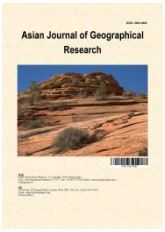

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Assessment of Seagrass Ecosystems' Goods and Services of India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Nearly every shallow coastal region on Earth is home to seagrass, a type of marine flowering plant. They grow down to depths where just 11% of surface light reaches the bottom after colonizing soft substrates like mud, sand, and cobbles. Seagrasses often choose wave-sheltered environments where sediments are shielded from waves and currents. The seagrass environment serves as a home to large animals like dugongs and marine mammals like ducks and geese. The seagrass serves as a feeding and refuge area for the related creatures for the entirety or a portion of their life cycles. Raw materials and food, medicine, fertilizer, coastal protection, erosion control, water purification, fisheries maintenance, nursery grounds, invertebrate habitats, carbon sequestration, tourism, recreation, support for education, and research are just a few of the goods and services provided by seagrass to the coastal community. The value of a seagrass ecosystem's products and services to human well-being can be measured, and this can be used to support the need for seagrass ecosystem preservation, transfer, and regeneration. Many valuation studies are conducted to estimate the various goods and services produced by the seagrass ecosystem. The total area of seagrass distribution in the coastal States and UTs of India is 51822 ha, distributed in

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4162 seagrass patches. Using meta-analysis and an average of Benefit Transfer (BT) method, the Total Economic Value (TEV) of seagrass has been estimated as Rs. 2594342/ha/yr. ($ 55,637/ha/yr.) with a maximum of Rs. 5948650 ha/yr. ($1,27,571/ha/yr.) and a minimum of 791448/ha/yr. ($ 16,973/ha/yr.). Subsequently, the total equivalent economic benefit from seagrass beds in India has been quantified at Rs.13444 crore/yr. ($ 2,88,31,22,453/yr.).

Keywords: Seagrass; coastal ecosystems; environment economics; goods and services; India.

1. INTRODUCTION

"Seagrass are marine flowering plants present along almost all the shallow coasts of our planet" [1]. "They colonize in soft substrates such as mud, sand, and cobble and grow to depths where 11% of surface light reaches to the bottom" [2]. "In general, seagrasses prefer wave-sheltered conditions where sediments have been protected from currents or waves" [3]. They normally co-exist with mangroves and coral reefs [4]. Since they are plants, they get primary energy from the sun and grow very fast either vertically or horizontally. They reproduce sexually and colonially. They are thus able to cover large extensions, in intertidal and sub-tidal areas [5]. "The structure of the seagrass stems and leaves are located above the ground and rhizomes and roots are located below the ground supporting numerous habitats for associated organisms. Seagrass has been considered as a foundation species, i.e. a species that provides habitat and enhances ecosystem biodiversity and is home to intrinsically valuable species such as the seahorse" [6]. "Large species such as turtles, ducks, geese, and marine mammals like dugongs use the seagrass ecosystem as a habitat. The associated organisms use the seagrass in their whole life cycles, or part of their life cycle as feeding and refuge ground. In general, seagrass has been considered as nursery grounds" [7]. Biomass production of seagrass was estimated at 1012gDW/day [8].

Seagrass ecosystems play a multi-functional role in human well-being. Seagrass resource usage by humans shall vary between regional and local levels [9]. "Seagrass goods and services to the coastal community include raw materials and food, medicine, fertilizer, coastal protection, erosion control, water purification, maintenance of fisheries, nursery grounds, habitats for invertebrates, carbon sequestration, and tourism, recreation, support for education, and research" [9,10,11,12,13].

"Despite being among the most productive ecosystems on the planet, seagrasses receive little attention when compared to other coastal ecosystems" [14]. "But, interactions between seagrass ecosystems and societal and economic systems are numerous and complex. Activities on and around the seagrass have put enormous pressure on the health and survival of this ecosystem and habitat. They are being lost at an alarming rate" [15,16]. Quantification of goods and services of a seagrass ecosystem to human well-being shall reveal and justify the conservation, protection, transplantation, and regeneration of seagrass ecosystems.

There are many valuation studies conducted to estimate the various goods and services produced by the seagrass ecosystem. The aggregate global flow value of seagrass services was estimated (2011 estimate) at $28,916 ha/yr. [17]. It has been estimated that the value of the services provided by seagrass ecosystems was estimated to be 15837 € ha^{-1}/yr, which is two orders of magnitude higher than the estimate obtained for croplands [10]. This present study estimated the goods and services of seagrasses in India and valued the seagrass patch goods and services using the benefits transfer (BT method). In addition, on-site valuation methods were used to elucidate the Total Economic Value (TEV) of the various patches of seagrasses in India. The study also estimated temporal changes in the seagrass ecosystem found the externalities of the seagrass production and recommended suitable decisions for sustainable management of seagrass ecosystems in India.

2. SEAGRASS BEDS IN INDIA

The total area of seagrass distribution in the coastal States and UTs of India is 51822 ha distributed across 4162 seagrass patches (List 1). The coastal States viz., Gujarat, Tamil Nadu, Odisha, and Union Territories of Lakshadweep, Andaman, and Nicobar Islands have seagrass distribution. Among the above coastal states and UTs, Ramanadhapuram coastal district area has 1363 seagrass patches covering an area of 22790ha which contributes to 48 % of total seagrass distributed areas of India. In the

List 1. Sea grass beds nearby – Indian Coastal Districts

Sl. No	State / Union Territory	Nearby coastal districts and islands	No of patches	Sea grass beds distribution - ha.
1.	**Gujarat**	DevbhumiDwarka coast	125	**1393.45**
2.		Jamnagar coast	27	**309**
		Sub Total	**152**	**1702.4**
3.	**Tamil Nadu**	Pudukkottai district coast	517	8102
4.		Ramanadhapuram district coast	1733	26595
5.		Thanjavur district coast	168	3932.54
6.		Tuticorin district coast	91	1250
		Sub Total	**2509**	**39880**
7.		Ganjam district coast	217	5516
8.	**Odisha**	Puri district coast	807	3191
		Sub Total	**1024**	**8708**
9.	**Lakshadweep**	Lakshadweep islands	8	71.66
		Sub Total	**8**	**72**
10.	**Andaman & Nicobar**	Andaman & Nicobar islands	469	1459.97
		Sub Total	**469**	**1460**
Total			**4162**	**51822**

seagrass patches, fifteen seagrass species have been recorded. These species fall under the following genera *Cymodocea sp., Enhalus sp., Halodule sp., Halophila sp., Portesia sp., Syringodium sp.* and *Thalassia sp.*. Benefits from seagrass in India include insulators in houses (hut), thatching of roofs, water quality maintenance, fishing grounds and tourism sites [18].

3. ACCOUNTING SEAGRASS BEDS ECOSYSTEM - GOODS AND SERVICES

In general, natural resource empirical values of an ecosystem for policy support in management are not readily available. In the absence of an original empirical resource valuation estimate, benefit transfer which means the use of an empirical value estimate or estimates from a previous study or studies for application in a similar context is being used [19]. It is called meta-analysis i.e., study of studies. Using meta-analysis, the seagrasses are found to provide all four ecosystem services viz., provisional, regulation, cultural, and supporting service.

Under the provisional service of the seagrasses, fishery including fin fish, mollusks, prawn, cattle fish, and echinoderms have been studied. The seagrasses are the raw materials for many demanding handicrafts. They are used to feed too many livestock and pet animals. The value of feed and raw materials has been studied under the provisional services by many resource economists. The seagrass functions as a nutrient filter around the aquaculture farms and reduces the nutrient content in the coastal waters. This aquaculture benefit has been estimated under provisional services in many studies. The seagrass supports the preparation of many cosmetics including soap, creams, and fragrance materials. Their value as a cosmetic function of seagrass has been studied in many researches. In addition, seagrass has been used as a composite fertilizer for manure agriculture farms. The value has been studied under provisional services.

Under the regulation services, many studies were conducted on coastal protection, nutrient cycling, waste water purification and carbon sequestration, and climate regulation. Under the cultural service, the seagrass ecosystem has been used as a research and knowledge support area and hence the research benefits of seagrass have been valued in many studies. In supporting the service of the seagrass ecosystem, services such as nursing grounds and secondary production services in the coastal areas have been studied. The global value of seagrass ecosystem benefit was studied in a few studies. Accordingly, the planets and seagrass ecosystem services are worth US$19,004 ha/yr. or US$3.8 trillion/yr. (1994 estimate), the above estimate was mainly

concentrated on nutrient cycling services of seagrasses [1,12].

The above estimate was revised in 1998 by [20] and the global benefit due to seagrass beds located in various patches was valued at US$28,000ha/yr. In the following sub-chapters, various seagrass ecosystem goods and services and their estimated value have been discussed. The values have been applied to Indian seagrass to estimate the sea grass value in various patches and the sea grass benefit to India.

3.1 Provisioning Services of Seagrass Beds

Provisioning Services are ecosystem services that describe the material or energy outputs from ecosystems. They include food, water building materials, and other resources [21]. Seagrasses provide many provisional services which have high economic importance [22,23]. The popular seagrass ecosystems' provisional goods and services are fishery, subsistence fisheries, cattle feeding material, roof insulation, stuffing of mattresses, medicinal uses, aquaculture uses, cosmetic uses, handicrafts, agriculture fertilizer, etc. There are several uses as roots of the seagrass *Enhalusacoroides sp.,* are used as food for local fishermen in the Solomon Islands and the leaf fibers have been used for making necklaces and to provide spiritual benefits such as a gift to a newborn child, for fishing luck, and to remove an aphrodisiac spell [24].

In Indonesia, seagrass is used for cattle feeding (cow, and sheep) [25]. Seagrasses are still harvested in Tanzania, Portugal, and Australia where they are used as fertilizer [10]. In the Chesapeake Bay, USA, seagrass is used to keep crabs moist during transport. In East Africa, some species are served as salad, while others are used in potions and rituals [11]. However, reliable estimates of many uses of the seagrass are not yet valued. Details of various popular provisional services and functions and their economic value estimations from various studies are given in the following chapters.

3.1.1 Fishery

The seagrass beds ecosystem is an important fishing ground for coastal communities. Seagrasses also generate value as a habitat for ecologically and economically important species such as scallops, shrimps, crabs, and juvenile fish. Seagrasses protect these fish species from predators and provide food in the form of leaves, detritus, and epiphytes. Fishes use the seagrass ecosystem for nursery ground, feeding, and permanent habitat [26,27]. All over the world, the seagrass ecosystem provides fish protein for human well-being [1]. Seagrass biomass/length is an important parameter for the abundance and species richness of the seagrass habitat [28].

It has been estimated that the seagrass meadows of the Mediterranean region provide a 4% direct contribution to total landings of commercial fisheries and 6% of recreational fisheries which arrive at to total approximate value of €78 million and €112 million/yr [29]. The fishery benefits are not only from fin fishes but also from molluscan and crustacean fisheries. In the Gulf waters of South Australia seagrass beds supported fisheries have been valued at US$114 million/yr [30]. A damage cost method was applied to quantify the seagrass benefits to fisheries in Southern Australia and it has been estimated that a loss of 2700 ha of seagrass beds results in lost fishery production of AU$235000 [30]. In another estimate, the loss of 12700 ha of seagrass in Australia was the reason for the loss of $212000 equivalent fishery production [31].

An economic benefit of seagrass in fishery production was estimated in many countries. Using fish harvest from the seagrass area, Hepu seagrass beds of China were estimated at US$939/ha/yr. and Lian seagrass beds of China was estimated at US$638 /ha/yr. Fish production service of the seagrass bed of Tam Giang-Cau Hai Lagoon, Vietnam was estimated at US$462/ha/yr. Fish production service of Thuy Trieu lagoon seagrass area, Vietnam was estimated at US$2500/ha/yr. Similarly, the fish production service of the Bai Bon seagrass area, Vietnam was estimated to be US$129/ha/yr. [32]. In a biomass study in the seagrass area of the Canary Islands, Espania the fishery biomass production was estimated at 310kg/ha/yr and its economic value was valued at €1,690/ha/yr. [33].

The total net benefits of harvesting fish from the seagrass ecosystem of Bohol Marine Triangle, Philippines was estimated at US$8-84/ha/yr [34]. In southern Australia, the landings of fish, shrimp, and crab were valued at US$1436/ha/yr [30]. In another study in Australia, fish landings due to seagrass bed area were estimated at $3500/ha/yr [31].

Seagrass meadows are an important habitat for crustaceans, especially the economically

important prawns and crabs. Crustacean production service of the Thuy Trieu lagoon seagrass area of Vietnam was estimated to be US$2400/ha/yr [32]. Prawn and crab production service of the seagrass meadow of Tam Giang-Cau Hai Lagoon, Vietnam was estimated at US$1140/ha/yr [32]. The market value of shrimp yield from seagrass beds in Western Australia was valued between $684 and $2511/ha/yr. The above value was very close to the estimate of Northern Queensland where the seagrass shrimps were valued at US$1500/ha/yr [35]. However, in a comparative literature survey conducted by [36]. The average value of shrimp production from seagrass meadows was found to be US$3,500/ha/yr.

It has been estimated that the total net benefits of harvesting mollusks from the seagrass ecosystem of Bohol Marine Triangle, the Philippines was US $12-120/ha/yr. [34]. However, the mollusk production service of the Thuy Trieu lagoon seagrass area, Vietnam, and Bai Bon seagrass area, Vietnam was estimated at US$3800/ha/yr., and US$111/ha/yr. respectively [32]. Based on the various fishery products captured in the seagrass the average benefits have been estimated at Rs. 64580/ha/yr. (2011) price.

3.1.2 Handicrafts from seagrass

Seagrasses have been used as a material (dead leaves) for packing, insulation, decomposing, etc., since prehistoric times all around the Mediterranean [37]. In the Netherlands, eelgrass leaves have been used for the stuffing of mattresses including for babies and chair seats. The handicrafts prepared from seagrass have significant value in the market. Handicrafts prepared and sold using seagrasses in Hepu and Lian seagrass beds, in China were estimated at US$462 ha/yr. and US$1086/ ha/yr. [32]. The average benefits of the handicraft services of seagrass has been estimated at Rs. 37433/ha/yr. (2011 price).

3.1.3 Feed and raw materials

Seagrass leaves have been used as soil amendment and to feed pigs, rabbits, and hens in several areas [10,38]. Seagrass has been used for roof insulation in isolated islands. They have also been used as cattle bedding. Feed and raw stuff service provided by the Hepu and Lian seagrass beds of China was estimated at US$550/ha/yr. [32]. The average economic benefit of seagrass used for feed and raw material in animal husbandry has been estimated for Rs. 26600/ha/yr (2011) price.

3.1.4 Aquaculture support

Seagrass absorbs and processes the nutrients and sediments discharged from the aquaculture farms and manages the biodiversity of the coastal region. Aquaculture benefits from Hepu and Lian seagrass of China were estimated at US$912ha/yr. and US$3393 /ha/yr. respectively [32]. The average economic benefit of supporting aquaculture activities has been estimated at Rs. 104101/ha/yr. (2011 price).

3.1.5 Cosmetics

Seagrass is being used in the cosmetic industry. The crude and purified fractions of seagrass (H. ovalis) have antibacterial activity against gram-positive and gram-negative human pathogens. The methanol extract of seagrass was found to be a promising candidate as an antioxidant and anti-inflammatory agent. Skin creams have been prepared from seagrass extracts. Extracted fragrance from seagrass has been used in the perfume industry. Cosmetic uses of the seagrass in Lian and Hepu seagrass beds; China were estimated at US$ 603/ha/yr. and US$832 /ha/yr. respectively [32]. The average economic benefit from seagrass used for cosmetic production equivalent benefit has been estimated at Rs. 34701/ha/yr. (2011 Price).

3.1.6 Fertilizer

Seagrass is a sustainable fertilizer available all over the world. Since common mineral fertilizers are increasingly costly and often induce water and air pollution. seagrass compost could be used as a sustainable fertilizer. It has been tested in the Mediterranean coastal areas, that the seagrass-based compost serves as a promising, sustainable fertilizer for tomato and lettuce [39]. It is being used in many places worldwide. Agricultural fertilizer service of the seagrass bed of Tam Giang-Cau Hai Lagoon seagrass area, Vietnam was estimated at US$20/ha/yr. [32]. The average equivalent economic benefit of seagrass used as fertilizer has been estimated at Rs.967/ha/yr. (2011 price).

3.2 Regulation Services of Seagrass Beds

Regulating services are the benefits obtained from the natural regulation of ecosystem

processes such as climate regulation, water regulation, soil erosion control, etc [21]. Seagrass ecosystems provide regulation functions such as coastal protection, nutrient recycling, water purification, carbon sequestration, etc. There are many studies supporting various regulation functions of seagrass. It has been reported that several species of seagrass produce antimicrobial compounds in the sediment and water and control microbial growth in the coastal water and sediment [40]. However, the economic value of such services and functions is not yet valued. In the following chapters, important seagrass services and their monetary value have been discussed.

3.2.1 Coastal protection

Coastal protection and erosion control are often listed as important ecosystem services provided by seagrasses [10,41,42]. Seagrass beds reduce wave intensity and current velocity by extracting momentum from the moving water [3,43,44]. Current momentum on seagrass beds is reduced by 2 to 10 times than the surrounding non-vegetated areas. Roots and rhizomes bind sediment and reduce re-suspension and these beach-casted debris are important for controlling onshore coastal erosion [45]. As rooted plants, seagrasses require a sufficient depth of sediment for proper development. Sediments anchor the seagrass against the effects of water surges and currents and provide the matrix for growth and nutrient supply. A study in Adelaide Australia recorded a positive relationship between a reduction in seabed elevation (or) increased erosion blow-outs with seagrass loss [46]. Thus seagrass protects the coastline properties from erosion, currents, and waves [42].

Coastal protection service of seagrass is highest in the intertidal areas than in deep waters [3]. Coastline protection service of Hepu and Lian seagrass bed of China was estimated at US$191/ha/yr. and US$201/ha/yr. respectively [32]. In Florida, USA, the disturbance regulation function of the seagrass ecosystem of Florida was estimated at $67400/ha/yr. [31]. In Mediterranean coastal areas, using avoided damage cost erosion prevention service of seagrass *Posidonia oceanic* was valued at €188/ha/yr. [47]. The average equivalent economic benefits of seagrass for coastal protection support have been estimated at Rs.742275/ha/yr. (2011 price).

3.2.2 Nutrient recycling

Seagrass beds improve the coastal water quality through two processes viz., (i) nutrient uptake (ii) suspended particle deposition. Seagrasses and their associated epiphytes remove the nutrients from the sediments and water column [48]. Once the plant is dead and decomposed, the nutrients incorporated into the tissue of seagrasses are released into the water column and buried in the sediment for a longer period [49]. The economic benefit of the nutrient cycling service is the highest of all other services provided by seagrasses. [12] valued the nutrient recycling service of seagrass of the world for US$3.8 trillion/yr. Nitrogen uptake service shares 46% of the total value of the ecosystem service provided [50].

[12] estimated the nutrient cycling benefit of seagrass beds at $19002/ha. However, it was revised in the year 2014 and estimated at US$26,200/ha [17]. Nitrogen accumulation service of seagrass by burying nutrients up to 25cm depth was valued at US$24,500/ha [51]. Using the avoidance cost method and replacement cost method, the nutrient regulation service of California state seagrass was estimated to be US$11,188 [52]. In Florida, the nutrient recycling function of the seagrass ecosystem was estimated at $20900/ha/yr. [31]. The average equivalent economic benefits of seagrass for nutrient recycling support have been estimated at Rs.966588/ha/yr. (2011 price).

3.2.3 Water purification

Seagrass drastically reduces the suspended sediment concentration and microalgae in the water [51]. Seagrass leaves obstruct the flow of water thereby depositing the sediment particles in the bottom hence improving the water transparency and water quality of the region [3,53]. The water purification service of seagrass is quite evident by comparing the water quality and transparency in the seagrass areas and non-vegetation areas [54].

Using the benefit transfer method, the wastewater treatment function of the seagrass meadows of *Posidoniaoceanica sp.,* in California seagrass ecosystem was estimated at € 60 /ha/yr. [46]. Purification of the coastal water service of Hepu and Lian seagrass beds of China was estimated to be 19002/ha/yr respectively [32]. In Abaco, the Bahamas, waste treatment service of the seagrass ecosystem calculated

using the global average was estimated to be $1,800/ha/yr. [55]. The average equivalent economic benefits of seagrass for water purification service have been estimated at Rs.334247/ha/yr. (2011 price).

3.2.4 Carbon sequestration and climate regulation

Seagrass is popular due to its high productivity capacity and its substantial ability to store carbon [13]. Seagrass removes carbon from the atmosphere either through the binding of organic material into the sediments or export into the deep waters off the continental shelf which supports climate regulation [56]. A global assessment of seagrass meadows as carbon sinks by [57], showed that seagrass meadows were important repositories of carbon produced not just from the seagrass but elsewhere (e.g. terrestrial and plankton), at a ratio of 50:50 also noted that a large proportion of seagrass can be exported to adjacent beaches or even the deep sea, the latter constituting a site of long-term storage.

Many scientific values are expressing the carbon sequestration capacity of seagrass. A global average estimate revealed that the carbon sequestration potential of seagrass is 138±38gC/m2/yr [58]. However, the carbon burial rate in the seagrasses of UK was estimated at 11,474 tC/UK/yr. which was valued at £59.58/ha/yr. [59]. and £106.96/ha/yr. [60]. Similarly, [61] estimated the climate mitigation capacity of seagrasses based on carbon fixation rates in seagrasses in the Isles of Scilly, UK, and valued at 77£/ha/yr. (or) 130US$/ha/yr. In Indonesia, seagrass carbon sequestration potentials were estimated for IDR 154,968/ha [13]. Using the benefit transfer method, the long-term carbon sequestration potential of the seagrass *Posidonia oceanic* in California was estimated to be € 7.7 and € 230 /ha/yr. [46]. The average equivalent economic benefits of seagrass for carbon sequestration and climate regulation have been estimated at Rs. 5194/ha/yr. (2011 price).

3.3 Cultural Services of Seagrass Beds

Cultural services are non-material benefits obtained from ecosystems such as recreation, education, spiritual, and aesthetic benefits, etc. [21]. Seagrass provides all the above cultural services. However, monetary valuations of seagrass cultural services are rare. In Florida, USA, the recreation benefits of the seagrass ecosystem were estimated at $564/ha/yr.,[31]. To estimate the seagrass ecosystem support on education, average annual funding to enhance knowledge on seagrass meadows of *Posidoniaoceanica* in California, USA was estimated at 0.33 €/ha/yr. [46]. Equivalent economic benefits of seagrass for recreation and education as a cultural service have been estimated at Rs.24632/ha/yr. (2011 price).

3.4 Supporting Service of Seagrass Beds

Supporting services are the processes necessary for the supply of all other services such as soil formation, biodiversity, ecology, etc. [21]. Seagrass provides many supporting services for marine and coastal ecology. They have been considered as foundation species, *i.e.* a species that provides habitat and enhances ecosystem biodiversity and it is a habitat of intrinsically valuable species such as seahorses [6]. Seagrasses fix carbon dioxide using the energy provided by light and transform it into organic carbon to sustain seagrass growth and biomass production. High rates of biomass production imply high rates of oxygen production, which is released to the surrounding waters [10]. Since seagrass beds contribute large portions of the primary production of coastal ecosystems [62], they attract many species and provide habitats for culturally important species. The three-dimensional structure of seagrasses creates hiding places to avoid predation. As a result, the abundance and diversity of the fauna and flora living in seagrass meadows are consistently higher than those of adjacent unvegetated areas. Seagrasses, therefore, increase habitat diversity and the biodiversity of the coastal zone [10].

The role of seagrass meadows as a nursery ground for many marine species, including those of commercial and recreational value, is well documented [26]. Seagrass is the main source of food for dugongs, manatees [63], and green sea turtles [64], and it is a critical habitat for thousands of other animals which has a great significance to the nonuse value of the seagrass ecosystem [65]. In addition, the seagrass ecosystem supports the productivity of nearby coastal ecosystems such as coral reefs and mangroves. It is the feeding habitat of predatory fish that move into seagrass meadows during high tide and at night to forage on crustaceans [66,67,68]. The fish and invertebrate standing stocks in the seagrass meadows of the northern area of Indonesia were estimated at US$97.5-41.4/ha [36].

3.4.1 Nursing ground service

Seagrass ecosystems provide a nursery habitat for fish stocks. Leaves and stems of seagrasses support numerous and abundant epiphytes which are fed by small epifaunal organisms, which, in turn, provide food to the small fishes foraging in the seagrass beds [10]. Nursing ground service of Hepu and Lian seagrass beds in China was estimated at US$8496/ha/yr. and US$1817/ha/yr. respectively [32]. The average equivalent economic benefits of seagrass nursing ground service have been estimated at Rs.249384/ha/yr (2011 price).

3.4.2 Secondary production

Seagrass habitat's contribution to total secondary production was estimated at $A 133.23/ha/yr. (£83/ha/yr.). This is equivalent to a contribution of $114 million (£71 million) per year in terms of secondary production in the gulf waters of South Australia [30]. The average equivalent economic benefits of seagrass by supporting secondary production have been estimated at Rs. 3640/ha/yr. (2011 price).

4. BENEFIT TRANSFER OF META-ANALYSIS OF SEAGRASS BEDS ECOSYSTEM

The average regulatory service contributes Rs. 2048304/yr./ha. ($43,882/ha/yr.) followed by provisional service Rs. 268382/yr./ha. ($5,750/ha/yr.), supportive service Rs. 253024/yr. /ha. (USD 5,421 /ha/yr.) and cultural service Rs. 24,632/yr/ha. ($528/ha/yr.) (Avg.). The aggregated economic value of India's seagrass beds ranges between Rs. 791448/ha/yr. ($16,973/ha/yr.) minimum and Rs. 5948650/ha/yr. ($127,443/ ha/yr.) maximum. In a meta-analysis, averages of various services have been used to value Total Economic Value/ha./year consequently, the average total economic benefit out of goods and services of seagrass beds is Rs.2594342/ha./yr. ($ 55,637/ ha/yr.). The minimum value is very close to the similar TEV study on seagrass beds conducted by a global meta-analysis estimate [17] $28,916/ha/yr., being standardized for 2011 Indian Rs. 1,27,571/ha/yr. Similarly, the meta-analysis value of seagrass beds estimated by [49] was 170,000 SEK/ha (equivalent to $20,700/ha). It's standardized for 2011 India Rs.8, 91,761. The equivalent economic benefit of India's seagrass beds' minimum value is Rs. 8966,07,32,759/yr. ($1,920,873,405/yr). Application of the maximum value estimated by this present study (NCSCM) for India seagrass beds amounts to Rs. 30826 crore/yr. ($6,604,099,894/yr.). The average value estimated from this study is value the of India's' seagrass beds for Rs. 13444 crore/yr. ($2,88,31,22,453/ yr).

Among the coastal States and UTs, Tamil Nadu has a huge area (39880ha.) of seagrass beds which share Rs. 103462358960/yr. ($2 billion/yr.) which is about 77% of the total seagrass beds benefit out of the National Green Account.

5. CONCLUSION

Quantification of goods and services of a seagrass ecosystem to human well-being shall reveal and justify the conservation, protection, transplantation, and regeneration of seagrass ecosystems. The findings of this study are also valuable for developing a comprehensive information management and decision-support system and more research is required to evaluate the range of ecosystem services provided by seagrass ecosystems as recommended by Honey Jane Mascariñas, and Julie B. Otadoy (67). This study attempted to review of literature focusing on seagrass ecosystem goods and services to identify knowledge gaps and improve our understanding of the use of these habitats as nature-based solutions to societal challenges including climate change as suggested by Amaral Camara Lima (68). Assigned values goods and services from the seagrass beds shall allow policymakers to quantitatively assess the economic benefits and threats to select suitable intervention measures for sustainable management and functioning of the coastal landscapes. The equivalent economic valuation shall support planning in coastal ecosystems, welfare, and infrastructure development in the coastal landscapes. This research study shall justify and decide how to allocate public spending on conservation, preservation, or restoration initiatives. It also attracts public participation and participatory management of coastal ecosystems since common property values have been established for seagrass management.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Green EP, Short FT. World atlas of seagrasses. Univ of California Press; 2003.
2. Duarte CM. Seagrass depth limits. Aquatic botany. 1991 Jan 1;40(4):363-77.
3. Larkum AW, Orth RJ, Duarte CM, Koch EW, Ackerman JD, Verduin J, Keulen MV. Fluid dynamics in seagrass ecology—from molecules to ecosystems. Seagrasses: Biology, Ecology and Conservation. 2006;193-225.
4. Ogden JC, Gladfelter EH. Coral reefs, seagrass beds, and mangroves: Their interaction in the coastal zones in the Caribbean. UNESCO reports in Marine Sciences. 1983;23.
5. Marba N, Duarte CM. Rhizome elongation and seagrass clonal growth. Marine Ecology Progress Series. 1998 Nov 26;174:269-80.
6. Curtis JM, Vincent AC. Distribution of sympatric seahorse species along a gradient of habitat complexity in a seagrass-dominated community. Marine Ecology Progress Series. 2005 Apr 28;291:81-91.
7. Chittaro PM, Usseglio P, Sale PF. Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environmental Biology of Fishes. 2005 Feb;72:175-87.
8. Duarte CM, Chiscano CL. Seagrass biomass and production: a reassessment. Aquatic Botany. 1999 Nov 1;65(1-4):159-74.
9. Maricela de la Torre-Castro M. Humans and seagrasses in East Africa: A social-ecological systems approach (Doctoral dissertation, Department of Systems Ecology, Stockholm University); 2006.
10. Hemminga MA, Duarte CM. Seagrass ecology. Cambridge University Press; 2000 Oct 19.
11. de la Torre-Castro M, Ronnback P. Links between humans and seagrasses - an example from tropical East Africa. Ocean & Coastal Management. 2004 Jan 1;47(7-8):361-87.
12. Costanza R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J, Raskin RG. The value of the world's ecosystem services and natural capital. Nature. 1997 May 15;387(6630):253-60.
13. Mintje Wawo, Adrianto L, Bengen DG, Wardiatno Y. Valuation of seagrass ecosystem services in Kotania Bay Marine Nature Tourism Park, Western Seram, Indonesia. Asian Journal of Scientific Research. 2014;7(4):591-600.
14. Duarte CM, Dennison WC, Orth RJ, Carruthers TJ. The charisma of coastal ecosystems: Addressing the imbalance. Estuaries and Coasts. 2008 Apr;31:233-8.
15. Orth RJ, Carruthers TJ, Dennison WC, Duarte CM, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT. A global crisis for seagrass ecosystems. Bioscience. 2006 Dec 1;56(12):987-96.
16. Waycott M, Duarte CM, Carruthers TJ, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck Jr KL, Hughes AR, Kendrick GA. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the national academy of sciences. 2009 Jul 28;106(30):12377-81.
17. Costanza R, De Groot R, Sutton P, Van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK. Changes in the global value of ecosystem services. Global

environmental change. 2014 May 1;26:152-8.
18. Asir Ramesh, Ramachandran S. Seaweeds and seagrass ecosystems. In: Chapter 5, Coastal Environment Management ed. Institute for Ocean Management, Anna University; 2005.
19. Boutwell JL, Westra JV. Benefit transfer: A review of methodologies and challenges. Resources. 2013 Oct 21;2(4):517-27.
20. Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG. The value of ecosystem services: Putting the issues in perspective. Ecological Economics. 1998 Apr 1;25(1):67-72.
21. Clifton J, Cullen-Unsworth LC, Unsworth RK. Valuing and evaluating marine ecosystem services: Putting the right price on marine environments?. Environment and Society. 2014 Sep 1;5(1):66-85.
22. Dorenbosch M, Grol MG, Christianen MJ, Nagelkerken I, Van Der Velde G. Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. Marine Ecology Progress Series. 2005 Nov 4;302:63-76.
23. Dahlgren CP, Kellison GT, Adams AJ, Gillanders BM, Kendall MS, Layman CA, Ley JA, Nagelkerken I, Serafy JE. Marine nurseries and effective juvenile habitats: Concepts and applications. Marine Ecology Progress Series. 2006 Apr 24;312:291-5.
24. Lauer M, Aswani S. Indigenous knowledge and long-term ecological change: Detection, interpretation, and responses to changing ecological conditions in Pacific Island communities. Environmental Management. 2010 May;45:985-97.
25. Dirhamsyah. An economic valuation of seagrass ecosystems in East Bintan, Riau Archipelago, Indonesia. Oseanologi dan Limnologi di Indonesia. 2007;33:257-270.
26. Jackson EL, Rowden AA, Attrill MJ, Bossey SJ, Jones MB. The importance of seagrass beds as a habitat for fishery species. Oceanography and Marine Biology. 2001 Jul 19;39:269-304.
27. Vizzini S, Sara G, Michener RH, Mazzola AJ. The role and contribution of the seagrass *Posidonia oceanica* (L.) Delile organic matter for secondary consumers as revealed by carbon and nitrogen stable isotope analysis. Acta Oecologica. 2002 Aug 1;23(4):277-285.
28. Neil Hutchinson, Jenkins GP, Brown A, Smith TM. Variation with depth in temperate seagrass-associated fish assemblages in southern Victoria, Australia. Estuaries and coasts. 2014 Jul;37(4):801-14.
29. Jackson EL, Rees SE, Wilding C, Attrill MJ. Use of a seagrass residency index to apportion commercial fishery landing values and recreation fisheries expenditure to seagrass habitat service. Conservation Biology. 2015 Jun;29(3):899-909.
30. McArthur LC, Boland JW. The economic contribution of seagrass to secondary production in South Australia. Ecological modelling. 2006 Jul 10;196(1-2):163-72.
31. Blair S, Adams C, Ankersen T, McGuire M, Kaplan D. Ecosystem services valuation for estuarine and coastal restoration in Florida; 2015.
32. UNEP. National reports on seagrass in the South China Sea; 2008.
33. Espino F, Tuya Cortés F, Haroun Tabraue RJ, Brito Hernández AM. Fishery economic value of *Cymodoceanodosa* (sebadales) seagrass meadows of Canary Islands: An approach. Vieraea: Folia Scientarum Biologicarum Canariensium. 2014;42:197-206.
34. Samonte-Tan GP, White AT, Tercero MA, Diviva J, Tabara E, Caballes C. Economic valuation of coastal and marine resources: Bohol Marine Triangle, Philippines. Coastal Management. 2007 Mar 16;35(2-3):319-38.
35. Watson RA, Coles RG, Long WL. Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. Marine and Freshwater Research. 1993;44(1): 211-9.
36. Unsworth RKF, Cullen LC. Recognising the necessity for Indo-Pacific seagrass conservation. Conservation Letters. 2010 Apr;3(2):63-73.
37. Boudouresque CF, Meinesz A. Decouverte de l'herbier de posidonie: Cahiers du Parc National de Port-Cros. 1982;4.
38. Bulthuis DA, Brand GW, Mobley MC. Suspended sediments and nutrients in water ebbing from seagrass-covered and denuded tidal mudflats in a southern Australian embayment. Aquatic Botany. 1984 Dec 1;20(3-4):257-66.
39. Grassi F, Mastrorilli M, Mininni C, Parente A, Santino A, Scarcella M, Santamaria P.

Posidonia residues can be used as organic mulch and soil amendment for lettuce and tomato production. Agronomy for Sustainable Development. 2015Apr;35: 679-89.
40. Yuvaraj N, Kanmani P, Satishkumar R, Paari A, Pattukumar V, Arul V. Seagrass as a potential source of natural antioxidant and anti-inflammatory agents. Pharmaceutical Biology. 2012 Apr 1;50(4): 458-67.
41. Short FT. World atlas of seagrasses. Univ of California Press; 2003.
42. Koch EW, Barbier EB, Silliman BR, Reed DJ, Perillo GM, Hacker SD, Granek EF, Primavera JH, Muthiga N, Polasky S, Halpern BS. Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. Frontiers in Ecology and the Environment. 2009 Feb;7(1):29-37.
43. Fonseca MS, Cahalan JA. A preliminary evaluation of wave attenuation by four species of seagrass. Estuarine, Coastal and Shelf Science. 1992 Dec 1;35(6):565-76.
44. Prager EJ, Halley RB. The influence of seagrass on shell layers and Florida Bay mudbanks. Journal of Coastal Research. 1999 Oct 1;1151-62.
45. Hemminga MA, Nieuwenhuize J. Seagrass wrack-induced dune formation on a tropical coast (Banc d'Arguin, Mauritania). Estuarine, Coastal and Shelf Science. 1990 Oct 1;31(4):499-502.
46. Tucker R, Parker J, Barnett L, Cole R, Cox S, Davis J, Deans J, Detman S, Eaton A, Fotheringham D, Hutchens C. Adelaide's Living Beaches: A Strategy for; 2005–2025.
47. Campagne CS, Salles JM, Boissery P, Deter J. The seagrass *Posidonia oceanica*: Ecosystem services identification and economic evaluation of goods and benefits. Marine Pollution Bulletin. 2015 Aug 15;97(1-2):391-400.
48. Thomas FIM, Cornelisen CD, Zande JM. Effects of water velocity and canopy morphology on ammonium uptake by seagrass communities. Ecology. 2000 Oct;81(10):2704-13.
49. Romero J, Lee KS, Perez M, Mateo MA, Alcoverro T. Nutrient dynamics in seagrass ecosystems. Seagrasses: Biology, Ecology and Conservation. 2006;227-54.
50. Cole SG, Moksnes PO. Valuing multiple eelgrass ecosystem services in Sweden: Fish production and uptake of carbon and nitrogen. Frontiers in Marine Science. 2016 Jan 13;2:121.
51. Raheem N, Lopez RD, Talberth J. The economic value of coastal ecosystems in California. Washington, DC, USA: US Environmental Protection Agency, Office of Research and Development; 2009.
52. Gacia E, Granata TC, Duarte CM. An approach to measurement of particle flux and sediment retention within seagrass (*Posidonia oceanica*) meadows. Aquatic Botany. 1999 Nov 1;65(1-4):255-68.
53. Lee KS, Dunton KH. Inorganic nitrogen acquisition in the seagrass *Thalassia testudinum*: Development of a whole-plant nitrogen budget. Limnology and Oceanography. 1999 Jul;44(5):1204-15.
54. Rybicki NB, Jenter HL, Carter V, Baltzer RA, Turtora M. Observations of tidal flux between a submersed aquatic plant stand and the adjacent channel in the Potomac River near Washington, DC. Limnology and Oceanography. 1997 Mar;42(2):307-17.
55. Clavelle T, Jylkka Z. Ecosystem service valuation of proposed protected areas in Abaco, Sustainable Fisheries Group, University of California The Bahamas. 2013;1-48.
56. Short FT, Carruthers T, Dennison W, Waycott M. Global seagrass distribution and diversity: A bioregional model. Journal of Experimental Marine Biology and Ecology. 2007 Nov 9;350(1-2):3-20.
57. Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marbà N, Middelburg JJ. Seagrass sediments as a global carbon sink: Isotopic constraints. Global Biogeochemical Cycles. 2010 Dec;24(4).
58. Mcleod E, Chmura GL, Bouillon S, Salm R, Björk M, Duarte CM, Lovelock CE, Schlesinger WH, Silliman BR. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment. 2011 Dec;9(10):552-60.
59. Price R, Thornton S, Nelson S. The social cost of carbon and the shadow price of carbon: What they are, and how to use them in economic appraisal in the UK.
60. DECC A. Brief guide to the carbon valuation methodology for UK policy appraisal. DECC, London; 2011.

61. Mangi SC, Davis CE, Payne LA, Austen MC, Simmonds D, Beaumont NJ, Smyth T. Valuing the regulatory services provided by marine ecosystems. Environmetrics. 2011 Aug;22(5):686-98.
62. Thayer GW, Bjorndal KA, Ogden JC, Williams SL, Zieman JC. Role of larger herbvores in seagrass communities. Estuaries. 1984 Dec;7:351-76.
63. Lefebvre LW, Reid JP, Kenworthy WJ, Powell JA. Characterizing manatee habitat use and seagrass grazing in Florida and Puerto Rico: Implications for conservation and management. Pacific Conservation Biology. 1999;5(4):289-98.
64. Lal A, Arthur R, Marbà N, Lill AW, Alcoverro T. Implications of conserving an ecosystem modifier: Increasing green turtle (*Chelonia mydas*) densities substantially alters seagrass meadows. Biological Conservation. 2010 Nov 1;143(11):2730-8.
65. Teske PR, Beheregaray LB. Evolution of seahorses' upright posture was linked to Oligocene expansion of seagrass habitats. Biology Letters. 2009 Aug 23;5(4):521-3.
66. Unsworth RKF, De León PS, Garrard SL, Jompa J, Smith DJ, Bell JJ. High connectivity of Indo-Pacific seagrass fish assemblages with mangrove and coral reef habitats. Marine Ecology Progress Series. 2008 Jan 17;353:213-24.
67. Honey Jane C. Mascariñas, and Julie B. Otadoy. The findings of this study are valuable for developing a comprehensive information management and decision-support system for the management and protection of the seagrass ecosystem. However, more research is required to evaluate the range of ecosystem services provided by seagrass ecosystems. Biodiversitas. 2023; 24(8):4448-4456.
68. Amaral Camara Lima M, Bergamo TF, Ward RD et al. A review of seagrass ecosystem services: Providing nature-based solutions for a changing world. Hydrobiologia. 2023;850: 2655–2670.
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