

Policy Article

Assessment of Seagrass Ecosystems' Goods and Services of India

Abstract

Seagrass are marine flowering plants present along almost all the shallow coastal landscapes of our planet. They colonize in soft substrates such as mud, sand, and cobble and grow to depths where 11% of surface light reaches the bottom. In general, seagrasses prefer wave-sheltered conditions where sediments have been protected from currents or waves. The structure of the seagrass stems and leaves located above the ground and rhizomes and roots located below the ground support numerous habitats for associated organisms. Seagrass has been considered as a foundation species. Large species such as turtles, ducks, geese, and marine mammals like dugongs use the seagrass ecosystem as habitat. The associated organisms use the seagrass in their whole life cycles, or part of their life cycle as feeding and refuge ground.

Seagrass ecosystems play a multi-functional role in human well-being. Seagrass resource usage by humans shall vary between regional and local levels. 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. 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.

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 total area of seagrass distribution in the coastal States and UTs of India is 51822 ha which is distributed in 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. with a maximum of Rs. 5948650 ha/yr. and a minimum of 791448/ha/yr. Regulatory service of seagrass meadows contributes Rs. 2048304/yr. /ha. (Avg.) followed by provisional service (Avg. Rs. 268382/yr/ha., supportive service (Avg. Rs. 253024/yr. /ha. and cultural service Rs. 24632/yr./ha. (Avg). The total economic benefit from seagrass beds has been quantified as Rs.13444 crore.

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 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 benefit 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 recommends suitable decisions for sustainable management of seagrass ecosystems of India.

2 SEAGRASS BEDS IN INDIA

Total area of seagrass distribution in the coastal States and UTs of India is 47189 ha distributed across 3699 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 sea grass patches, fifteen sea grass species have been recorded. These species fall under the following genus; *Cymodocea*, *Enhalus*, *Halodule*, *Halophila*, *Portesia*, *Syringodium* and *Thalassia*. Benefits from sea grass in India include; insulators in houses (hut), thatching of roofs, water quality maintenance, fishing ground and tourism site [18].

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	26595.28
5.		Thanjavur district coast	168	3932.54
6.		Tuticorin district coast	91	1250
Sub Total			2509	39880
7.	Odisha	Ganjam district coast	217	5516
8.		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

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.

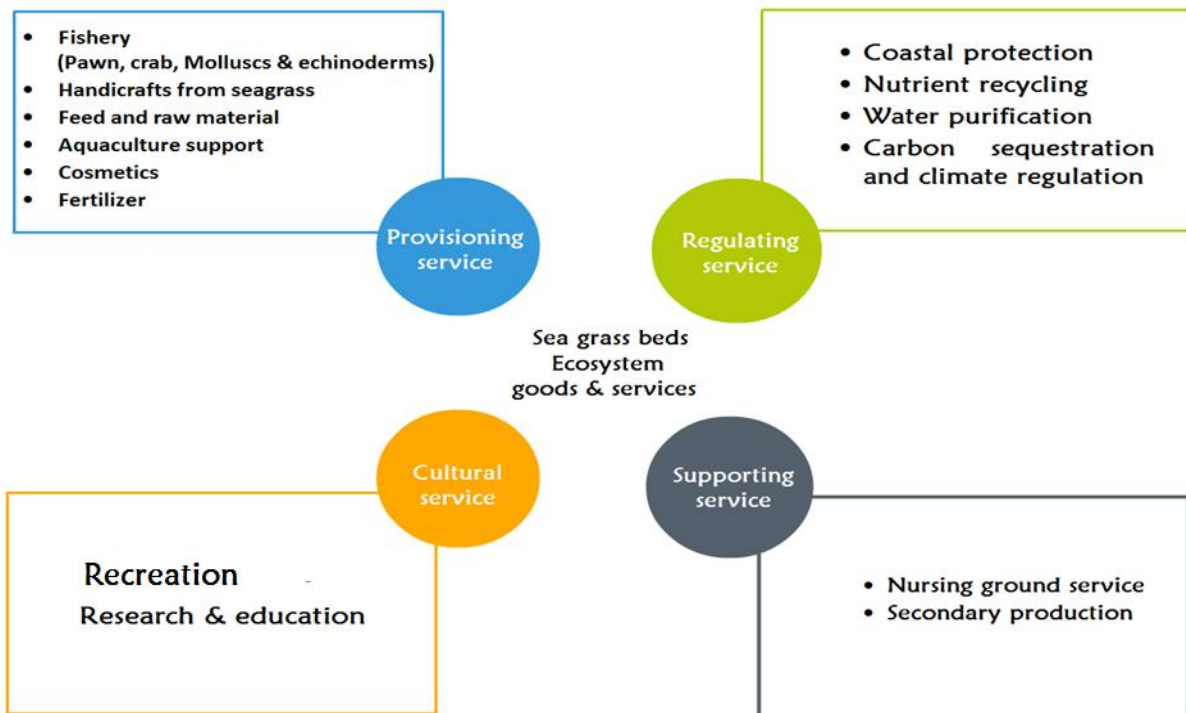


Figure 1. Sea grass beds ecosystem

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 many 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. All over the world, there are many valuation studies conducted for the above provisional services from the seagrasses. The uses of seagrass beds ecosystem services differ from region to region. There are several uses such as roots of the seagrass *Enhalusacoroides* 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 sea grass 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].

The seagrass ecosystem provides enormous fishery-related benefits to the region. 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 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.

Mollusks and echinoderms use seagrass as a habitat in their lifetime. 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]. Various fishery-related estimates in the seagrass ecosystem have been described in Table 1.a below.

Table 1a. Various fishery-related estimates in the seagrass ecosystem

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price / ha
I Provisioning Services						
Table 1.a. Fishery						
1.	[29]	Seagrass residency index	78 million €	15.53	722	64580/ ha (Over all fisheries)
2.	[29]	Seagrass residency index	112 million €	22.30	1036	
3.	[30]	Lost productivity	52.9 million \$	59.91	2783	
4.	[30]	Lost productivity	32.6 million \$	36.93	1716	
5.	[30]	Lost productivity	28.5 million \$	32.29	1500	

6.	[30]	Damage cost	235000 \$	94.80	4404	
7.	[31]	Seagrass residency index	212000 \$	15.68	729	
8.	[32]	Market price	939 \$	97746	45413	
9.	[32]	Market price	638 \$	664.13	30856	
10.	[32]	Market price	462\$	480.92	22344	
11.	[32]	Market price	2500\$	2602.40	120908	
12.	[32]	Market price	129\$	134.28	6239	
13.	[33]	Market price	1690€	2784.62	129374	
14.	[34]	Net benefit	8\$	8.49	395	
15.	[34]	Net benefit	84\$	89.16	4142	
16.	[30]	Damage cost avoided	1436\$	1564.69	72696	
17.	[31]	Market price	3500\$	3287.23	152725	
18.	[32]	Market price	2400\$	2498.30	116071	(prawn, crab)
19.	[32]	CVM	1140\$	1186.69	55134	
20.	[35]	Market price	684 \$	978.09	45442	
21.	[35]	Market price	2511 \$	3590.60	166819	
22.	[36]	Benefit transfer	3500 \$	3572.27	165968	
23.	[34]	Net benefit	12 \$	12.74	592	(mollusks)
24.	[34]	Net benefit	120 \$	127.36	5917	
25.	[32]	Market price	3800 \$	3955.64	183779	
26.	[32]	Market price	111 \$	115.55	5369	

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 Hupu and Lian seagrass beds, in China were estimated at US\$462 ha/yr. and US\$1086/ ha/yr. [32]. The equivalent economic benefit studies conducted have been described in Table 1.b below;

Table 1b. equivalent economic benefit studies

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price/ha
I Provisioning Services						
Table 1.b. Handicrafts						
1.	[32]	Market price	462 \$	480.92	22344	37433
2.	[32]	Market price	1086 \$	1130.48	52522	

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 Hupu and Lian seagrass beds of China was estimated at US\$550/ha/yr. [32]. Economic estimates of the seagrass as feed and raw materials have been given in Table 1.c below;

Table 1c. Economic estimates of the seagrass as feed and raw materials

Sl. No	Value Estimation Study & year	Methods	Value estimate	US \$ 2011 price/ ha	₹ 2011 price/ ha	Avg value ₹ 2011 price/ha
I Provisioning Services						
Table 1.c. Feed and raw material						
1.	[32]	Benefit transfer	550 \$	572.53	26600	26600

3.1.4 Aquaculture support

Seagrass absorb and process the nutrients and sediments discharged from the aquaculture farms and manage the biodiversity of the coastal region. Aquaculture benefits from Hupu and Lian seagrass of China was estimated at US\$912ha/yr. and US\$3393 /ha/yr. respectively

[32]. Equivalent economic benefits of seagrass to the aquaculture support have been given in Table 1.d below;

Table 1d. Equivalent economic benefits of seagrass to the aquaculture

Sl. No	Value Estimation Study & year	Methods	Value estimate	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price/ha
I Provisioning Services						
Table 1.d. Aquaculture						
1.	[32]	Market price	912 \$	949.35	44107	104101
2.	[32]	Market price	3393 \$	3531.97	164095	

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 Hepuseagrass beds; China were estimated at US\$ 603/ha/yr. and US\$832 /ha/yr. respectively [32]. Equivalent economic benefits of seagrass to cosmetic production have been given in Table 1.e below;

Table 1e. Equivalent economic benefits of seagrass to cosmetic production

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price/ha
I Provisioning Services						
Table 1.e. Cosmetics						
1.	[32]	Market price	\$ 603	627.70	29163	34701
2.	[32]	Market price	\$ 832	866.08	40238	

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]. Equivalent economic benefits of seagrass as fertilizer production have been given in Table 1.f below;

Equivalent economic benefits of seagrass as fertilizer production

Sl. No	Value Estimation	Methods	Value estimated /	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
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	Study & year		yr.			
I Provisioning Services						
Table 1.f. Agriculture fertilizer						
1.	[32]	CVM	20 \$	20.82	967	967

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]. Equivalent economic benefits of seagrass for coastal protection support have been given in Table 2. below;

Table 2a. Equivalent economic benefits of seagrass for coastal protection

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
II Regulating Services						
Table 2.a. Coastal protection						
1.	[32]	Index based	191 \$	198.82	9237	742275

2.	[32]	Index based	201\$	209.23	9721
3.	[31]	Damage cost avoided	67400 \$	63302.62	2941040
4.	[47]	Damage cost avoided	188€	195.95	9104

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]. Equivalent economic benefits of seagrass for nutrient recycling support have been given in Table 2.b below;

Table 2b. Equivalent economic benefits of seagrass for nutrient recycling support

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
II Regulation Services						
Table 2.b. Nutrient recycling						
1.	[12]	CVM	19002 \$	25164	1169133	966588
2.	[17]	CVM	26200 \$	24872	1155544	
3.	[51]	CVM	24500 \$	22712	1055192	
4.	[52]	Avoided cost & replacement cost	11188 \$	11646	541085	
5.	[31]	replacement cost	20900 \$	19629	911984	

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 benefit transfer method, the wastewater treatment function of the seagrass meadows of *Posidoniaoceanica* 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]. Equivalent economic benefits of seagrass for water purification service have been given in Table 2.c below;

Table 2c Equivalent economic benefits of seagrass for water purification service

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price/ha
IIRegulation Services						
Table 2.c. Water purification						
1.	[46]	Substitute for production expenditure	60€	66.58	3093	334247
2.	[32]	Index based	19002 \$	19780	918993	
3.	[55]	Benefit transfer	1800 \$	1736	80655	

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 50:50also 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, long-term carbon sequestration potential of the seagrass *Posidonia oceanic* in California was estimated to be € 7.7 and € 230 /ha/yr. [46].Equivalent economic benefits of seagrass for carbon sequestration and climate regulation have been given in Table 2.d below;

Table 2d Equivalent economic benefits of seagrass for carbon sequestration and climate regulation

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
II Regulation Services						
Table 2.d. Carbon sequestration and Climate regulation						
1.	[59]	CVM	59.58 £	117.33	5451	5194
2.	[60]	CVM	106.96 £	171.58	7972	
3.	[61]	Meta-analysis	77 £	123.52	5739	
4.	[13]	Replacement cost	154968 IDR	10.64	494	
5.	[46]	Damage cost avoided	7.7 €	8.02	373	
6.	[46]	Damage cost avoided	230 €	239.69	11136	

3.3 Cultural services of seagrass beds

Cultural services are non-material benefits obtained from ecosystems such as recreation, education, spiritual, aesthetic benefits etc. [21]. Seagrass provide all the above cultural services. However, monetary valuations of seagrass cultural services are rare. In Florida, USA, recreation benefits of seagrass ecosystem was 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 for 0.33 €/ha/yr. [46].Equivalent economic benefits of seagrass for recreation and education as cultural service have been given in Table 3.below;

Table 3. Equivalent economic benefits of seagrass for recreation and education

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
cultural Services						
Table 3. Recreational benefits						
1.	[31]	Travel cost	564 \$	529.71	24610	24610
III 2. Education						
1.	[46]	Market price	0.33€	0.47	22	22

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 and manatees [63], and green sea turtles [64], and it is a critical habitat for thousands of other animals which has a great significance to nonuse value of 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]. 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]. Equivalent economic benefits of seagrass nursing ground service have been given in Table 4.a below;

Table 4a Equivalent economic benefits of seagrass nursing ground service

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price/ha	₹ 2011 price/ha	Avg value ₹ 2011 price/ha
IV Supportive service						
Table 4.a. Nursing ground service						
1.	[32]	Index based	8496 \$	8843.99	410892	249384
2.	[32]	Index based	1817 \$	1891.42	87875	

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 \$A 114 million (£71 million) per year in terms of secondary production in the gulf waters of South Australia [30]. Equivalent economic benefits of seagrass by supporting secondary production have been given in Table 4.b. below;

Table 4b Equivalent economic benefits of seagrass by supporting secondary production

Sl. No	Value Estimation Study & year	Methods	Value estimated / yr.	US \$ 2011 price / ha	₹ 2011 price / ha	Avg value ₹ 2011 price/ha
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IV Supportive service						
Table 4.b. Secondary production						
1.	[30]	Lost production cost	133.23 \$	93.26	4333	3640
2.	[36]	Market price	41.4 \$	42.25	1963	
3.	[36]	Market price	97.5 \$	99.51	4623	

4 BENEFIT TRANSFER OF META-ANALYSIS OF SEAGRASS BEDS ECOSYSTEM

Accordingly, the regulatory service contributes Rs. 2048304/yr. /ha.(Avg.) followed by provisional service (Avg. Rs. 268382/yr. /ha. supportive service (Avg. Rs. 253024/yr. /ha. and cultural service Rs. 24,632/yr/ha.(Avg.), Chart Fig 2, describes various service contributions in economic values of seagrass services

Total Economic value of Seagrass beds

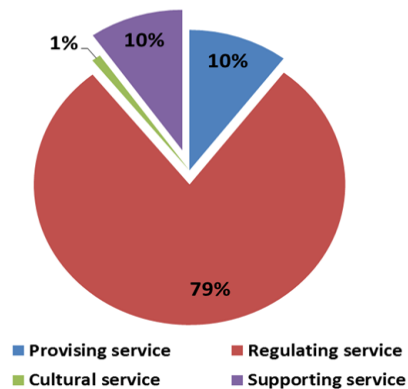


Fig 2. Economic value of seagrass beds

The aggregated economic value of India's seagrass beds ranges between Rs. 791448/ha/yr. (minimum) and Rs. 5948650/ha/yr. (maximum). In a meta-analysis, averages of various services have been used to value total economic value per ha./year consequently, the average total economic benefit out of goods and services of seagrass beds is Rs.2594342/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. 12,75,285. Similarly, the meta-analysis value of seagrass beds estimated by [49] was 170,000 SEK/ha (equivalent to US\$20,700U/ha). It's standardized for 2011 Indian Rs.8, 91,761. India's seagrass beds minimum value is Rs. 8966,0732759 (8966 crores)/yr. Application of the maximum value estimated by this present study (NCSCM) for India seagrass beds amounts to Rs. 30826 crore/yr. The average value estimated from this study is value the of India's seagrass beds for Rs. 13444 crore/yr.

Among the coastal States and UTs, Tamil Nadu has a huge area (39880ha.) of seagrass beds which share Rs. 103462371878/yr. which is about 77% of the total seagrass beds benefit out of the National Green Account. State / UTs Seagrass beds economic share in the National Green Account is given in Table 5

Table 5 Total economic value of Seagrassbed services

Rs. / Yr.			
S. No	State / Union Territories	Seagrass beds distribution - ha	TEV of Seagrass beds

1.	Gujarat	1702	4416753314
2.	Tamil Nadu	39880	103462371878
3.	Odisha	8708	22590263847
4.	Lakshadweep UT	72	185899592
5.	Andaman & Nicobar Island	1460	3787666639
Total		51822	134442955272 (13444 crore)

5 CONCLUSION

Seagrass are marine flowering plants present along almost all the shallow coasts of our planet. Seagrass ecosystems play a multi-functional role in human well-being. Seagrass resource usage by humans shall vary between regional and local levels. Seagrass goods and services to the coastal community includes 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. Interactions between seagrass ecosystems and societal and economic systems are numerous and complex.

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. Many valuation studies are conducted to estimate the various goods and services produced by the seagrass ecosystem. Using meta-analysis and the average of Benefit Transfer (BT) method, the Total Economic Value (TEV) of seagrass has been estimated as Rs. 2594342/- ha/yr. The total economic benefit from seagrass beds has been quantified as Rs.13444 crore. Economic valuation of various benefits of seagrass is a useful tool to support conservation and the decisions of mangrove ecosystem management and governance.

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