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RESEARCH PAPER

Valuation of Marine and Coastal Ecosystem Services in India

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Abstract: Coastal and marine ecosystems provide a host of services that are of vital importance to human well-being. We estimate the values of several provisioning, regulating, and recreational services using a combination of valuation methods. We find that the total value of these services in India was approximately ₹1.9 trillion (or US$0.11 trillion in purchase price parity [PPP] terms) in 2012–13, which constitutes about 2.4% of India's net national product that year. Recreational services account for the largest share (45%), followed by regulating services (35%) and provisioning services (20%). These estimates do not include all the services provided by coastal and marine ecosystems; therefore, our estimates should be treated as a conservative underestimate of their total economic value. To the best of our knowledge, this is the first such attempt at the national level in India.

Keywords: Coastal and marine ecosystems; Ecosystem services; Economic valuation; India

JEL codes: Q57; Q51; Q22; Q26

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1. INTRODUCTION

There have been a series of international efforts to address a significant gap in the conventional economist's toolkit—an understanding of the state of the environment and how it impacts the economy and human welfare (Ayres 2008; Dasgupta 2008). While ecological economics and environmental economics emerged half a century ago (Dasgupta and Heal 1979; Georgescu-Roegen 1971; Hartwick 1977; Martínez Alier 1987; Røpke 2004; Solow 1974), the importance of the environment for sustaining life has attracted attention only in the last few decades (Daly 1993; Kates *et al.* 2001; WCED 1987). National governments too have committed to expanding this knowledge base by commissioning focused studies on climate change (Stern 2007) and biodiversity (Dasgupta 2021).

Just as economists and policymakers study national accounts to understand the state of the economy, we require a similar accounting framework to understand the implications of policy interventions for sustainability. This creates the need for comprehensive national accounts that not only tabulate conventional economic variables but also flows and stocks of natural and human resources (Arrow *et al.* 2012). The common problems that arise with natural resource accounting are that (a) many natural resources and assets do not have market prices; and (b) when they exist, these are not efficient (shadow) prices (Krutilla and Fisher 1975; UN 2014).

Despite these limitations and the ethical issues that surround the valuation of natural resources (Daly 1993), there has been a growing consensus that unless an effort is made to value them, public policy will fail to give the environment its due place in decision-making (Torres and Hanley 2017). There has been remarkable progress in the evolution of techniques in this field (Arrow *et al.* 1993; Bateman 1993; Freeman 2003; Haab and McConnell 2002), and this has helped researchers place a price on natural resources to fit them into a utilitarian framework (Dasgupta 2009; Mäler, Aniyar, and Jansson 2008). One of the early studies that drew global attention to nature's contribution estimated that ecosystem services that enhance human welfare far outweigh any contribution from conventional human-made capital (Costanza *et al.* 1997). This triggered a worldwide effort to understand the impact of anthropogenic pressures on natural capital, which was given a more concrete form by the Millennium Ecosystem Assessment (MA 2005). This was followed by the Global Initiative on the Economics of Ecosystems and Biodiversity (TEEB), which managed to bring together a wide range of studies on valuation (TEEB 2010).

Several studies were also commissioned in India under the Green Accounting for Indian States Project (GAISP), which attempted to replicate the methods used in global studies in the Indian context (GIST n.d.). Of the six studies carried out under GAISP, three were on forests, and of the remaining, there was one each on agriculture and pastures, education, and freshwater. Marine and coastal ecosystems were not studied separately under the GIST project.

India has, for some time, been contemplating the adoption of a system of natural resource accounting to complement its annual national accounts of domestic product. Since 1997, the Indian government has been publishing an annual report titled the *Compendium of Environmental Statistics*. The Central Statistics Office of the Government of India also set up a technical working group called Natural Resource Accounting in the late 1990s, which commissioned a set of eight studies (land, forests, air, water, and subsoil resources) across eight selected Indian states (GASAB 2020).

India took its most significant step toward evaluating ecosystem services in 2011, with the formation of an expert committee headed by Partha Dasgupta (GoI 2013). The framework that this committee proposed went beyond that of the System of Environmental Economic Accounting (SEEA) developed under the United Nation's System of National Accounts (UN 2014). The report also provided a way to integrate changes in natural capital with conventional national income accounts. It went on to record that "Empirical studies of the value of ecosystem services in India are sorely needed" (GoI 2013, 50). In fact, the TEEB database on ecosystem valuation records 1310 studies globally, of which only 32 pertain to India and only nine deal with coastal and marine ecosystems (CMEs) (Mukhopadhyay and Shyamsundar 2012; Ploeg and de Groot 2010). A recent review of 146 studies conducted between 1980 to 2018 on ecosystem services in India found that only 19 belonged to the CME category (Verma 2018).

There have been some international efforts at valuing CME services. In a comprehensive review, Schaafsma and Turner (2015) cover journal articles and book chapters published between 2000 and 2014. They found that most of these are case studies in Europe, the USA, and Southeast Asia, including 233 primary studies and nine meta-analyses. In recent years, there have been increased efforts at scaling up these valuation studies to the national, regional, and continental scale, especially in other parts of the world. We mention a few of these here. Recently, Trégarot *et al.* (2020) assessed the value of the mangroves, seagrass beds, coral reefs, and kelp forests of the whole African continent, across nine large marine ecosystems. They estimated the annual value of ecosystem services to be US$814 billion/year (at 2018 USD values) for four ecosystems—(a) coral reefs (US$588 billion/year); (b) seagrass (US$135 billion/year); (c) mangroves (US$91 billion/year); and (d) kelp (US$0.4 billion/year). In Asia, a regional-level study found that CME services contributed about US$72 billion a year, amounting to about 6% of the gross domestic product (GDP) of the countries involved—Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, and Thailand (BOBLME 2014). The study included 10 categories of ecosystem services under the classification of (a) provisioning services—capture fisheries, aquaculture, wood-based energy, and timber and medicines; (b) regulating services—coastal protection and hazard mitigation, regulation of water flow and quality, mitigation of climate variability and change, maintenance of nursery populations and habitats; and (c) cultural services—recreational and cultural services, mainly tourism. This study relied almost entirely on benefit transfer values.

In recognition of this knowledge gap, an Indo-German partnership between the Ministry of Environment, Forest and Climate Change (MoEFCC) and Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (popularly known as GIZ) was formed to launch a national-level effort called The Economics of Ecosystems and Biodiversity – India Initiative (TII). The effort started with a scoping study that established the current landscape of ecosystem studies in India (Parikh *et al.* 2012). The programme funded 12 studies on three ecosystems—forests, wetlands, and CMEs—which were completed by 2016. Even though these studies led to new knowledge, they were primarily case studies and have not led to national-level aggregated estimates of the value of ecosystem goods and services.

The absence of macro-level studies on ecosystem services in India, therefore, remains a knowledge gap. The current study aims to fill this gap by estimating the value of ecosystem services provided by CMEs. India, with its 7,517 km-long coastline, and over two million square kilometres of exclusive economic zone, which is rich in living and non-living resources, has a unique maritime position. The CMEs of India are not only relevant from an economic and environmental perspective, but also from a social perspective, with over four million fisherfolk and other coastal communities deriving their livelihoods from CMEs.

The ecosystem classification we have followed derives from the Millennium Assessment (MA 2005) and TEEB (TEEB 2010). The study focuses on three types of ecosystem services: provisioning, regulating, and recreational services. It does not focus on supporting services due to data limitations. The results suggest that the total value of CME services in India is approximately ₹1.9 trillion (or, US$0.11 trillion, in PPP terms[1]), which constitutes about 2.4% of India's net national product in 2013.

This study, to the best of our knowledge, is the first attempt to estimate the value of coastal and marine ecosystem services at the national level in India. Methodologically, it improves upon earlier attempts at large-scale valuation by combining different methods as well as local values rather than relying solely on global estimates and the benefit transfer method. It thus contributes to the relatively thin literature on the valuation of coastal and marine ecosystems at the national level.

The rest of the paper is organized as follows. Section 2 describes the material and methods used for estimating ecosystem services. Section 3 presents the results and analysis. Section 4 concludes the paper and provides a brief discussion of the findings.

2. MATERIAL AND METHODS

CMEs provide a wide range of goods and services, including marine fisheries, seaweeds, coastal minerals, coastal salt, seawater for drinking (after desalination) and industrial cooling, coastal shipping, coastal protection, carbon sequestration, and coastal recreation. The total value of ecosystems is generally divided into two categories: use- and non-use-value. The use values of ecosystems are the benefits that individuals derive from the direct or indirect use of ecosystem services. Non-use-values, on the other hand, reflect the satisfaction that individuals derive from knowing that ecosystem services are maintained and that others will have access to them. In the current valuation exercise, only the use values of coastal ecosystem services are estimated, including the benefits obtained from the direct or indirect use of ecosystem services. Among the direct use values estimated in this study, the values of fish, seaweeds, minerals, salt, and seawater used for desalination and industrial cooling fall under the extractive or consumptive use category, while the values of coastal shipping and coastal tourism fall under the non-extractive or non-consumptive use category. Either way, both categories of direct use values are reflected in market transactions (at least partially in some cases). Indirect use values are usually associated with regulating services such as coastal protection and carbon sequestration, both of which have also been estimated in this study. These may be seen as public services that are generally not reflected in market transactions.

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[1] The purchasing power parity exchange rates are sourced from the OECD (n.d.) database.

Following the Millennium Ecosystem Assessment (MA 2005), the above mentioned coastal goods and services are further classified under three broad heads: (a) provisioning services, which includes the values of marine fisheries, seaweeds, coastal minerals, coastal salt, seawater used for desalination and industrial cooling, and coastal shipping; (b) regulating services, which includes the value of coastal protection provided by mangroves and the value of carbon sequestered by mangroves and seagrasses; and (c) recreational services, which includes the value derived from coastal tourism.

The total economic value of ecosystem services is the sum of the consumer surplus (CS) and the producer surplus (or net rent), excluding the cost of production. In the case of essential ecosystem services that are not easily substitutable, there are no costs of production, and, thus, the product of the price and quantity estimates represents the producer surplus value. Further, if the ecosystem service approaches infinity as the quantity available approaches zero (or some minimal value), the CS is negligible. In such cases, the product of the price and quantity values could serve as a conservative underestimate of the sum of the consumer and the producer surplus, i.e., the ecosystem service value (Costanza *et al.* 1997). It must, however, be noted that such a conceptualization may provide an underestimate of the total economic value of the ecosystem service, as CS values are typically non-negligible. Simultaneously, since the input costs were not subtracted, the product of the price and quantity values could be upwardly biased.

The present study uses three methods to estimate the value of coastal ecosystem services: (a) the direct market valuation approach; (b) the travel cost method; and (c) benefit transfers. We use three types of methods due to the complexity involved in evaluating different types of ecosystem services. While method (a) is suitable for provisioning services, method (b) is suitable for recreational services. For the remaining types of services, in the absence of reliable data, method (c) was adopted. In fact, the benefits transfer method is the most popular among these methods, as evidenced by its use in recent large-scale studies (BOBLME 2014; Milon and Alvarez 2019; Trégarot *et al.* 2020).

Where markets for ecosystem services exist, individuals' preferences for ecosystem services are directly reflected in data from actual markets. Thus, in such cases, market data such as price, quantity, and cost information has been used to value coastal ecosystem services. This is commonly referred to as the direct market valuation approach, and it may be further divided into the market price-based approach and the cost-based approach, depending on whether price or cost information is used. The values of provisioning services such as fish, seaweeds, minerals, salt, and seawater used for desalination and industrial cooling have been obtained by multiplying the price of the service by the quantity produced in a given year. Cost-based approaches are based on estimates of the costs that would be incurred if the ecosystem's benefits need to be recreated through artificial means (TEEB 2010). One of the techniques used to estimate the value of ecosystems in this approach is the avoided cost method, which relates to the costs that would have been incurred in the absence of marine ecosystem services. The value of coastal and marine ecosystems in transporting goods via shipping has been estimated using the avoided cost method; specifically, we look at the costs avoided by transporting via sea instead of by road or rail.

We use the travel cost method, which is a revealed preference approach, to estimate the value of coastal tourism. The rationale behind this method is that the opportunity costs of time, and the direct expenses that people incur when visiting a particular tourist site, represent the lower bound of the value of the recreational experience. Based on the number of trips that people make to a particular site and the travel costs incurred by them (i.e., based on the demand function for visiting the site), individuals' willingness to pay to visit the site and associated CS can be estimated. Moreover, the demand function can be used to infer the value of a change in the quality or size of a particular tourist site due to changes in the ecosystem.

In this study, the demand for recreational services is estimated using the zonal travel cost method. The travel cost (the total of actual travel expenses, accommodation and food expenses, and the opportunity costs of time) for domestic and foreign tourists was also estimated. This cost was deducted from the area under the demand curve to arrive at an estimate of the CS for all tourists who visited various coastal destinations in India in 2012–13.

The third approach used is benefit transfer, which is the method of transferring values estimated in one study, location, and/or context to another. The advantage of using this method is that it circumvents the need to undertake several new ecological and economic studies, which are likely to prove expensive and time-consuming. The value of coastal protection (provided by mangroves) has been estimated using the benefits transfer method. The unit value of coastal protection estimated by Das and Vincent (2009) for Kendrapada district in Odisha has been scaled-up to the all-India level after adjusting for differences across coastal states and union territories (UT) in terms of a) the physical characteristics of cyclonic activity, b) the probability of occurrence of severe storms, c) mangrove quality, and d) income.

A brief description of the approaches adopted to evaluate various coastal ecosystem services is presented below. Table 1 summarizes the data sources and methodology followed to estimate the value of various coastal ecosystem services. Unless otherwise mentioned, data corresponding to the year 2012–13 has been used for the analysis.

2.1 Marine Fisheries

The fish catch statistics used in this study are taken from official sources (CMFRI 2014). The marine fishery resources are classified under three broad categories—demersal, pelagic, and shellfish. Pelagic species, which include common varieties such as oil sardines, mackerels, and tunas, dominate fish landings in India, amounting to 56% of landings in 2013. Demersal fish, including snappers, catfishes, pomfrets, and croakers, contributed to over 26% of landings. Shellfish, including crustacea, which comprise sought-after resources like prawns and lobsters and molluscs (clams, oysters, and squids), together contributed 18%.

Using the direct market pricing method, each fish species' value is estimated by multiplying its annual landing quantity across India by its standardized annual average price for 2012–13. The total of all values is estimated for three broad marine fish categories.

2.2 Seaweeds

Seaweed is commercially-processed to manufacture processing agents such as agar, alginate, and carrageenan in the pharmaceutical, food, fertilizer industries (Kaliaperumal, Kalimuthuand, and Ramalingam 2004; McHugh 2003). In India, agar is used as a gel in food products such as processing jelly, dairy products, biopolymers, and many others. It has specific properties that make it suitable for use in solidifying agents in pharmaceuticals and disinfectants, nutraceuticals, veterinary medicines, tablet coating, and food supplements. There are three main types of carrageenan derived from red algae—lambda, kappa, and iota—each having its own gel characteristics. The culturing of *Kappaphycus alvarezii* was introduced due to its commercial viability in the Indian market. It is used as a clarifying agent while brewing beer and is used extensively in the dairy industry to stabilize ice-creams, flavoured milk, and evaporated milk products. The first attempt at culturing seaweed at a commercial scale was undertaken by PepsiCo Holdings India Ltd. in 2000, and this was further taken up by the Council of Scientific and Industrial Research–Central Salt and Marine Chemicals Research Institute (CSIR–CSMCRI) in Bhavnagar, Gujarat. Using production and price (at seashore) data sourced from the Seaweed Association and CSIR–CSMCRI, we estimated the total value generated by seaweed for provisioning services. The price and quantity data have been collected at the primary stage of the production cycle to avoid double counting.

2.3 Coastal Minerals

Indian beaches and coastal dunes contain several heavy minerals including ilmenite, rutile, garnet, zircon, sillimanite, and monazite. Information on production quantities and the average prices of these minerals are sourced from the *Indian Mineral Year Book* (IBM 2014). The quantity of reserves of ilmenite (including leucoxene) and rutile present in Indian coasts as of 2011–12 was estimated to be 334.24 million and 28.91 million tonnes, respectively. Both minerals are found in coastal states such as Andhra Pradesh, Kerala, Odisha, and Tamil Nadu. The annual production of these minerals is less than 1% of the reserves. A total of 56.81 million tonnes of garnet is available on Indian coasts as of 2011–12, with Tamil Nadu and Andhra Pradesh—the states with the largest reserves of garnet—producing close to 4% and 0.3% of their total reserves, respectively, in 2011–12. The production of other minerals (sillimanite, zircon, and monazite) is largely concentrated in the states of Andhra Pradesh, Odisha, Tamil Nadu, Kerala, and Maharashtra. The valuation of coastal minerals in India is based on the amount produced in 2011–12 and their respective declared average prices for the same year.

2.4 Coastal Salt

Gujarat, Tamil Nadu, and Rajasthan are the major salt-producing states in India, meeting over 90% of the country's requirements. The salt produced in coastal states and their respective prices were taken from the *Annual Report of the Salt Department*, Ministry of Commerce and Industry (2013–14) (GoI 2014). The production values were estimated by taking the difference between the salt stocks as of 31 March 2013 and 31 March 2014. For this study, only the average price of non-iodized salt in the respective states was taken to calculate the price of all salt entering the market in these states. The price of iodized salt was not considered, as the cost of iodization added to that of non-iodized salt would lead to an overestimation of salt prices.

2.5 Seawater Desalination

Given increasing water stress, several Indian states have started looking for alternative sources to address water scarcity. Seawater (and brackish water) desalination is increasingly being seen as an important means to address water scarcity in India. Tamil Nadu and Gujarat, two states that have widely adopted desalination technologies, account for over 96% of the total installed seawater desalination capacity in the country.

The value of seawater desalination is assessed as the installed production capacity multiplied by the price of water. The monetary value of the water (its scarcity cost) is taken as equal to the cost of the new source of supply, i.e., desalination. The desalination cost from the Minjur plant in Tamil Nadu is used to value this service. The price range used to estimate the value of the desalination service is ₹48.66–60 per m^3 (in 2005 prices), which, when converted to 2012–13 prices using a GDP deflator, is estimated as ₹80.9–99.7 per m^3.

2.6 Seawater Used for Industrial Cooling

Given that power plants consume the most water among all industries, and that coal-based thermal power plants and nuclear power plants have relatively lower efficiencies and thus higher water requirements for cooling, the analysis has been restricted to valuing the benefits of seawater used for cooling in coal-based thermal and nuclear power plants located along the coasts in India.

The direct market valuation approach is used to value this service by multiplying the volume of seawater used by power plants with the price of raw water or freshwater. The value represents the water costs that power companies would have incurred if they did not have access to seawater and had to use freshwater instead. To that effect, this approach can also be seen as the avoided cost method, since the benefit power companies derive is the cost they avoid by using seawater instead of freshwater.

Further, since the water requirements of power plants vary depending on the type of cooling system they use (i.e., once-through, closed-cycle, or dry), the valuation exercise considers the type of power plant, the cooling system it uses, and its operating capacity. The data on the capacity of power plants (CEA 2013), their water requirements, and the price of raw water (CEA 2012) is obtained from the reports of the Central Electricity Authority.

2.7 Coastal Shipping

The benefits of coastal shipping are assessed as the costs avoided by transporting goods via sea instead of transporting them by road and rail. The analysis takes into consideration (a) all the maritime zones through which goods have been transported in 2012–13 (the year of analysis); (b) the different commodities transported (e.g., petroleum oil and lubricants, cement, among others); and (c) the economic as well as environmental costs associated with transportation. The benefits of coastal shipping as a means of transportation are estimated as:

$$V_{Si} = \Sigma_{zjk}((D_{iz} \times C_{ijk} \times T_{Szj}) - (D_{Sz} \times C_{Sjk} \times T_{Szj})) \qquad (1)$$

where,

V_{Si} are the benefits of coastal shipping, *S*, in terms of costs saved with respect to *i*, the alternate mode of transportation;

i is the mode of transport other than shipping. Only the two major modes of freight transportation, namely, road and rail transport, are considered as alternatives in this exercise;

z represents a pair of maritime zones across which goods are transported. There are 12 maritime zones and 48 pairs of maritime zones across which goods were transported in 2012–13;

j is the type of commodity transported across maritime zones (e.g., petroleum oil and lubricants, cement). Transportation costs tend to vary by the type of commodity transported both within and across the different modes of transportation. Moreover, different commodities are transported via specific routes, depending on the demand and supply of the same;

k is the category of the cost estimated. Economic and environmental costs alone are considered;

D is the distance in kilometres between a representative port in one maritime zone and another port. Note that transportation routes, and, thus, distances, vary for the different modes of transportation for the same *z*;

C is the cost in rupees per tonne-km by commodity. Costs vary not only by the type of commodity being transported but also by the distance travelled in some cases (road transport) as well as other specifics of the route (type of terrain (*ghat*/plain), type of road (national highway/other), type of track (single line/double line)) and the mode of transportation (whether diesel or electric traction; more on this in the subsequent section); and

T is the tonnes of goods transported by coastal shipping between the different maritime zones.

Various economic and environmental cost parameters have been sourced from a Planning Commission study on Total Transport System (TTS-RITES) (2013). The data on the commodity-wise quantity of goods transported across the maritime zones of India is taken from the Directorate General of Commercial Intelligence and Statistics (DGCIS 2013).

Sea distances between representative ports were calculated with the help of the SeaRates port distance calculator, road distances were calculated using Google Maps, and rail distances between the main railway stations closest to the representative ports in each maritime zone were obtained from the Indian Railways website.

2.8 Coastal Protection by Mangroves

We used the benefit transfer method to estimate the value of the storm-protection service of mangroves. In particular, the value of the storm-protection service rendered per hectare of mangrove per year from a study for Kendrapada district (Das and Vincent 2009) was first scaled-up to the coastal state/UT level and then to the all-India level. The coastal protection value of mangroves is estimated as follows:

$$V_{ij} = V^{*} \times p_i \times \frac{CD_j}{CD_{md}} \times SF_i \times A_{ij} \tag{2}$$

$$SF_i = \frac{WS_i}{WS_b} \times \frac{SH_i}{SH_b} \times \frac{pcNSDP_i}{pcNSDP_b} \tag{3}$$

$$\sum_{i,j} V_{ij} = V_{AI} \tag{4}$$

where V^* is the one-time value of the storm-protection service as estimated by Das (2009) in INR/ha, p_i is the probability of occurrence of a severe cyclonic storm over a 30-year period, *i* is the state/UT in question, *CD* is the mean canopy density in percentage, *j* is the category of mangroves (very dense, moderately dense, and open), CD_{md} is the mean canopy density of the moderately dense mangrove cover category (i.e., 55%), SF_i is the state-wise scaling factor, and A_{ij} is the mangrove area (in ha) of the state *i* under mangrove cover category *j*.

Summing the values across states and mangrove cover categories (the V_{ij}s) gives the all-India value (V_{AI} in INR/yr). The scaling factor (*SF*) is used to scale the Kendrapada storm-protection value to the state/UT level based on three variables: maximum wind speed (or probable maximum wind speed), probable maximum surge height, and per capita net state domestic product. Differences in the two former variables capture differences in the physical characteristics of cyclonic activity across states; meanwhile, differences in the latter capture differences in income (a proxy for the stock of goods and built infrastructure) across states.

The data on the state-wise physical characteristics of cyclonic activity comes from the *Vulnerability Atlas* (BMTPC 2006). The historical data on the number of severe cyclonic storms that occurred over the past 30 years (from 1983–2013) in each coastal state is sourced from the *Cyclone eAtlas* (IMD, Version 2.0 web-based application). Data on the per capita net state domestic product (at constant 2004–05 prices) are from the Central Statistics Office. Data on mangrove area disaggregated by states/UTs and the three categories of mangrove cover were obtained from the *India State of Forest Report* (FSI 2017).

2.9 Carbon Sequestration

The direct market pricing approach is used to value the carbon sequestration service of mangroves and seagrass meadows in India. Estimates of the value of carbon sequestration by CMEs is based on the sequestration potential of the respective ecosystems, the extent of coverage of the coastal ecosystem, and the market rate or the social cost of carbon. The following function is used to determine the economic value of the blue carbon sequestered:

$$(VS_i) = (SQ_i) \times A_i \times C \tag{5}$$

where the value of carbon sequestered (*VS*) by a particular ecosystem (*i*) is measured by the product of its rate of carbon sequestration (*SQ*), measured in tonnes CO_2-e/ha/year, the area (*A*) measured in ha, and the social cost of carbon (*C*) measured in INR/tonne CO_2.

The state-wise annual rates of carbon sequestration are estimated from total biomass stocks in mangrove forests in different coastal states, the data for which is taken from Sahu *et al.* (2015). The mean annual increase in mangrove biomass was estimated from the total biomass stock using Von Mantel’s formula, which states that the sustained annual yield is equal to twice the growing stock volume of the forest divided by the rotation age of the forest. For the rotation age of mangrove forests, we use the weighted average rotation period for littoral and swamp forests (averaging very dense, moderately dense, and open littoral and swamp forests), which is 68.67 years (Verma *et al.* 2014). The mean annual biomass increment is converted to an annual rate of carbon sequestration, assuming 50% of biomass as carbon and 1 tC as equivalent to 3.67 tCO_2 following the IPCC (2003). The rates of carbon sequestration for seagrass meadows are sourced from Murray *et al.* (2010). It combines estimates from a variety of species and considers other characteristics such as sediment characteristics and the depth range of the seagrass habitat. The social cost of carbon is obtained from Nordhaus (2011).

2.10 Coastal Recreation

There were two methods available to estimate the recreational value of coastal and marine tourism. One possibility was to estimate the recreational value using the benefits transfer approach based on average values from the received literature (Costanza *et al.* 2014, 1997). The second possibility was to estimate the CS using the travel cost method (TCM), which is considered a robust technique (Freeman 2003; Mendelsohn and Olmstead 2009). This study relied on state-level studies conducted to estimate the tourism demand based on surveys of tourists. Using a normalization procedure, the zonal travel cost method (ZTCM) was used to estimate tourism demand for coastal zones (destination states) from various regions of the world as well as every state in India (origin zones) (Mukhopadhyay *et al.* 2020). The ZTCM estimates the visitation rate (V) to a destination (zone "i") as follows:

$$V_i = \frac{N_i}{P_i} \tag{6}$$

where, "N_i" is the estimated number of visitors from zone "i", and P_i is the total population of the origin zone.

The average travel cost is calculated per visitor. It includes all actual expenses like entry-fee (if any) and the opportunity cost of time. The trip-generating function (TGF) is the relation between the visitation rate (Vi), the average travel cost from zone "i" (T_i), and other zonal characteristics:

$$V_i = f(T_i, Z_i) \tag{7}$$

The demand function for each zone is assessed by applying the relevant value of "Z_i" in the estimated TGF. The sum of such demand for all originating states to a destination state would provide an estimate of the aggregate demand curve for that coastal state. The CS is estimated as the area under the demand curve net of the visitor's actual travel cost.

Every destination state's demand curve will have a choke price. At this price, the visitation from that zone reduces to zero. If "T_a" is the average (actual) price paid by visitors and "T_c" is the choke price for a zone, then the zonal CS would be:

$$CS = \int_{T_a}^{T_c} V\,dt \tag{8}$$

The sum of all such zonal CS was considered as the recreational value of the destination state site (equation 8).

Table 1: Valuation of Coastal Ecosystem Services – Data Source and Methodology

Sl. No.	**Coastal and Marine Ecosystem Services**	**Data Sources**	**Methodology**
1	Marine fisheries	CMFRI (2014)	Direct market pricing
2	Seaweeds	Seaweed Association and CSIR–CSMCRI; seaweed collectors; seaweed industries (Reddy, Rao, Meenakshisundaram, *et al.* 2014; Rao and Mantri 2006; personal communication)	Direct market pricing
3	Coastal minerals	IBM (2014)	Direct market pricing
4	Coastal salt	Ministry of Commerce and Industry, GoI (2014)	Direct market pricing
5	Seawater desalination	Bulk water purchase agreement (BWPA), 2005, between Chennai Metropolitan Water Supply and Water Sewerage Board (CMWSSB) and Chennai Water Desalination (CWDL) (for the cost of desalination at Minjur plant) (CMWSSB n.d.; Water Technology n.d.); Global Water Intelligence reports; Chennai Metropolitan Water Supply and Sewerage Board	Direct market pricing

Sl. No.	Coastal and Marine Ecosystem Services	Data Sources	Methodology
6	Seawater – industrial cooling	CEA (2013; 2012); Batra (2012)	Direct market pricing / avoided cost
7	Coastal shipping	DGCIS (2013)	Avoided cost
8	Coastal protection (mangroves)	Das and Vincent (2009); Das (2009, 2); BMTPC (2006); FSI (2017)	Benefit transfer
9	Carbon sequestration (mangroves)	IPCC (2003); Nordhaus (2011); Sahu *et al.* (2015); Verma *et al.* (2014)	Direct market pricing
10	Carbon sequestration (seagrasses)		
11	Coastal recreation	Mukhopadhyay *et al.* (2020)	Zonal travel cost

Source: Authors' compilation.

3. RESULTS AND ANALYSIS

The values of different coastal ecosystem services are reported here for 2012–13 prices. This section discusses the estimated values of coastal ecosystem services.

3.1 Marine Fisheries

The total estimated value of marine fish is approximately ₹295 billion as of 2012–13. It may be noted that because cured fish as well as subsistence fish have not been accounted for in the valuation, the estimated value is significantly lower than that reported by the Central Statistics Office for 2012–13. On the other hand, since the value of inputs has not been deducted, the estimates reported here also overestimate marine fish value in India. Among the broad fish types, results suggest that shellfish contribute 40% to the total value of marine fish, even though shellfish landings account for only 18% of total landings. Pelagic and demersal fish contribute 31% and 29%, respectively, to the total marine fish value in India.

3.2 Seaweeds

The estimated value of seaweeds is approximately ₹92 million in 2012–13 prices. In terms of seaweed used in the manufacture of major processing agents, agarophyte, alginophyte, and carrageenophyte contribute about 31%, 25% and 43%, respectively, of the total value of seaweed.

3.3 Coastal Minerals

Coastal minerals worth about ₹12.44 billion were produced per year in India. Ilmenite contributed close to 60% of the total value of coastal minerals, followed by zircon (about 18%), garnet (9%), and rutile (8%). Owing to the non-production of monazite in 2010–11 and 2011–12 by Indian Rare Earths Limited, the estimated value of coastal minerals does not include this mineral. Thus, the true annual value of coastal minerals in India is likely to be higher than that reported in this study.

3.4 Coastal Salt

The value of coastal salt in India is about ₹12.4 billion per year, with close to 80% of this value coming from the western state of Gujarat, followed by the southern state of Tamil Nadu (about 15%). As the recreational and cultural services offered by coastal salts are not included, the values reported here provide an underestimate of the true value of coastal salt.

3.5 Seawater Desalination

The value of saltwater desalination is estimated to be in the range of ₹18–22 billion per year (in 2012–13 prices), with a mean value of roughly ₹20 billion per year. Since Tamil Nadu and Gujarat have the highest production capacity in the country, together, they account for more than 96% of the value of saltwater desalination in India. Since the desalination capacity in India is likely to increase significantly in the future, the value of saltwater desalination could increase fourfold to about ₹80 billion per year.

3.6 Seawater Used for Industrial Cooling

For coal-based coastal thermal power plants that use seawater for cooling, the annual value of services ranges between ₹2.52–4.66 billion. Plants using the once-through cooling system account for almost 60% of this value, with the remaining value accruing to the plants using closed-cycle cooling systems. The value of seawater used by coastal nuclear power plants is estimated to be about ₹0.06–0.10 billion, making the total average annual value of the cooling service contributed by the seawater, ₹3.67 billion.

3.7 Coastal Shipping

Coastal shipping leads to significant savings on transportation costs for goods compared to transporting via road and rail. Table 2 below presents the estimated range of values for the benefits of coastal shipping a) under the baseline scenario (i.e., considering economic and environmental costs only), b) with the inclusion of accident costs in addition to baseline costs, and c) with the removal of bottlenecks in coastal shipping, which would lead to an increase in the share of coastal shipping in the overall cargo movement. It is important to note that the first two categories of benefits are currently realizable (estimated for 2012–13). In contrast, the third category of benefits is hypothetical. An increase in the share of coastal shipping would occur only if the bottlenecks in the coastal shipping sector are dealt with effectively by the government.

Table 2: Annual Value of Coastal Shipping (in INR billion)

Category of Benefits	Cost Savings over Road Transport	Cost Savings over Rail Transport
Baseline value (economic + environmental costs)	61.85	15.86
Inclusion of social (accident) costs	63.80	15.88
Increase in the share of coastal shipping	127.59	31.76

Source: Authors' estimates

3.8 Coastal Protection by Mangroves

The annual storm-protection values for mangroves in India are estimated to range between ₹560–754 billion, with an average value of approximately ₹650 billion per year. The storm-protection value of the Andaman and Nicobar Islands alone contributes almost 30% to the total, annual all-India storm-protection value, providing a strong basis for the conservation of mangroves on the islands.

It is important to note that the values estimated in this study only include the storm-protection service of mangroves in terms of lives saved, livestock saved, and damages to buildings averted. Presumably, other types of damages are prevented by mangroves during storms, such as damages to agricultural land and public infrastructure. Similarly, mangroves could also serve as a nursery for young fish and hence contribute towards productivity enhancement in the fishery sector (Anneboina and Kavi Kumar 2017). Thus, the estimated benefits of mangroves reported in this study would be a lower bound of the true value.

3.9 Carbon Sequestration

The carbon sequestration service of seagrasses is valued between ₹12–40 million per year (with a mean value of ₹30 million per year). In contrast, mangroves in India are estimated to provide carbon sequestration valued at between ₹0.76 and ₹1.65 billion (with a mean value of ₹1.21 billion per year), depending on the range of carbon sequestration rates and the average social cost of carbon considered.

Verma *et al.* (2014) estimated the annual per hectare carbon sequestration values of littoral and swamp forests in India to be ₹8,736 for very dense forests, ₹3,729 for moderately dense forests, and ₹1,207 for open forests. Applying these values to mangrove areas with these canopy density classifications gives the total carbon sequestration value for mangrove forests in India as ₹1.94 billion per annum. This value is in the ballpark of the carbon sequestration value estimated for mangroves in the present study (i.e., mean of ₹1.21 billion), though it is slightly higher, which is expected since the values by Verma *et al.* (2014) were estimated for all littoral and swamp forests in India, whereas the value estimated in this study is for mangrove forests alone.

3.10 Coastal Recreation

The estimated CS by coastal recreation for visitors is estimated at ₹857.2 billion. CS for domestic visitors is estimated at ₹295 billion, and that for visitors from the rest of the world is estimated at ₹562 billion. The extent of CS generated for visitors from the rest of the world is almost 1.8 times (in aggregate) more than the CS generated for domestic visitors (Mukhopadhyay *et al.* 2020).

3.11 Consolidated Values

As described above, the benefits derived from a wide range of CME services are estimated for India in this study. The CME services considered include provisioning services such as marine fisheries, seaweeds, coastal minerals, coastal salt, seawater desalination, seawater used for industrial cooling, and coastal shipping; regulating services such as coastal protection and carbon sequestration; and recreational services such as coastal tourism. The estimates of CME services across these broad categories in India for 2012–13 are presented in Table 3.

Table 3: Annual Values of Coastal and Marine Ecosystem Services in India (2012–13 Prices; in INR Billion)

S. No.	**Service Valued**	**Method of Estimation**	**Value Range**		**Average Value**	**% of Total Value**
			Min.	**Max.**		
I.	**PROVISIONING SERVICES**					
1.	Marine fisheries	Direct market pricing	-	-	294.48	**20**
2.	Seaweeds	Direct market pricing	-	-	0.09	
3.	Coastal minerals	Direct market pricing	-	-	12.47	
4.	Coastal salt	Direct market pricing	-	-	12.40	
5.	Seawater desalination	Direct market pricing	18.01	22.21	20.11	
6.	Seawater – industrial cooling	Direct market pricing	2.58	4.76	3.67	
7.	Coastal shipping	Avoided cost	15.88	63.80	39.84	
	Total provisioning		**-**	**-**	**383.06**	
II.	**REGULATING SERVICES**					
8.	Coastal protection (mangroves)	Benefit transfer	560.38	754.04	653.98	**35**
9.	Carbon sequestration (mangroves)	Direct market pricing	0.76	1.65	1.21	
10.	Carbon sequestration (seagrasses)	Direct market pricing	0.01	0.04	0.03	
II.	**Total regulating**		**561.16**	**755.73**	**655.21**	
III.	**RECREATIONAL SERVICES**					
11.	Coastal recreation	Zonal travel cost		-	**857.15**	**45**
III.	**Total recreational**				**857.15**	
IV.	**GRAND TOTAL (I+II+III)**				**1,895.42**	**100**

Note: In cases where the parameters have been borrowed from other studies (e.g., coastal protection and carbon sequestration), all necessary adjustments have been made to standardize the values for use in the present study.

Source: Authors' estimates.

The total value of the provisioning services estimated amounts to ₹383 billion. The total value of the regulating services estimated is roughly 1.7 times that of the provisioning service value at ₹655 billion, with a value range of ₹561–756 billion. The total coastal recreational value is more than double the value of the provisioning services (estimated at ₹857 billion) and is the highest of the three services examined in this study. The total value of CME services in India is approximately ₹1.9 trillion, of which provisioning services account for 20%, regulating services account for 35%, and coastal recreation accounts for 45%. The net national product (NNP) at factor cost (in current prices) in 2012–13 was ₹80.3 trillion (RBI 2020). Therefore, the estimated mean total CME service value for India (₹1.9 trillion or US$0.11 trillion in PPP terms) is approximately 2.4% of the net national product (NNP).

4. DISCUSSION AND CONCLUSION

As discussed earlier, research on marine and coastal ecosystem services have mainly focused on provisioning services (like fisheries, seaweeds, and minerals, including sand and rare minerals), regulating services (like carbon sequestration and coastal protection), and recreation. There are several other services provided by CMEs, such as marine bio-pharmaceuticals and bio-prospecting, shoreline stabilization (erosion control), and cultural and spiritual values. These are domains that the present study could not value and constitute an area for future research. Knowledge gaps are not always caused by a lack of data or information—they are also caused by access restrictions and a lack of standardized data-collection protocols and coordination across different sectors.

Questions have also been raised about the validity of aggregating ecosystem services as independent components to determine the value of a biome, especially since the science of interlinkages and feedbacks between ecosystems and the services they produce is incomplete (Barbier 2012).

On the other hand, despite the increased importance of ecosystem services, coastal and marine resource policy and planning decisions are often not informed by ecosystem service valuations. A review of four major geographic regions across the globe (the European Union, the United States, Australia, and the Caribbean) indicates that CME service values are most often used for informational purposes and rarely used to evaluate trade-offs in policy decisions (Milon and Alvarez 2019).

Studies cite a variety of reasons for this situation. The most common concerns are a lack of understanding of ecosystem services among both policymakers and the public and the limited availability of valuation information for non-provisioning services in specific settings. This decision-making context for CME services policy and planning is a classic "wicked problem" with complexities, interdependence, and conflicting social interests. This emphasizes the need for valuation research on CME services in a wealth accounting framework. An economic valuation will build a case for investment in neglected sectors that have huge potential (Torres and Hanley 2017).

It must be reiterated that the estimates reported in this study include only three broad types of services—provisioning, regulating, and recreational services—and exclude estimates for supporting services. Thus, the aggregate estimate reported here must be seen as a floor value of ecosystem services from CMEs in India.

The only national estimate available for comparing the values reported in the present study is the one by World Bank (2013). They found the total value of ecosystem services from all biomes (including coastal ecosystems) to be ₹1.4 trillion in 2009. To put this in a comparative perspective, the value of ecosystem services was about 3% of India's GDP in that year. The classification used for biomes (services) was forests, grasslands, wetlands (including coastal wetlands), mangroves, coral reefs, lakes, and rivers. In this classification, CMEs include mangroves, coral reefs, and coastal wetlands. However, ecosystem services from wetlands have not been separated by location (coastal or non-coastal). So, the contribution of the coastal zone cannot be separated clearly. The World Bank study found that wetlands accounted for the highest percentage contribution (48%), followed by coral reefs (22%) and mangroves (2%).

The estimates reported in the present study suggest a much larger contribution of ecosystem services in India as compared to earlier studies. This assumes importance from the point of policy-making, where decisions about preserving natural capital need to be made. Another World Bank study estimated the extent of environmental degradation in India to be about ₹3.75 trillion as of 2009, which was 5.7% of the GDP (Mani *et al.* 2012). This study focused largely on damages due to air pollution, land degradation, and water and sanitation but did not examine coastal and marine issues. UNISDR/UNDP highlighted threats to coastal ecosystems, especially in the context of climate change and sea-level rise (2012). These findings emphasize the need for economic policies and environmental laws to be cognizant of the importance of ecosystems in sustaining human welfare.

To better inform the management of ecosystems and the sustainable development of ocean economies, data needs to be integrated across environmental, economic, and social knowledge domains. The development of more holistic statistics and indicators to measure the contribution of CME services to society and the economy, as has been attempted in this study, is in line with the Government of India's stated policy towards the "Blue Economy" (GoI 2020). Such an attempt is also in sync with the central idea of *The Dasgupta Review* — that "economies are embedded within the Nature, not external to it" (Dasgupta 2021). For a comprehensive assessment of the contribution of coastal and marine ecosystem services, one must address the potential trade-offs and/or complementarities among various services to avoid overestimation and double counting and also to carry out assessments across multiple years. Future research could address some of the limitations of the present study and contribute towards the development of ocean accounts that are compatible with national accounting.

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