Assessment of ecosystem services provided by seagrass

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Received: 19 January 2026; Revised: 05 February 2026; Accepted: 25 March 2026; Published: 20 April 2026

Abstract

The seagrass meadows, commonly known as the lungs of the sea, are important coastal ecosystems that provide many environmental services, such as habitat for marine life, improved water quality, and reduced climate change through carbon sequestration. These ecosystems are facing threats from human activities, including coastal development, pollution, and climate change, despite their important role in the economy. This research paper will determine the ecosystem services offered by seagrass meadows with particular reference to their contribution to biodiversity support, carbon sequestration, and coastal protection. The research methodology involved is an ecological evaluation integrated with biophysical modeling as well as economic evaluation approaches. The ecological processes used were biodiversity and water quality observation, whereas carbon sequestration and sediment stabilization were assessed by using biophysical models. Contingent and market-based methods were used to carry out economic valuation to estimate the monetary value of the ecosystem services provided. The findings have shown that seagrass meadows trap in excess of 0.5 million tons of carbon per year, thus playing an important role in mitigating climate change. Also, seagrass meadows enhance water quality by filtering surplus nutrients and pollutants and mitigating risks of eutrophication by up to 30 %. In addition to this, the meadows also curb the problem of coastal erosion by stabilizing the sediments and also minimizing the effect of storm surges. Nevertheless, there are threats to these ecosystems, as continue to degrade due to developments at the

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DOI: 10.70102/IJARES/V6I1/6-1-31

coastline and pollution. The paper highlights the necessity of conservation and restoration approaches and suggests combined management approaches and multinational cooperation in the preservation of such endangered ecosystems. These results point to the significance of seagrass meadows to the health of coastal ecosystems as well as climate change reduction.

Keywords: Seagrass meadows, Ecosystem services, Carbon sequestration, Biodiversity, Water quality, Coastal protection, Climate change, Marine ecosystems

Introduction

Seagrass meadows are underwater ecosystems formed by flowering plants that are located in shallow coastal areas and that are found growing in sandy or muddy substrates. Although seagrass meadows have a great ecological and socio-economic value, the currently facing many threats due to human-anthropogenic factors, including the development of coastal areas, pollution, and climate change. Although past researchers have outlined several ecological roles of seagrass ecosystems, there is no in-depth knowledge about the quantification of such services, especially the contribution towards climate change mitigation, as well as economic value. This paper aims to fill these gaps by analyzing the ecosystem services offered by seagrass meadows, the ecological and economic value of these ecosystems, and giving practical recommendations on their conservation and restoration. Seagrass meadows can immensely contribute to the ecological soundness and well-being of the marine and coastal ecosystems. Likewise, several seagrasses such as Zostera, Posidonia, and Thalassia afford key shelter and sustenance for various marine species such as fish, invertebrates, and sea turtles (Al-Asif *et al.,* 2022). Seagrass meadows are intricate and interconnected systems that offer diverse ecosystem benefits, such as the sustenance of biodiversity and the shelter and food provision for the juvenile stages of fish, various species of crustaceans, and others. However, the biologically significant habitat is the meadows themselves, as biologically capture and sequester atmospheric carbon, thereby curtailing the impacts of climate change and increasing the ecosystem's value to the Biome (Tuya, Haroun and Espino, 2014; Ruiz-Frau *et al.,* 2017). Seagrass meadows, like any other ecosystem, augment the ecosystem by absorbing water and improving water quality, as well as enhancing the ecological soundness of the coastal ecosystems by removing excess nutrients and sediments along with any pollutants from the water column. Seagrass meadows provide cohesive effects on sediments, mitigate coastal erosion, reduce wave energy, and act as a natural buffer against storm waves by lessening the effects of storm impacts. Seagrass ecosystems function as natural flood barriers and protective infrastructures and as protective buffers for coastal communities (Manjunath *et al.,* 2025). The socio-economic and ecological adverse ramifications caused by the damage to seagrass meadows are the biodiversity loss, coastal erosion, and damage caused by climate change. Therefore, the restoration and maintenance of seagrass meadows are essential for the defense of coastal

ecosystems and for the seagrass meadows to provide.

Key Contribution of the Paper:

- The article highlights the climate change mitigation capacity of aquatic vegetation ecosystems as a natural carbon sink by sequestering and storing carbon in sediments and roots at the base of the carbon cycle, Carbon Sequestration.
- The article highlights the role of seagrass ecosystems in nutrient, sediment, and pollutant over-enrichment of water bodies to enhance coastal ecosystem health.
- Protection of Shorelines: Protection of shorelines- the ecological and marine ecosystem enhancements that coastal communities and marine organisms gain from the wave and surge buffering, coastal erosion reduction, and sediment movement mitigation by seagrass meadows and natural ecosystem engineering.

This study uses a combination of ecological, biophysical, and economic approaches in evaluating the ecosystem services of seagrass meadows. The ecological approaches entail the measurement of the biodiversity, the observation of the water quality enhancement, and the measurement of the carbon sequestration in the seagrass sediments. Biophysical methods include field data collection and modeling of the measurement of sediment stabilization and wave attenuation. The contingent valuation and market-based methods will be applied in order to construct the economic valuation of the services, including carbon sequestration and coastal protection, in terms of money. Also, a series of case studies of Florida Bay will be evaluated to point out successful models of valuation. Seagrass meadows are keystone ecosystems that support the life cycles and provide habitat and food for various species within the trophic levels of the ocean. offer nutritional and protective shelter for a distinctive collection of juvenile fishes, vertebrates, and invertebrates, marine life, thereby sustaining marine biodiversity and the food webs that depend on it (Ramesh *et al.,* 2024; Kaewsrikhaw, Upanoi and Prathep, 2022). Beyond ecology, meadows of seagrass also economically serve as an efficient natural carbon sequestering ecosystem that aids in climate change mitigation through carbon storage in roots and sediments. These meadows also serve the economy by enhancing and improving water quality because filter off and remove excess nutrients, sediment, and pollutants that surround the water. Water quality and the health of the marine ecosystem as a whole are improved by the natural pollution-reducing ways of seagrasses that serve as filters by capturing particulates. Finally, seagrass meadows protect coastlines by providing sediment stabilization and controlling erosion. The seagrass dense root systems reduce wave action and storm surges, resulting in lowered coastal erosion and protecting shore-related human structures and communities. Taking all these benefits into account, seagrass meadows are essential for the interrelated sustainability of marine ecosystems and coastal communities (Dewsbury, Bhat and Fourqurean, 2016). Furthermore, seagrass meadows provide sediment stabilization and erosion control, and

protect coastlines from distress. The seagrass dense root systems mitigate wave action and storm surges, preventing coastal erosion and protecting the shore-located communities and infrastructure. Considering all of these services, seagrass meadows are essential for the sustainability of marine ecosystems and coastal communities.

The structure of the paper is as follows: Section I, introduction, which gives some background information on seagrass meadows, their ecological importance, and the utility have in biodiversity, mitigating climate change, and coastal protection. Section II expounds on the different ecosystem services offered by seagrass meadows, including carbon sequestration, water quality enhancement, and coastal defense. In section III, it covers the threats to the seagrass meadows, such as human activities, pollution, and climate change. In section IV, it provides the opening of the methods used to evaluate the value of seagrass ecosystem services, including the economic, ecological, and biophysical methods of assessment. Section V elaborates the conservation and restoration plans with a focus on the level of significance of policy recommendations, global projects, and the local practice of management. The paper concludes by restating the importance of seagrass meadows and the necessity to implement extensive conservation in order to save these ecosystems in section VI.

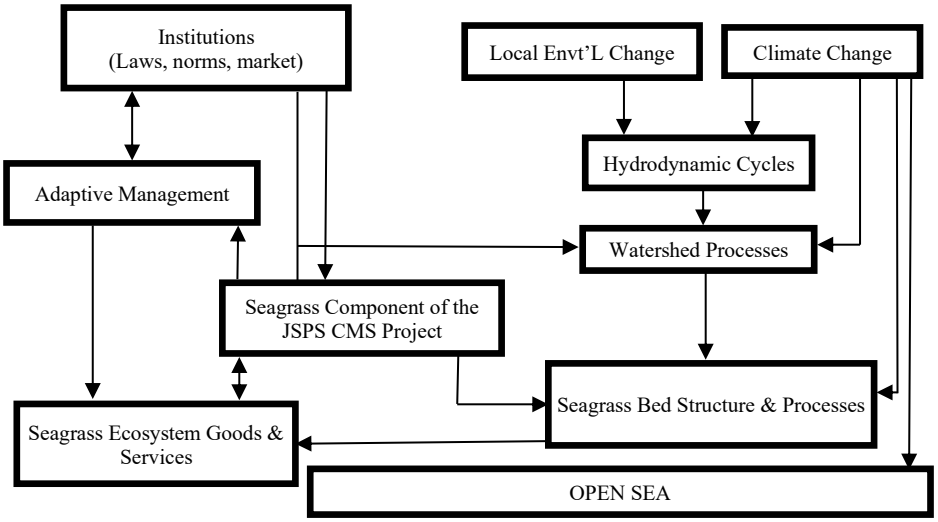

Figure 1: Philippine seagrass conservation strategy plan.

Figure 1 represents an integrative phenomenon on seagrass conservation in the Philippines, connecting anthropogenic management with ecological systems. It identifies the Seagrass Component of the JSPS CMS Project as the main link between institutional factors (e.g., laws, markets) and environmental drivers, such as climate change and hydrodynamic cycles. As illustrated in figure 2, maintaining Seagrass Ecosystem Goods & Services necessitates adaptive management, or an active approach in response to changes in external environmental pressures, and human impact on the health of seagrass beds, and their relationship to the open ocean.

Literature Review

The ecosystems of the meadow grass have a broad spectrum of services, such

as habitat, water quality, and climate change mitigation through carbon sequestration. Investigations have pointed to the significance of these meadows in aiding biodiversity and maintaining the health of the ecosystems.

Houssa *et al.,* (2025) evaluate ecosystem services of lagoonal seaweeds and seagrasses in the Moroccan coastline and highlight their role in improving water quality and offering essential habitat to sea creatures. Likewise, Gaylard *et al.,* (2025) discuss how ecosystem service analysis can be incorporated into the development planning process with particular attention to the effects of dredging operations on seagrass in South Australia. The article highlights the necessity to address the ecosystem services in the environmental impact assessment, particularly where a development will affect a significant marine habitat. The use of seagrass meadows as a blue carbon sink to address climate change has been well documented. The article by Song et al., (2025) also explains the adverse effects of climate change on the capacity of seagrass ecosystems to store carbon, which makes the latter vulnerable and the conservation of these ecosystems urgent.

Xu and Salauddin, (2025) give an in-depth overview of seagrass as a wave attenuator and present evidence of the different methods of assessing such an ecosystem service vital in preserving the coastline. The restoration activity of seagrass has been a subject of an in-depth study, and several methods have demonstrated different degrees of success. A meta-analysis was done by Pansini *et al.,* (2025) on Mediterranean seagrass restoration and established the best practices related to the field and their effectiveness in the restoration of seagrass ecosystems. Additionally, Addamo *et al.,* (2025) compared the monetary and physical values of the seagrass ecosystems in the Mediterranean Sea, which contributes even more to the importance of the ecosystem services. The significance of community contribution to the conservation of seagrass was also emphasized by Ambo-Rappe *et al.,* (2019), who examined the views of a coastal community regarding the seagrass ecosystem services. Their results show that local involvement is necessary in order to provide successful conservation and sustainable management. Himes-Cornell, Pendleton and Atiyah, (2018) analyzed the systematic review of the valuation of ecosystem services offered by blue forests, such as seagrass beds, and emphasized the necessity of stronger techniques to measure and combine the services for decision-making.

According to the reviewed literature, it is clear that seagrass meadows are very important in facilitating marine biodiversity, improving water quality, and alleviating climate change by sequestration of carbon. The reviewed studies point to the broad scope of ecosystem services that the seagrasses offer, such as living space for several marine species, sediment control, and coastal defense. These precious ecosystems are, however, becoming more threatened due to human activities, including coastal development, pollution, and climate change. Another common theme in the literature is the challenge of incorporating ecosystem service

assessment into the development planning and conservation practice, with various studies demonstrating the beneficial nature of restoration practices and community participation in conservation of the seagrasses. Although the importance has been realized, further valuation procedures and integration of the policies are required to ensure that seagrass meadows are managed and safeguarded in a sustainable manner.

Threats to Seagrass Meadows

Disruptive human undertakings in the ecological sphere, such as pollution, fishing, and coastal development, have a dire impact on seagrass meadows. Urban sprawl and coastal infrastructure development are primary causes of habitat destruction and sedimentation. Additionally, seagrass beds may be smothered and, further, water quality may be degraded. Polluted coastal waters as a result of industrial waste, sewage, and agricultural runoff introduce detrimental nutrients and chemicals, producing algal blooms that prevent seagrass from accessing the sunlight needed for unimpeded growth. Furthermore, the destruction of bottom trawling stagnant meadows, seagrasses in a host of delicate ecosystems, is further unmitigated.

$$Seagrass\ Habitat\ Loss = Coastal\ Development + Sedimentation \quad (1)$$

This equation (1) shows the main causes of the degradation of seagrass habitat, concentrating on the effect of urbanization, coastal development, and the rise in sedimentation, which destroy or eliminate seagrass beds, therefore, lowering its total coverage and ability to perform correctly within the ecosystem.

Coastal development, similar to urbanization and community-based construction, results in habitat loss caused by either the removal of seagrass beds or damage to surrounding areas. Sedimentation due to construction can stunt seagrass meadows and hinder their ability to live and grow.

$$Total\ Impact\ on\ Seagrasses = Human\ Activities + Climate\ Change \quad (2)$$

The cumulative impacts of human activities and climate change on the seagrass ecosystems are highlighted in this equation (2). The seagrass meadows are made more vulnerable due to human-induced factors like pollution, overfishing, and coastal development, coupled with climate change effects like increased temperatures and acidification of the oceans, which make them less effective in providing ecosystem services.

Climate change, resulting from heightened greenhouse gas emissions, is causing increasing water temperatures and greater ocean acidification. Warmer water temperatures induce stress responses in seagrasses, contributing to reduced growth rates, negatively affecting their reproduction, and making them more prone to disease. Ocean acidification, a result of increased levels of atmospheric CO2, is inhibiting seagrasses from being able to produce calcium carbonate structures, an important building block for resisting the effects of stress.

Assessment of Ecosystem Services

Assessing the Worth of Ecosystem Services of Seagrass

The quantitative and qualitative techniques and methods to assess the

worth of ecosystem services of seagrass. One of these techniques is an economic valuation where, for example, in a given economic valuation service, carbon sequestration, coastal protection services, or water purification, for example, were expressed in monetary value by various methods - contingent valuation, market-based methods, and cost-benefit valuation. Other techniques are to use ecological models as a way of estimating the direct and indirect effects of the ecological service of seagrass meadows on water quality, biodiversity, and sediment stabilization. Biophysical assessments measure specific ecosystem functions, such as how much carbon was sequestered by seagrass meadows, or how seagrass filtration has lowered sediment levels or nutrients.

Examples of Seagrass Ecosystem Service Assessment Case Studies

Several case studies have examined successful assessments of seagrass ecosystem services. For example, in Florida Bay, the valuation of seagrass meadows for carbon sequestration and water filtration services has been assessed using economic and biophysical models.

Case studies demonstrate the evidence of the real-world significance of seagrass meadows in coastal ecosystems. In Florida Bay, economic calculations have revealed that the seagrass meadow carbon sequestration value is over $10 million per year. Likewise, nutrient and pollutant filtration has been discovered to save millions in municipal water management costs by eliminating the use of expensive water treatment plants. These case studies show the practical advantage of seagrass meadows and emphasize the need to protect them. The results have quantified the role of seagrasses in enhancing water quality and decreasing coastal area impacts of land-based pollution, directly supporting protection and conservation efforts.

Table 1: Assessment of seagrass ecosystem service evaluation methods.

Assessment Technique	Method Effectiveness (1-5)	Service Impact (1-5)	Case Study Success (1-5)
Economic Valuation	5	5	4
Ecological Models	4	4	5
Biophysical Assessments	4	4	3

Table 1 gives a critique of some of the methodologies developed for measuring ecosystem services of seagrass meadows. The Method Effectiveness column deals with the effectiveness of every assessment method and scores them between 1 and 5. Here, Economic Valuation and Remote Sensing and GIS scored five, and Biophysical Assessments received 4, as the assessment deals with some more specific aspects. The Service Impact column deals with evaluating the importance of the services under assessment, like the ones that sequester carbon and provide protection for vulnerable coastlines.

Conservation and Restoration Strategies

How to Preserve and Restore Seagrass Meadows

In an attempt to further reinforce conservation and restoration efforts,

novel methods in this direction are being adopted, including the adoption of sediment stabilizers and environmentally safe artificial constructions. These methods include the use of natural resources such as oyster shells and coral reefs to accelerate the sediment stabilization of areas that have seagrass meadows that have become too degraded to re-establish themselves naturally. Additionally, multi-stakeholder cooperation has also been successful, and local communities, government agencies, and environmental organizations have collaborated to put them into action. The presence of the local communities makes the practices more sustainable, but also makes the general population more aware of the significance of the seagrass ecosystems. There is a need for further conservation and restoration strategies, as well as sustainable management, to conserve and restore losses to seagrass meadows. The most common approach to this issue involves manifold strategies called Marine Protected Areas (MPAs), which limit anthropogenic activities such as fishing, coastal development, pollution, and much more. Within the protected, restricted areas, seagrass meadows are able to grow. Restoration approaches that transplant seagrass species into degraded areas or improve their state of growth are the next most common. Water quality improvement, sediment management, and nutrient pollution management can lead to enhanced growth conditions as well. There are additional methods that include sediment stabilizers; using forms of artificial construction to reduce wave and current force will stabilize the sediment in areas where seagrass cannot exist. Sustainable land use practices can also help decrease runoff from the construction effects of agriculture, to reduce pollution and sediment inputs that reach seagrass meadows directly. These restoration projects will only succeed when the local community, scientists, and policymakers work together, especially where the human impact on seagrass ecosystems is greatest.

Policy Recommendations and Global Initiatives

Synchronized policies and advanced global governance facilitate the protection and conservation of the world's seagrass meadows. In order to foster the conservation of seagrass meadows in an overall coastal management policy, governments should implement integrated coastal zone management (ICZM) methodologies that consider the ecological, economic, and social dimensions. Private sector financing mechanisms, such as acquiring carbon credits for the ecosystem services of seagrass meadows, can be leveraged to engage private sector interests in seagrass restoration. Support for global awareness and collaboration to conserve coastal and seagrass ecosystems is expressed through international initiatives administered through the United Nations Environment Program (UNEP) and the International Seagrass Conservation Network (ISCN). International agreements, such as the Convention on Biological Diversity (CBD), also share awareness and engage the demand for protecting seagrass ecosystems by calling for more robust national policy and international collaboration.

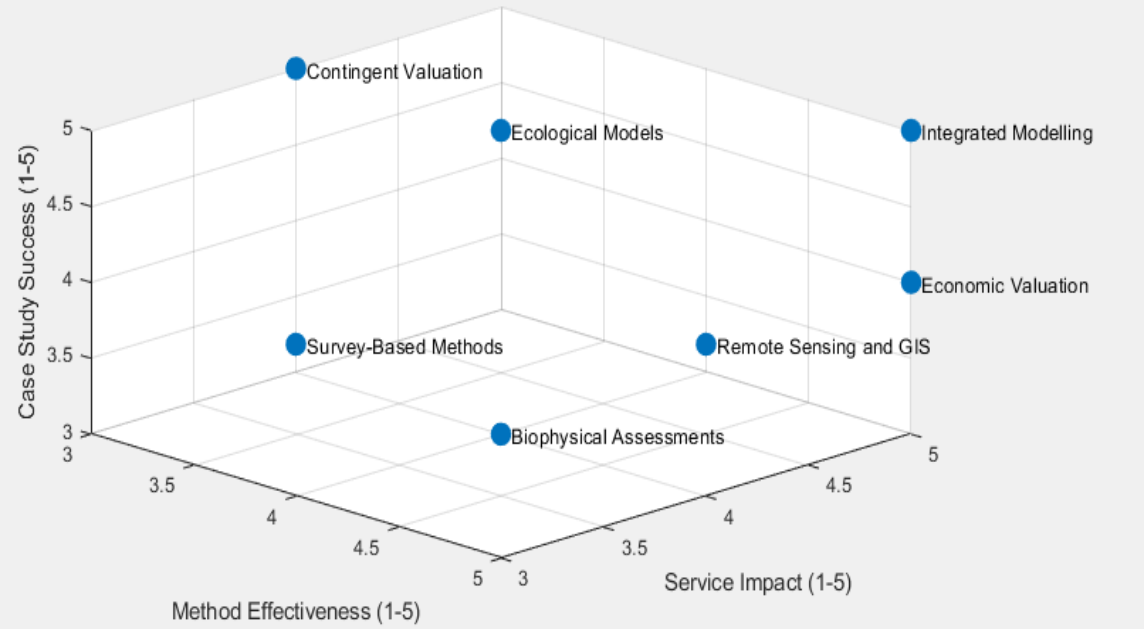

Figure 2: 3D assessment performance plot for seagrass ecosystem service evaluation methods.

Figure 2 performance for the Seagrass Ecosystem Services Evaluation Tool illustrates the position of the assessment methods on a scale from 1 to 5 on the Method Effectiveness, Service Impact, and Case Study Success axes. Method Effectiveness refers to the degree to which each of the methods was capable of quantifying ecosystem services; Service Impact refers to the significance of those services related to wellbeing for the marine and coastal ecosystem; Case Study Success refers to the degree of success of using the method in real-world contexts. Integrated Modelling in combination with Economic Valuation methods performed well at all axes, demonstrating high effectiveness and impact of the services, and, by contrast, Survey Methods yielded moderate impact. This image allows for the assessment of ecosystem services provided by seagrass, and, consequently, helps in the development of more effective conservation and management initiatives.

Conclusion

The seagrass meadows support the sustainability of marine and coastal ecosystems. The results of this study support the critical importance of seagrass meadows in the health of coastal ecosystems. As have demonstrated, seagrass meadows play an essential role in mitigating climate change by sequestration of more than 0.5 million tons of carbon each year, an important service. Also, seagrasses filter nutrients and pollutants in seawater and mitigate the eutrophication hazards along shorelines by 30 % to improve the water quality. But these critical ecosystems are still threatened by the very processes of coastal development, pollution, and climate change. The future of seagrass ecosystem services is to develop more accurate models to forecast the long-term effects of restoration projects and include seagrass ecosystem services in the national coastal management policy. Moreover, international cooperation in getting financial grants to restore the habitats, like the carbon credits of the

seagrass services, should be given priority so that these ecosystems survive to be used by the next generations. Meadows provide important ecosystem services by serving as a habitat for aquatic organisms as well as offering sequestration of carbon, enhancing water quality, and coastal defense. Meadows support a diversity of organisms, providing food and shelter for different elements of the marine food web. Meadows also enhance the mitigation of climate change as a result of carbon sequestration. Meadows enhance diy water quality as a result of pollutant and nutrient filtration. Meadows also advanced coastal defense by stabilizing sediments and dissipating wave energy. Meadows, however, have been subject to increasing human pressure and threats of climate change, such as coastal development, pollution, and climate change. Meadows have in result of this led to loss of biodiversity, poor water quality, and loss of ecosystem resilience. Meadows therefore require greater protective and restoration action, the creation of marine protected areas, the management of water quality, and the restoration of meadows through seagrass transplanting. Meadows require greater international collaboration to fund the protection of coastal communities and ecosystems. Conserving seagrass will also allow these ecosystems to function and provide their essential services to future generations.

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