Ecosystem Assessment for Sustainable Management : A Case Study of Coringa Mangroves, Andhra Pradesh, India

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Abstract

Coastal ecosystems contribute to the economy by providing various goods and services. Ignorance about the economic importance of these goods and services leads to overexploitation and depletion of ecosystems in the long run, thereby affecting sustainability. This study attempted to estimate the economic value of goods and services of Coringa mangroves, Andhra Pradesh, by adopting the System of Environmental Economic Accounting – Experimental Ecosystem Accounting framework. The framework guides to assess the extent and condition of ecosystem assets and estimates the ecosystem service flows in physical and monetary terms for better decision making on sustainable management. The goods and services identified in Coringa mangroves were classified as provisioning, regulatory, and cultural services as specified in the framework. The study found that Coringa mangroves produce 11 goods and services with a total economic value of ₹ 549.6 crores per year. A meta-analysis study was conducted to compare the benefits of Coringa mangroves with other mangrove sites of the world. The study revealed that honey and medicinal benefits, with an estimated worth of ₹ 1.92 crores per year, have remained unutilized in Coringa. To exploit the unutilized potentials of Coringa mangroves in a sustainable way, this study recommends capacity-building activities that will help link the environment with economics and seed investments.

Keywords : economic valuation, Mangrove ecosystem, livelihood, SEEA, blue economy

JEL Classification Codes : E01, Q51, Q56, Q57

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Coastal ecosystems comprise stock and flow of resources that are beneficial for human wellbeing. Ecosystems are a dynamic complex of plant, animal, and micro-organism communities and their

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non-living environment interacting as a functional unit. Coastal areas, where the land and the sea interact, have many ecosystems, including mangroves. Mangroves are a group of trees and shrubs that are distributed in intertidal zones of low-energy coasts of tropical and subtropical areas (approximately between 30°N and 30°S). Mangroves have also been called tidal forest, swamp, wetland, and mangal (Food and Agriculture Organization, 2007; Spalding et al., 2010). Mangroves facilitate ample goods and services, which have been extensively used and demanded by coastal communities, especially for their livelihoods. Important goods and services of mangroves of the globe are wood, non-wood forest products, medicines, tannins, apiculture, wildlife resources, fishery, recreation, ecotourism, bio-filtration, nursery grounds, coastal protection, and carbon sequestration. The small-scale dry fish industry is another important economic activity of the mangroves, and millions of poor fishermen are engaged in this for their livelihood (Giri & Biswas, 2018). The shells also provide livelihood support to the local community through the creation of employment and income (Paul & Jana, 2014). Mangroves are bio-shields that protect the life and livelihood of coastal communities from disasters like tsunamis, cyclones, and erosion (Cabahug, 2002). These areas are important tourism destinations in coastal areas, and tourism contributes to the GDP (gross domestic product) (Murthy, 2014). Mangrove ecosystems provide direct and indirect input for production, consumption, accumulation, imports, and exports that reinforce the nation's economy.

Economic utilization of the stock and flow of the goods and services of mangrove ecosystems has been increasing rapidly. The importance of the goods and services of mangroves is often either ignored or overlooked because of a lack of information about their potential economic gain (Ong & Gong, 2013). Overexploitation of ecosystem resources influences the capacity for continuous production and function of mangroves. Ignorance towards the conservation of the assets of mangroves is the main reason for ecosystem degradation and destruction (McLeod & Salm, 2006). Quantification of ecosystem goods and services that contribute to welfare economics shall motivate public participation in their conservation and sustainable management. Initiatives on the economic valuation of mangroves are a crucial instrument for conservation and selection of suitable decisions for mangrove ecosystem management and governance (Laurans et al., 2013). Although the need for understanding the economic values of ecosystem services is well understood in the literature, such studies are limited in the Indian context. The available ecosystem valuation studies have estimated either a single service for a large area or multiple services in a small, confined area. However, large-scale policy decisions require multi-disciplinary large-scale values to implement uniform general policy at national and regional levels.

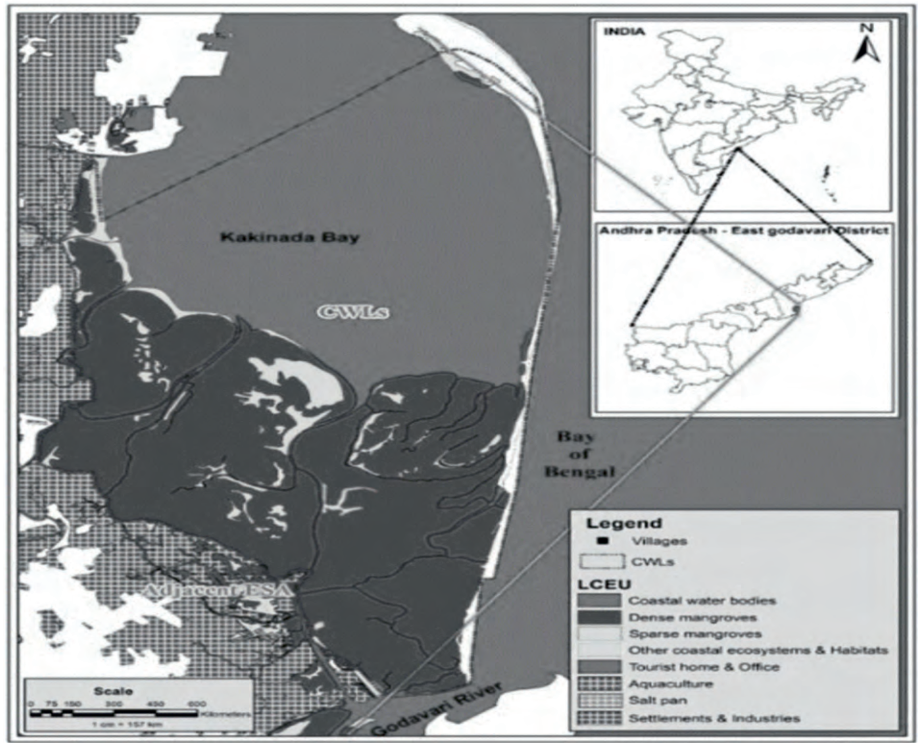
Methodology

Study Area

Total mangrove cover in coastal areas of India is about 559,097 hectares (National Centre for Sustainable Coastal Management, 2017). These mangroves are randomly distributed in 43,135 patches in all coastal states and union territories (National Centre for Sustainable Coastal Management, 2017). Coringa is the second largest mangrove area (12,556 hectares), with 214 patches located in the East Godavari District of Andhra Pradesh. At Coringa, the river Godavari merges with the Bay of Bengal with its distributaries, namely, Matlapalem, Coringa, Gaderu, and Pillarava creeks. The creeks discharge water and sediment to the mangrove ecosystem and are influenced by the tidal inundations of the sea up to 25.7 km. The mangrove forests of the Godavari delta extend over 321.2 km^2, out of which 235.70 km^2 was already declared as Reserve Forests (RF). In 1998, Corangi, Corangi Extension, and Bhairavapalem, distributed in Tallarevu and Polavaram Mandals, were designated as Coringa Wildlife Sanctuary (CWLS) under the management of Wildlife Management Division, Rajahmundry. This valuation study was conducted in the CWLS area and its adjacent Ecologically Sensitive Areas (ESAs).

In the CWLS area, fishing and navigational rights have been permitted to the general public. The mangrove

Figure 1. ***Location Map of CWLS and Adjacent ESA***



ecosystem covers 11,476 hectares (48.9%) of the land of the CWLS. Although dominated by mangroves, other coastal ecosystems and habitats such as mudflats and turtle nesting ground were found in 578.60 hectares and 16.08 hectares, respectively, in the CWLS. A Coastal Regulation Zone (CRZ) notification (Department of Environment, Forests, and Wildlife, 2011) has classified the ESAs buffering around the CWLS, covering 7,377 hectares.

Functional units of the ecosystem such as biodiversity and abiotic factors have extended outside the protected area, and many of the ecosystem services have been utilized outside the protected area limit. Therefore, the accounting of its extent and condition outside the CWLS has been getting importance. ESAs are an important aspect of the livelihood of communities living in the adjacent 26 coastal villages. In addition, aquaculture, salt pan, fishing harbors, and industries have been benefitted using the CWLS and ESA assets such as creek and bay water, mangrove ecosystems, and mudflat. CWLS and adjacent ESAs have been presented in Figure 1. Economic activities in and around the coastal ecosystems lead to depletion of ecosystem assets and consequently reduce their capacity to provide adequate services on depending communities. Accounting of the flow of services from CWLS and adjacent ESAs will help in assessing the positive and negative impacts of human activity on the coastal environment and guide people to choose the trade-off among the services and alternative uses of ecosystems.

Conceptual Framework for Economic Assessment

Many concepts and frameworks have been established and practiced to value ecosystem goods and services. Frameworks such as Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2008), and System of Environmental Economic Accounting (SEEA, 2014) are some of the popular frameworks for ecosystem accounting. Using the above concepts and frameworks, many valuation exercises were conducted worldwide, bringing forth the benefits of the conservation of ecosystems. SEEA Experimental Ecosystem Accounting (EEA) was released under the auspices of the United Nations, the European Commission, the Food and Agriculture Organization, the Organisation for Economic Co-operation and Development, and the World Bank Group. SEEA-EEA has synthesized the current knowledge in the measurement of ecosystems by converging many sectors and disciplines across ecology, economics, and statistics. The UN Statistical Commission welcomed the SEEA ecosystem accounting in its 44th session held in 2013. The conceptual framework of SEEA-EEA is combined with the international statistical standard for environmental–economic accounting, SEEA Central Framework (CF), and System of National Accounts (SNA), that is, international statistical standard to compile national accounts (SNA, 2009; United Nations, 2014a). The SEEA has defined a measurement framework for integrating biophysical data, tracking changes in ecosystems, and linking those changes to economic and other human activity. The SEEA ecosystem accounting process evaluates the extent, condition of ecosystem assets, and estimates the expected ecosystem service flows in physical and monetary terms. The UN Statistical Commission encouraged the use of SEEA-EEA by international and regional agencies and countries wishing to test and experiment with this framework.

The present study has been conducted with an objective to account for the goods and services of Coringa mangroves and test the SEEA-EEA concepts and principles in areas covering the CWLS in order to build knowledge and capacity to include environmental economics in the SNA of India.

Methods

In an economic context, assets are a store of values providing a single or series of benefits over a period of time. Assets of coastal ecosystems (spatial) are land and waterbody areas covering both biotic and abiotic features that function together to produce a basket of services. The quality and capacity of the assets produce a flow of goods and services that have been measured in terms of ecosystem condition and extent.

In this study, the spatial units of the CWLS and its adjacent ESA assets were classified into three different but related units followed by SEEA-EEA, namely, basic spatial units (BSUs), land-cover/ecosystem functional units (LCEUs), and ecosystem accounting units (EAUs). BSUs are lower-scale spatial units covering 1 sq. km (grid) area falling in various land cover classes (LCEUs) of ecosystems, and the EAUs are administrative units at different levels. GIS (Geographic Information System) and remote sensing applications were used to estimate the extent of the ecosystem by classifying LCEUs that are assets of CWLS. Primary and secondary data of BSUs were collected and used to assess the condition of LCEUs. To account for the flow of services from CWLS and adjacent ESAs, information on the flows of services was collected from primary and secondary data sources. Primary data were collected during May 2018 on the flow of services and quantum of benefits from various LCEUs of the ecosystem as intermediate to the final product and beneficiaries as economic units. The method used for primary data collection was interviews with local people and personnel from various economic units.

Goods and services produced by the economic assets are classified as provisioning, regulating, and cultural services followed by the SEEA framework. Though the approach to measuring ecosystem services was similar to Millennium Ecosystem Assessment (2005) and TEEB (2008), accounting principles differed in SEEA. In SEEA-EEA, supporting services were accounted as they were considered inter and intra ecosystem flows that supported the ecosystem function and helped in avoiding double counting.

Services of the ecosystems were recorded if there were associated benefits to economic or other human activity that correlated with the volume of services and number of beneficiaries or quantum of benefits. If no beneficiaries utilized the goods or services, the production values were not recorded. Primary data sets were used to evaluate the past and present scenarios of the BSUs and LCEUs. A four-digit bar code, established under Common International Classification of Ecosystem Services (CICES), was applied for the goods and services of the ecosystem, which helped to standardize the services and application of international nomenclature for accounting purposes followed by Haines-Young and Potschin-Young (2018). Economic principles and environmental economic valuation methods were used to estimate the monetary value of various mangrove ecosystem services. The total economic value (TEV) of CWLS and its adjacent ESAs was estimated by aggregation of provisioning, regulating, and cultural services.

As per the economic principles, beneficiaries pay the currency for goods and services utilized. If there was no market price for a service, alternative estimations using revealed and stated preference methods were applied to approximate the value of the service. Provisional services generally have a market price and are naturally documented under GDP and SNA. However, the market price was absent for regulatory services and, hence, the "damage cost avoided" method was used to estimate the value of protecting the life and livelihood of coastal villages, industries, and infrastructure. Aquacultural wastes are released into the waterbodies regularly. These water bodies naturally filter the nutrients from the contaminated discharge and thus purify the water. The water quality maintenance service was estimated by using the benefit transfer method. To estimate the carbon sequestration service, the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model was applied, and prices were fixed based on the social cost of carbon (SCC). SCC is an estimated economic cost based on the cost of emission of each additional tonne of carbon dioxide, or its equivalent, which can be avoided by the damage cost method (Nordhaus, 2017). In order to estimate the tourism benefits under the cultural services, relative importance delivered by various recreation activities in Coringa was estimated by using the travel cost method. Monetary values of CWLS and adjacent ESAs were aggregated and compared with meta-analysis values to understand the economic values of various mangrove ecosystem services around the world. This meta-analysis comparison provided insights on the potential services that remained unutilized in Coringa.

Analysis and Results

Extent and Condition

Accounting the ecosystem extent of CWLS and its adjacent ESAs helped track the changes brought by natural and man-made activities. The extent of the ecosystem and its condition are important parameters for understanding ecosystem flows (productivity). Stocks of an ecosystem are represented by spatial areas called ecosystem assets. SNA defines that assets are stores of value representing a benefit or series of benefits accruing to the economic owner over a period of time. Creeks and bays, dense mangrove, sparse mangrove, mudflat, turtle nesting ground, salt marsh, aquaculture, and salt pan are the major LCEUs that are the assets of CWLS and its adjacent ESAs. In addition, a small patch (0.2 hectares) in the ESA land area has been used for ecotourism purposes along with nearby creeks located inside the CWLS area, especially for boating to enjoy the mangrove nature. Aquaculture and salt pan activities are located only in the ESAs. Salt pans were not functioning in the accounting period. Table 1 shows various assets of CWLS and its adjacent ESAs.

Table 1. ***Ecosystem Extent and LCEUs of CWLS and its Adjacent Coastal Ecosystems in 2001 and 2011***

CWLS	Area in Hectares (2011)	Patches (2011)	Area in Hectares (2001)	Patches (2001)
Coastal waterbodies (creek, bay)	10990.72	18	11273.16	13
Dense mangroves	10878.92	31	9907.25	33
Sparse mangroves	597.11	40	1540.39	85
Mudflat	578.60	30	347.46	42
Turtle nesting ground	16.08	1	16.08	1
Others (shrubland, sandy area)	508.73	24	485.82	12
Total CWLS	23570.16	144	23570.16	186

ESAs Adjacent to CWLS				
Coastal waterbodies (creek)	1238.02	11	1181.77	18
Dense mangroves	770.28	120	916.19	85
Sparse mangroves	310.23	23	330.33	35
Mudflat	86.78	5	254.81	21
Salt marsh	6.55	3	6.55	3
Turtle nesting ground	45.64	1	45.64	1
Ecotourism area	0.02	2	0	0
Aquaculture	4750.50	33	4308.89	31
Salt pan	169.18	14	201.92	11
Total ESAs	7377.2	212	7246.1	205
Settlements and industries	4546.50	37	3271.09	41

Source : National Centre for Sustainable Coastal Management (2017).

Table 2. *Condition of CWLS and Its Adjacent ESAs*

Opening condition Extent: Waterbody 11273.16 ha; mangrove 11447 ha (1)	Fishing cat 112 (2), Otter 324, Fox 305, Wolves 25, Feral cattle 200, Rhesus monkey 150, Birds 236 sp. (3); 15 sp. mangroves (4); fishery 4,000 tonnes (5)	Organic carbon 0.3 – 0.5% (6)	River discharge = 7.672×10^{10} m^3 ; POC = 45 – 1460 µmol1^{-1} (7) ; PN = 4 – 152 µmol1^{-1} (8)
Improvements by natural causes	Increase of dense mangrove cover in 3,109 ha; increase of mudflat in 231ha area ; increase of bird species diversity		
Improvements by man-made activities	Awareness created by CWLS ; increase of technical and financial capacity of fishermen in marine fishing ; alternate employment opportunities		
Reduction due to extraction	–	–	–
Reduction by human activity	Poaching on fishing cat		–
Reduction by catastrophic loss of human activity	–	–	–
Reduction by catastrophe of nature	Reduction water spread area of 283 ha		
Closing condition, waterbody 10990.72 ha; mangrove 11,476 ha (1)	Fishing cat 73–92 (9); Birds 269 sp. (8); in water benthos, polychaetes 50 sp., crustaceans 9 sp., bivalve 8 sp., gastropods 7 sp. (10); 16 sp. mangrove (11) ; carbon stock 55–216 tonne/ha; fishery 756 tonnes (1)	TOC 0.645–1.44% (10) ; TP 0.95–1.74 µg/g (10)	River discharge = 8.613×10^{10} m^3(12) ; TN = 21.3–196.6 µM (13)

Source : Computed from National Centre for Sustainable Coastal Management (2017); National Environmental Engineering Research Institute (2011); Rao et al., (2004); Satyanarayana et al. (2002); Ravishankar et al. (2004); Department of Ocean Development (2001); Dehairs et al. (2000); UNDP (2011-2018); Murugesan et al. (2018); Rao et al. (2010); Ray et al. (2006); and http://forestsclearance.nic.in/writereaddata/17022017J59DPFK8Mitigationplangmr.pdf

Primary and secondary data such as physical, chemical, carbon stock, biological, ecological characteristics at a micro-level (BSUs) in different time scales (Landsat 2001– Landsat 2011) were compared to register the status and condition of the ecosystem. Comparative ecosystem characteristics and indicators to estimate the condition of CWLS and its adjacent ESAs for a 10-year period have been given in Table 2.

Waterbody and mangroves (LCEUs) occupied 95.3% of the total extent of CWLS and possessed many economic assets. The extent of waterbody in CWLS is an important indicator of coastal ecosystem conditions since erosion, accretion, sea-level changes, river discharge, and any other man-made activities in lower and upper reaches have been expressed in its spatial extent. Waterbodies of CWLS are an important economic asset since these stock fisheries and directly contribute to the national GDP. A bay located inside CWLS that extends to 29 sq. km and 34 creeks distributed in the core mangroves form the waterbody of LCEU. Many endangered species, including fishing cat, wolf, fox, feral cattle, rhesus monkey, otter, green turtle, leatherback turtle, and birds are there in this area. There has not been any continuous research on biological diversity and distribution of the above species in the study area, which was a demerit to appraise the condition. It was found that the fishing cat and otter population had been decreasing due to habitat alteration and developmental activities.[1]

The waterbody of the mangrove ecosystem is the nursery ground for many economically and ecologically important fishes which supply stock to the open seawater by the inter-ecosystem flow. The waterbodies supply water for aquaculture production and receive effluents. Biotic compositions of the waterbody along with mangroves filter aquaculture effluents and provide water quality maintenance service. Remote Sensing (RS) and Geospatial Information System (GIS) of the present study revealed that the waterbody of CWLS decreased by 3% and mudflat increased by 40% in 10 years (from 2001 to 2011). The water discharge data of the Godavari delta indicates that there was no major change in the quantity of water discharge, but there was almost a three-fold reduction in its suspended sediment loads from 150.2 million tonnes during 1970–1979 to 57.2 million tonnes by 2000–2006. It was observed that the sediment retention at the dams located in the river's upper reaches was the reason for a reduction in sediment flow into the Godavari delta, which was imposed by coastal erosion along the delta (Rao et al., 2010). However, the turtle nesting beaches bordering CWLS and the sea had no change in their distribution (16.8 hectares) for the past 10 years (from 2001 – 2011).

Mangrove patches were classified as dense and sparse mangroves (LCEU) since a distinct zonation was observed. Out of the total mangrove extent of CWLS, 94% are dense mangroves with large and old trees. Sixteen true mangrove species are distributed in these mangrove forests (UNDP, 2011–2018). Using the InVEST model, the carbon stock in dense and sparse mangroves was estimated at 216 tonnes and 55 tonnes per hectare, respectively.

Since the provisions of CWLS do not permit activities inside the mangrove area, the dense tree extent increased by 9%. However, 38.8% of the spatial extent of sparse mangrove area was reduced in 10 years and was reclassified as dense mangroves. Mangroves in CWLS and its adjacent ESAs provide flood protection and water quality maintenance services, apart from providing supply of firewood, fodder, and timber for house construction to the fishermen community and other economically weaker sections of the area (Ravishankar et al., 2004).

The area of ESAs is estimated as 7377.2 hectares. In the ESAs, mangroves were distributed in 1080.51 hectares, out of which 71% were dense mangroves. Reduction in mangrove's extent was observed in dense (16%) and sparse mangrove (6%), and they were reclassified as aquaculture. Industrial activities such as tourism, aquaculture, and salt pan were extended to 66% of the total area of the ESAs. In addition, 0.02 hectares were classified as ecotourism areas where the forest department ecotourism office is located. Few developmental activities for ecotourism, including jetties for boat riding, have been established. CWLS waterbody has been used

[1] Scheme (project) proposal: Mitigative measures against activities (proposed) in ecosensitive zone area by GMR Enterprizes Private Limited, New Delhi in Coringa Wildlife Sanctuary. Kakinada Wildlife Range of Wildlife Management Division, Rajamahendravaram. http://forestsclearance.nic.in/writereaddata/17022017J59DPFK8Mitigationplangmr.pdf

Table 3. *Physical Flow of Ecosystem Services Per Year*

		CWLS				ESAs Adjacent to CWLS						
Ecosystem Services with CICES barcode	LCEU	Coastal waterbodies (Creek and Bay)	Dense mangroves	Sparse mangroves	Other coastal ecosystems	Coastal water bodies(Creek)	Dense mangroves	Sparse mangroves	Ecotourism area	Other coastal ecosystems	Aquaculture	Salt pan
	Extent (ha) + CICES	10990.7	10878.9	597.1	594.6	1238.0	770.2	310.2	0.02	138.7	4750.	169.1
Provisioning Services	Fishery (tonnes) 1.1.6.1	756	–	–	–	18	–	–	–	–	95,010	–
	Shell collection (tonnes) 1.1.6.2	2,717	–	–	–	66.53	–	–	–	–	–	–
	Fuel wood (tonnes) 1.1.1.2	–	429	–	–	–	1,001	–	–	–	–	–
	Timber (tonnes) 1.1.5.3	–	–	–	–	–	2.4	–	–	–	–	–
	Fodder (tonnes) for 1102 livestock 1.1.3.2	–	–	10,251	–	–	–	573	–	–	–	–
	Fencing 1.1.5.2	–	–	–	–	–	3.5	–	–	–	–	–
	Thatch (no. of pieces) 1.1.5.2	–	–	–	–	–	–	3,500	–	–	–	–
Regulating Services	Protection against storms and floods (hectare) 2.2.1.3	–	426.12	–	–	–	–	–	–	–	–	–
	Water quality maintenance (incl. nutrient regulation) (Kilo liter) 2.1.1.1	2,132,312	–	–	–	240,188	–	–	–	–	–	–
	Carbon sequestration (tonnes) 2.2.6.1	–	18,494	137	–	–	1,309	71	–	–	–	–

Cultural Services	Tourism (no. of visitors in thousand) 3.1.1.1	58.5	–	–	–	–	237.5	–	–	–

for boating for tourists since navigation is a permissible activity and is open to the general public. In the ESAs, aquaculture activities increased by 9% in 10 years. This shows that there is a continuous demand for space for aquaculture activity. However, the extent of salt pan activities in the ESA region decreased by 17% in 10 years, and salt pans were not functioning in the accounting period.

Accounting Physical Flow of Services

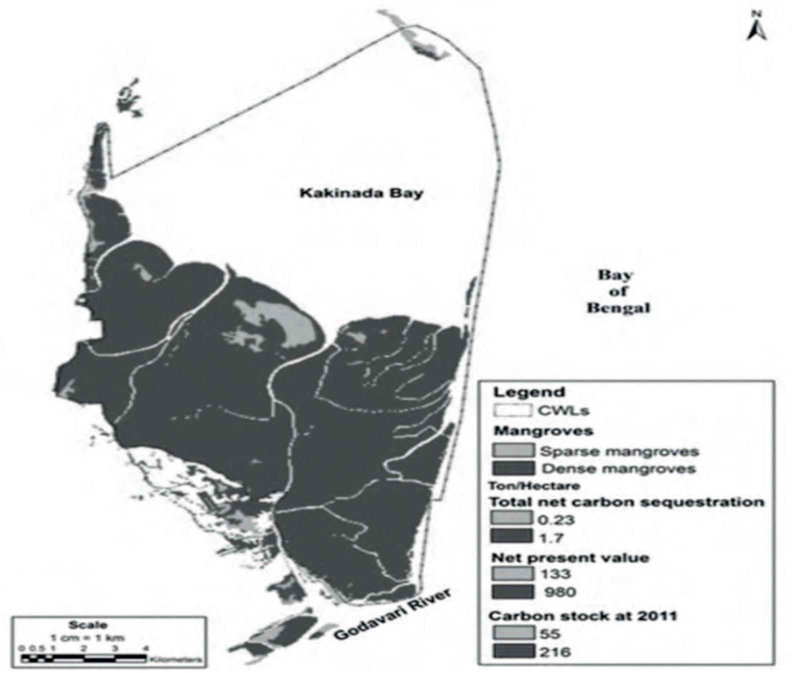
Accounting the services of an ecosystem is the core activity that links assets and the benefits derived and enjoyed by people from the ecosystem. Waterbodies and mangroves produce a variety of services that include fishery, shell collection, water quality maintenance, and boating service for tourists. At CWLS and its adjacent waterbodies, such services were classified as provisional, regulatory, and cultural services followed by Millennium Ecosystem Assessment (2005), TEEB (2008), and SEEA-EEA (United Nations, 2014a). Common International Classification of Ecosystem Services (CICES) provides additional detail within these broad groups. Table 3 enumerates various services and quantities from the mangrove ecosystem with the CICES barcode.

Fisheries and shell collection were classified under provisional service, whereas water quality maintenance and boating service for tourists were classified under regulatory and cultural services, respectively. Fishing in the creeks of CWLS was very meager, and mostly finfish and prawns have been harvested using artisanal crafts and gear. However, in the bay area, mechanized fishing practices to harvest fish and prawn was common. While comparing the opening and closing conditions of a fishery, it was observed that capture fishery efforts in the CWLS area have been decreasing owing to better awareness among fishermen to handle suitable crafts, gear, and other fishing technologies to fish in the open sea. Live and dead bivalves and gastropod shells were densely distributed in the bay and creeks, which local people harvested to supply to the calcium carbonate industries. The quantity of shell collection was relatively high in the CWLS area than in the ESAs due to biological and ecological characteristics of mollusks preferring mouth and near-shore for their distribution.

Water from the mangrove creeks is pumped for semi-intensive aquaculture ponds and has its share in the production cost/factor cost of aquaculture as they provide adequate O_2, pH, nutrient, and food materials for the growth of prawns. Water is cultured in the pond to increase productivity. In addition, human input by means of labor and produced assets are invested for production. Hence, aquaculture is not under the natural resource category but is classified as cultivated biological resources. Aquaculture effluents are discharged into the water bodies, where the ecosystem filters the nutrients and other pollution loads from the discharged water and maintains water quality for continuous intake for aquaculture. It is estimated that about 2,372,500 kiloliters of aquaculture effluents per year are treated naturally by the waterbody through its physical, chemical, biological, and ecological functioning. The creeks of CWLS and its adjacent ESAs are used for boat riding by tourists. It has been estimated that about 24.63% of tourists prefer boat riding in the creeks of CWLS.

Mangroves of the CWLS and its adjacent ESAs are classified as dense and sparse mangroves based on their biomass. The dense and sparse mangroves produce the following services: (a) fuelwood, (b) timber, (c) fodder, (d) fences, (e) thatching, (f) protection against storm and floods, and (g) carbon sequestration. Among the above services, fuelwood and thatching are provisional household services; whereas, protection against storms and floods and carbon sequestration are regulatory services. Provisional services of the mangroves are utilized by the

Figure 2. ***Carbon Sequestration in CWLS and Adjacent ESA***



underprivileged local people for their basic requirements. Though there were many interventions to shift the coastal communities to utilize alternative energy for cooking purposes, a small population still depends on the dry mangrove stalks for fuelwood. It was observed that the coastal villagers collect dry stalks from dense forests for fuel purposes. The dry stalks from dense forests of ESAs are used more (231%) than the CWLS area (429 tonnes). Strict regulations in the CWLS area and awareness created by the forest department and NGOs on protected area regulations and the importance of protection of mangroves have reduced the stalk collection there. In the ESAs, a small quantity of timber is harvested by the coastal communities, but in the CWLS area, this activity is totally banned. Fodder and thatching materials are harvested in the sparse mangroves. Coastal villagers abutting the sparse mangroves utilize these for livestock feed by either cutting them to twigs or allowing the livestock to graze in these areas. A meager amount of long and short stems of dense mangroves of ESA areas are used for fencing.

Coastal Andhra Pradesh is prone to cyclones, storms, floods, and tsunami. The CWLS and adjacent ESAs provide a shelterbelt to the life, livelihoods, and investments in the inland areas of this region. Ecosystem services comprise not only material benefits by means of harvest or extraction of resources from ecosystems but also its functioning, such as flood protection and clean air that is provided by trees in a forest. Usually, the estimation of protection service is not applied to the places where there are neither any beneficiaries nor any users of the service. Protection service of mangroves has been recorded in Coringa, as an area of about 4546.50 hectares has been used by 26 villages abutting CWLS and its ESAs, which are again surrounded by many industries (National Environmental Engineering Research Institute, 2011).

It has been estimated that mangroves sequestrate 22.8 million metric tonnes of carbon every year, covering 0.1% of the earth's forests, which accounts for 11% of terrestrial carbon into the ocean and 10% of terrestrial dissolved organic carbon exported to the ocean (Jennerjahn & Ittekkot, 2002). The current study uses the InVEST model to analyze the carbon stock of CWLS and its adjacent ESAs and its carbon sequestration potential per hectare for the year 2011 based on temporal land cover maps. The output of the InVEST model indicated that carbon stock in the dense and sparse mangrove areas was, respectively, 216tC and 55tC per hectare. The InVEST carbon model inferred that carbon sequestration was high in dense mangroves by 1.7tC per year and low at the rate of 0.23tC per year in sparse mangroves. Figure 2 shows the InVEST model output.

Monetary Accounting

Many goods and services of the mangrove ecosystems are not traded in markets. Hence, monetary valuation becomes difficult. When market price does not exist for a service, a proxy value equivalent to the service provides an approximate market price of the particular service. It brings the ecosystem and economy together and determines the missing prices that are implicitly embedded in the values of marketed goods and services. CWLS and its adjacent ESAs produce 11 services out of which seven are provisional, three are regulatory, and one is cultural. Aggregation of the monetary values of the services fetches the overall ecosystem value. Accordingly, aggregation of the 11 services was estimated to be about ₹ 516.78 crores (2011 price). Among the monetary value, the waterbody (LCEU) contributed with ₹292.09 crores; whereas, the mangrove patches, including the dense mangroves and sparse mangroves, contributed with ₹224.69 crores. The regulatory service of protection against catastrophes and the provisioning service of fishery contributed more to the total economic value (TEV)

Table 4. ***Monetary Benefit of Ecosystem Services Per Year (₹ in Crore for 2011 Value Per Year)***

	EAU	CWLS				ESAs Adjacent to CWLS					
Ecosystem Services	LCEU Unit	Coastal waterbodies (Creek and Bay)	Dense mangroves	Sparse mangroves	Total	Coastal water bodies(Creek)	Dense mangroves	Sparse mangroves	Aquaculture	Salt pan	Total
	Extent (ha)	10990.7	10878.9	597.1		1238.0	770.2	310.2	4750.5	169	
Provisioning Services	Fishery	7.27	–	–	7.27	0.18	–	–	1465.7*	–	0.18
	Shell mining	4.9	–	–	4.9	0.12	–	–	–	–	0.12
	Fuel wood	–	0.13	–	0.13	–	0.3	–	–	–	0.3
	Timber	–	–	–	–	–	0.005	–	–	–	0.005
	Fodder	–	–	0.85	0.85	–	–	0.44		–	0.44
	Fencing	–	–	–		–	0.0002	–	–	–	0.0002
	Thatch	–	–	–	–		–	0.02	–	–	0.02
Regulating Services	Protection against storms and floods	–	222.64	–	222.64	–	–	–	–	–	–
	Water quality maintenance (including nutrient regulation)	279.31	–	–	279.31	31.46	–	–	–	–	31.46
	Carbon sequestration	–	1.066	0.008	1.07	–	0.0755	0.004	–	–	0.0795
Cultural Services	Tourism	0.61	–	–	0.61	–	0.15	0.06	–	–	0.21
	Total	292.09	223.84	0.858	516.78	31.76	0.5307	0.524	1465.78	–	32.82

*Accounted under ISIC - A0321.

of CWLS with a share of ₹ 222.64 crores and ₹7.27 crores, respectively. Also, the ESAs provided ₹32.81 crores worth of ecosystem services. On the other hand, the area reclassified as aquaculture generated ₹1,465.78 crores worth of shrimps. Among the ESAs, waterbody services such as fishery and shell mining contributed with ₹31.76 crores to the TEV. Discontinuous small dense and sparse mangrove patches of the ESAs contributed ₹1.05 crores worth of services to the TEV. The monetary value of various ecosystem services of the LCEU has been given in Table 4.

Meta-Analysis

A meta-analysis consists of the study of studies (Barrio & Loureiro, 2010), where multiple ecosystem valuation studies are synthesized and integrated to construct a relationship that reflects changes in the values of ecosystem services in relation to site characteristics and attributes, along with the statistical regressions for target

Table 5. ***Comparison of the Economic Values of Onsite and Meta-Analysis***

Sl. No.	Mangrove Ecosystem Service	Economic Value in 2011 (₹ per hectare per year)		
		CWLS (Coringa Wildlife Sanctuary)	ESAs Adjacent to CWLS	Meta-Analysis Value
I	**Provisioning Services**			
1	Fishery	6,617	1,415	18,177
2	Aquaculture	–	3,085,536 (cultured)	7,619
3	Fuel wood	120	3,960	8,531
4	Timber	–	66	
5	Fodder/Grazing	14,256	14,256	929
6	Shell mining	4,523	995	–
7	Honey collection	–	–	188
8	Medicinal uses	–	–	1,464
9	Fencing	–	3	–
10	Thatch	–	557	–
	Sub-Total	25,516	20,692	36,908
II	**Regulating Services**			
11	Protection against storms and floods	204,656	–	233,624
12	Erosion prevention & soil accretion	–	–	19,578
13	Water quality maintenance	254,136	254,136	254,136
14	Carbon sequestration	936	737	17,923
	Sub-Total	459,728	254,873	525,261
III	**Cultural Services**			
15	Tourism	558	1,947	27,623
16	Education	–	–	4,760
	Sub-Total	558	1,947	27,663
	Economic value in 2011 (₹ per hectare per year)	485,802	278,072	594,552

ecosystems (United Nations, 2014b). The TEV of mangrove habitat has been estimated in many valuation studies conducted all over the world. The economic value of mangroves globally was estimated at US$181 billion (Alongi, 2002), or US$10,000 per hectare (Rönnbäck, 1999). This value was the result of a regression analysis of many studies. The studies were conducted prior to the SEEA publication. They applied Millennium Ecosystem Assessment (2005) and TEEB (2008) concepts and incorporated economic values of supportive services, which inflated the TEV. SEEA-EEA classified the supportive services as inter and intra ecosystem flow, which are distantly relevant for monetary accounting.

In the current study, a meta-analysis study was conducted for Coringa ecosystems. The meta-analysis regression values were applied for the goods and services of CWLS, and the economic value was estimated at ₹594,552 per hectare per year. However, on-the-spot values were estimated at ₹485,802 per hectare per year and ₹278,072 per hectare per year in CWLS and ESAs, respectively. Out of all meta-analysis values, protection function and water quality maintenance services shared a major benefit of ₹487,760 per hectare per year. A comparison of the estimated benefits of the meta-analysis and on-the-spot studies has been given in Table 5. Semi-intensive shrimp farming has been practiced in mangroves using produced assets, labor inputs, industry feed, manure, etc. Hence, the Coringa area aquaculture has been classified under cultured product, accounted under International Standard Industrial Classification of All Economic Activities (ISIC-A0321). The value was not counted under SEEA-EEA.

The adjacent ESAs, occupied by aquaculture activities, registered a shrimp production value of ₹3,085,536 per hectare per year, which was not accounted for under SEEA-EEA since the aquaculture industry is listed under ISIC-A0321. In addition, the meta-analysis study revealed that CWLS and its adjacent ESAs have the potential to benefit from services such as honey collection and apiculture, medicinal applications, and birding. Investments in these services are likely to promote economic growth, social inclusion, and preservation or improvement of livelihoods, while at the same time ensuring environmental sustainability of the oceans and coastal areas. These livelihood development activities will promote effective inclusion and active participation of the coastal communities (World Bank & United Nations Department of Economic and Social Affairs, 2017).

Conclusion and Policy Implications

The application of the SEEA-EEA framework in the mangroves of CWLS and its adjacent ESAs suggests that the ecosystem provides 11 goods and services with a total economic value of ₹549.6 crores per year. Understanding the economic importance of Coringa mangroves is imperative for policy decision-making with regard to the sustainable and efficient utilization of the mangrove ecosystem. The study suggests that either an annual or a five-year data collection should be done on the basis of physical, chemical, and biological parameters at select locations of Coringa to record and compare the extent and condition of the ecosystem. A uniform methodology, units, and guidelines should be established to support the monitoring of the condition of this region. The region's academic institutions and special organizations may be responsible for providing environmental inputs to help with the accounting process. Pilot investment for honey collection, apiary, and birding may be considered to broaden livelihood opportunities for the local residents. The monetary values of the present account period could be used in national, state, and regional policies as well as in cross-sectoral plans to integrate the environment and economics. Using the monetary value, government departments may assess the existing policies to choose alternative policies and match the stock, flow, demand, and supply toward sustainable development. Above all, the ecosystem’s monetary value should be communicated effectively to the stakeholders, which will improve knowledge on the conservation benefits of the ecosystem, eventually enabling them to participate in the monitoring and management processes.

Authors' Contribution

Dr. Devaraj Asir Ramesh conceived the idea and carried out the study. Dr. L. Muthukrishnan and S. Balamurugan assisted the corresponding author in estimating the physical flow and economic values of goods and services of Coringa mangroves. They also assisted in comparing the onsite economic values with meta-analysis. N. Karthi provided inputs on the extent and condition of Coringa mangroves and adjacent ESAs. S. Dhivya assisted in selecting the suitable methodology for valuation and analyzed the carbon sequestration through InVEST model. Dr. Devaraj Asir Ramesh compiled the assistance from co-authors on quantitative analysis and wrote the manuscript.

Conflict of Interest

The opinions expressed in this study are those of the authors concerned and do not necessarily represent the views of the organization to which they are attached.

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Appendix

Glossary
NCSCM - National Centre for Sustainable Coastal Management
CWLS - Coringa Wildlife Sanctuary
ESAs - Ecologically Sensitive Areas
CRZ - Coastal Regulation Zone
MEA - Millennium Ecosystem Assessment
TEEB - The Economics of Ecosystems and Biodiversity
SEEA - System of Environmental Economic Accounting
EEA - Experimental Ecosystem Accounting
SNA - System of National Accounts
UN - United Nations
BSUs - Basic Spatial Units
LCEUs - Land-Cover/Ecosystem Functional Units
EAUs - Ecosystem Accounting Units
GIS - Geographic Information System
CICES - Common International Classification of Ecosystem Services
TEV - Total Economic Value
GDP - Gross Domestic Product
InVEST - Integrated Valuation of Ecosystem Services and Trade-offs
SCC - Social Cost of Carbon
RS - Remote Sensing
UNDP - United Nations Development Programme

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