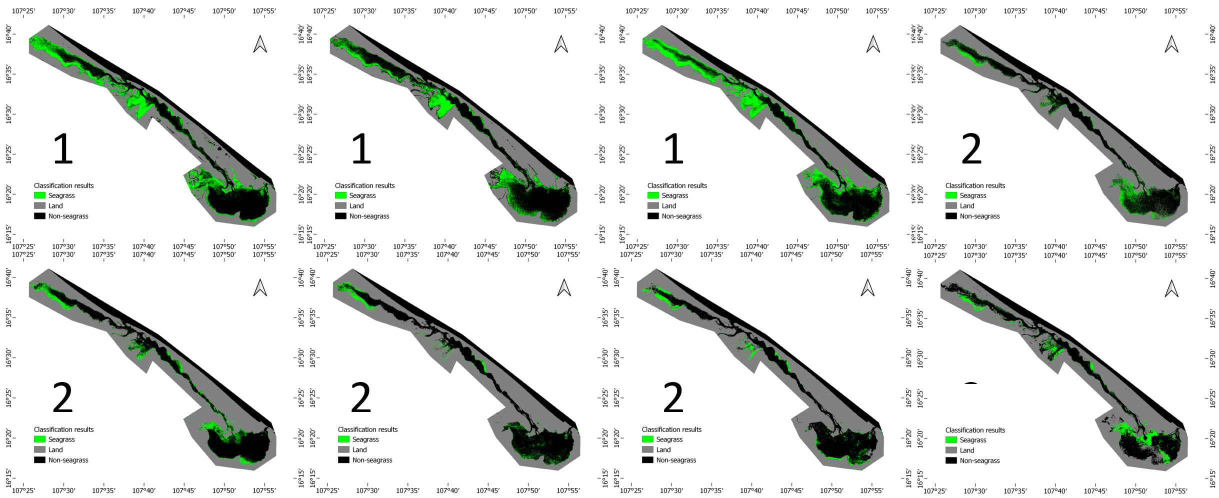

Figure 2: Changes in seagrass distribution in Tam Giang - Cau Hai Lagoon between 1985-2019.

Table 1: Changes of areas in major seagrass beds in Vietnam between 1985-2019.

Seagrass sites	**1985 - 1990**	**1990 - 1995**	**1995 - 2000**	**2000 - 2005**	**2005 - 2010**	**2010 - 2015**	**2015 - 2019**	**2019**	**Percentage lost**	**Main cause of loss**
Phu Quoc Island	12684	14738	13607	12731	11855	12005	10313	5398	18.69%	Tourism
Tam Giang – Cau Hai Lagoon	9914	6897	9959	2985	3580	1990	2141	3356	78.40%	Aquaculture
Van Phong Bay	3532	2220	1735	1408	1325	1300	704	1174	80.07%	Aquaculture
Cam Ranh Bay	2416	1832	1334	1342	1127	1772	870	1759	63.99%	Aquaculture
Thuy Trieu Lagoon	1666	1447	1335	902	1254	1100	895	1015	46.28%	Aquaculture
Cu Mong Lagoon	658	1058	441	653	687	164	350	434	46.81%	Aquaculture
My Hoa – My Tuong	457	466	407	319	330	308	233	262	49.02%	Port construction
Hon Khoi	317	410	154	131	176	83	73	85	76.97%	Salt farm
Hon Tre	137	94	104	68	56	69	58	96	57.66%	Tourism
Total	31781	29162	29076	20539	20390	18791	15637	13579	50.80%	

Within the most major seagrass beds in Vietnam, which counts for a total of 82% of seagrass distribution in Vietnam, according to the report by Cao, 2012, there have been more than 50% loss of seagrass areas between 1985-1990 period and the 2015-2019 period.

The most evident decrease was during the late 1990s, early 2000s. Seagrass beds in Tam Giang - Cau Hai Lagoon showed the most drastic change, decreasing from 9959 ha in the 1995-2000 period to 2985 ha in the 2000-2005 period. (Figure 1) These findings agree with the field survey results, which recorded a 60% decrease in total seagrass area in the same period (Nguyen, 2008).

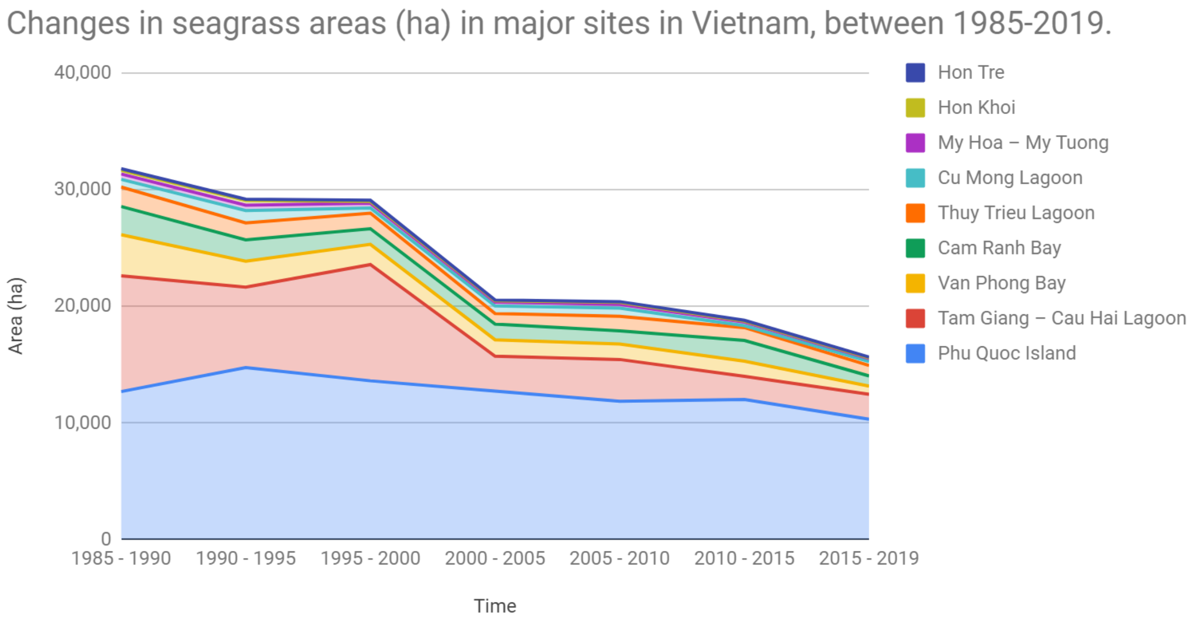

Figure 3: Graph of changes in seagrass distribution in major seagrass beds in Vietnam 1985-2019.

These trends continued, though more slowly in the subsequent years. New development projects, such as construction of ports, or tourism facilities, which occurred in more recent years (2005-2019) results in the decrease in seagrass distribution in Cam Ranh Bay, Hon Tre Island, My Hoa tidal flat, Phu Quoc Island.

Distribution maps show that most of the lost seagrass beds are those at the coast, especially those near populated areas. These seagrass beds are most likely to be subjected to land reclamation and conversion into aquaculture ponds. Losses due to conversion into reclamation are difficult to be reversed.

Many seagrass beds could not be identified accurately from Landsat images, due to these possible reasons. Firstly, some species have sparse distribution, such as species in the *Halophila* and *Halodule* genii. Therefore, seagrass beds that only consists of these species, or those with sparse distribution, could be mixed with other substrate in 30m or 15m resolution, hindering detection. Secondly, the water column could be too turbid to distinguish seagrass and non-seagrass pixels. This is most relevant near river mouths or in lagoons. Last but not least, the classifier may have included seaweeds or corals in the seagrass class, due to their similar spectral response profiles. In areas where there are many seaweeds, such as in Thuy Trieu lagoon, Tam Giang - Cau Hai lagoon, this may lead to a low consistency in classification. Those phenomena could be co-occurrent, for example *Halophila ovalis* is associated with areas with low light availability, and seaweeds are usually present in such areas. Due to those reasons, remote-sensing based monitoring is not efficient in seagrass beds in Northern Vietnam. Field surveys suggest that most of the seagrass beds in Northern Vietnam has completely disappeared as of 2003. (Nguyen, 2008)

Accuracy was above 60% for Landsat images. The Sentinel-2 images seemed to have a high accuracy (>80%) than those of Landsat, possibly because of their higher spatial resolution, which reduces the mixing of different substrates in one pixel. The higher resolution also allows for the clearer identification of aquaculture ponds or floating fish pens.

3.2 Factors contributing to the decrease

To examine the causes of the decrease in seagrass areas, visual interpretation was done. The most prominent factor affecting seagrass distribution was land reclamation. This caused direct replacement of seagrass beds by reclaimed land, for the purpose of mostly agriculture, aquaculture, and sometimes for tourism. Examples are shown in the figure showing the coastal development. Most of these activities happen in shallow intertidal or subtidal flats, where seagrass are distributed.

Figure 4: Images of 1995-05-25 (left) and 2000-05-06 (right) at Tam Giang Lagoon shows the replacement of seagrass beds by land reclamation for aquaculture ponds.

National Decree 773-TTg approved on December 21, 1994 strongly encouraged people to clear mangroves and reclaim coastal waterfronts for shrimp farming (Le, 2008). It led to rapid, extensive clearing of mangroves in favor of shrimp aquaculture. These movements could have had a similar impact to coastal seagrass beds, which received even less attention from conservation back then.

Another factor that could have impacted the seagrass distribution is aquaculture activities over the water surface. Floating Fish pens and various forms of aquaculture activities, mostly in enclosed bay or lagoons, have dominated the water surface, and could have displaced seagrass beds. Changing water quality also had an impact on seagrass. Increased turbidity due to eutrophication prevented the exact measurement from satellites on seagrass. That could also have limited the light available to benthic seagrass. Even though seagrass can survive several months with sunlight less than the required amount for growth, their photosynthesis functions are severely hindered, and would eventually die.

4. CONCLUSION

We were able to monitor the changes in most seagrass beds in Vietnam for more than 30 years, albeit with moderate accuracy. The results showed the temporal and spatial patterns of seagrass area changes. Most seagrass beds were lost between the late 1990s and early 2000s, and continued to decrease. This quantified the impacts of coastal development on coastal ecosystems, as 30% of seagrass in Vietnam were lost in a 5-year period. The continued decrease signified the lack of effective conservation and recovery for seagrass ecosystems. Spatial patterns showed that most seagrass loss occurred at the populated coast, and were directly displaced by land reclamation for aquaculture or constructions of infrastructure.

These findings demonstrated that remote sensing is a cost-effective method to monitor coastal seagrass ecosystems at this spatial and temporal scale. The results emphasized the necessity to update the seagrass distribution data, as many seagrass beds have decreased in size or disappeared totally. It also highlighted the urgency to monitor seagrass beds in Vietnam, because of the rapid degradation happening.

Vietnam is only one of the countries where coastal seagrass ecosystems are being threatened. It is potential to apply this approach to monitor other coastal zones to enhance our understanding about changes to seagrass ecosystems and improve on our conservation.

There are limitations to this method. Seagrass beds in turbid water and sparsely distributed seagrass species, such as *Halophila ovalis* can hardly be monitored via moderate resolution optical satellite images. Alternatives are high resolution images, which would be able to resolve for the patchy seagrass beds. Automated systems such as autonomous underwater vehicles can be deployed to assist monitoring in areas where field survey is required, yet costly and risky. Also, this method applied a rough batch process that put more emphasis on the ability to process a large number of images than carefully utilize each image. There are still potentials to improve the accuracy of assessment of individual images, such as by improving the masking algorithms to eliminate turbid pixels. In areas where remote sensing is the only choice to monitor seagrass beds, it is encouraged to consider further attempts to improve mapping accuracy.

At the moment, Sentinel-2 MSI have been launched for five years. The Sentinel-2 constellation provides a higher spatial and temporal resolution than that of Landsat mission, even with the anticipated launch of Landsat 9. It means the Sentinel-2 would be the key to monitoring coastal ecosystems at a global scale. It is important, thus, to improve the utilization of Sentinel images for the purpose of monitoring.

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