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Review

Ecosystem Services of Mangroves: A Systematic Review and Synthesis of Contemporary Scientific Literature

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Abstract: The paper narrates a systematic literature review on ''mangrove ecosystem services" to identify their typology, distribution, and utilization within the contemporary scientific literature. We performed a systematic review of 76 research articles derived from the Scopus database, and the dataset was scrutinized and classified against the four major categories of ecosystem services, namely provisioning, regulating, cultural, and supporting services, as per the Millennium Ecosystem Assessment (2005). We attempted to determine the existing state of the interconnectedness of mangrove ecosystem services by mapping the potential synergies and trade-offs. Further, an attempt was made to understand the critical linkages between mangrove ecosystem services and their contribution to the localization/achievement of the Sustainable Development Goals (SDGs). The results suggest disproportionate distribution of scientific literature, where nearly 56 of the studies were concentrated in Asia. The recognition of regulating the services of mangroves, particularly in carbon storage and disaster risk reduction, outnumbered the other types of ecosystem services. In particular, studies related to mangroves' cultural ecosystem services remain underrepresented. The results show a strong correlation in terms of synergies between the coastal protection ecosystem services and the high carbon sequestration ability of mangroves; and the trade-off between facilitating water transport services and the provision of fresh water. Of the 17 SDGs, three SDGs, namely, SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 14 and 15 (life below water and life on land) showed close interrelationships with the existing database. As such, the results are beneficial for coastal planners to better integrate and mainstream mangrove ecosystem services into coastal and regional planning, by maximizing synergies, encouraging the involvement of coastal communities as well as elaborating ameliorative adaptive measures.

Keywords: mangroves; ecosystem services; synergies and trade-off; Sustainable Development Goals (SDGs); bibliometric analysis

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1. Introduction

Mangroves provide an extensive array of ecosystem services that are indispensable to human well-being, particularly in the low-lying coastal areas of developing economies [1–4]. They serve as the breeding ground for aquatic fauna and an accumulation site for sediments and nutrients [5–7]. Additionally, they play a significant role in climate change adaptation and disaster risk reduction [8–12]. For instance, mangroves offer invaluable protection during typhoons and storm surges [13,14], and help in nutrient cycling and retention [15,16], and have the highest rate of carbon sequestration per area of habitat which is approximately ten times of the terrestrial ecosystems [4,17]. Such an exceptional ability to capture carbon brings them to the centre of the ongoing advocacy of Ecosystem-based mitigation and adaptation; strategies that help to harness nature and ecosystem services for a climate-resilient future [15,18,19].

Mangroves also offer several livelihood opportunities to local communities through the provisioning of fish, crabs, honey, nipa leaves, timber, fuel, and medical resources. [11,20]. These ecosystem services, such as fisheries, timber products, tourism, etc., add to the direct economic benefit of local populations in terms of income sources [21–23]. It has been estimated that the economic value of mangrove habitats ranges from USD 2772 per hectare/year up to as much as USD 80,334 per hectare/year, with an average of USD 28,662 per hectare/year [24–26]. However, owing to various anthropogenic pressures, such as coastal development, industrialization, deforestation of mangroves for palm oil plantations, expansion of rice paddies, expansion of shrimp farms for aquaculture, and environmental pollution, these coastal ecosystems are degrading at a significant pace. Between 2000 and 2010, the global losses of functioning coastal ecosystems were estimated to be approximately 1 to 2% every year [27–29]. However, recent estimates on global mangrove deforestation highlighted an annual loss of between 0.26 and 0.66/year, which is significantly lower than the previous estimates [28,29].

The concept of Ecosystem Services

To strengthen the fundamental association between human society and ecosystems, The Millennium Ecosystem Assessment has advanced the concept of ecosystem services since 2005. It provided a valuable framework for analysing ecosystem services and classified them into four utility classes, namely 'provisioning' (e.g., food and fibre, fuel, wood, construction materials, wood, medical resources), 'supporting' (e.g., nutrient cycling, soil formation, primary production, maintenance of genetic diversity), 'regulating' (e.g., climate regulation, flood and storm protection, erosion prevention) and 'cultural' (e.g., recreation, tourism, psychological benefits) services [11,20,23,30]. Over the past several years, researchers have extensively used this framework to assess and model mangrove ecosystem services across the world [11,31–33]. In general, these studies have argued for the conservation benefits of mangroves ecosystems as compared to the alternative uses [21,34,35]. To strengthen mangrove conservation policies, some recent studies have further analysed the inter-linkages of the role of mangroves and Sustainable Development Goals (SDGs) to quantify the contribution of mangroves in the global sustainability agenda [31,36–38].

Despite a plethora of research on mangrove ecosystem services, there is still a lack of integration studies, which provide a synoptic overview of the ecosystem services provided by mangrove ecosystems. Earlier, some studies mentioned that mangroves provide more than 70 ecosystem benefits/service [39]; however, to the best of our knowledge, studies that substantiate such claims from a global research perspective are not readily available. In other words, although the policy planners are now aware of the immense benefits provided by mangroves, there is a dearth of information that characterizes the nature and typology of mangrove ecosystem services, for example, which ecosystem services are appreciated most, what are the common synergies and trade-offs, etc. Such an understanding of the interrelationship of mangrove ecosystem services, i.e., the synergies and trade-offs between the different categories of mangrove ecosystem services, remains crucial for informed decision-making for coastal zone conservation, particularly at the local scale.

In this study, we aim to provide a synoptic overview of the current state of knowledge on mangrove ecosystem services as revealed in the contemporary scientific literature. Through a systematic literature review, we aim to answer the following research questions, namely (1) what are the different types of ecosystem services provided by mangroves, and how these are reflected in the contemporary scientific literature? (2) how do the mangrove ecosystem services contribute to the localization of Sustainable Development Goals (SDGs)? Lastly, (3) what are the synergies and trade-offs in the different categories of mangrove ecosystem services? Based on a systematic literature review, combined with a citation network and correlation analysis; we aim to elaborate on the current knowledge of mangrove ecosystem services and their utilization from the contemporary scientific literature. The study provides a comprehensive overview of the mangrove ecosystem services, by elucidating the interlinkages between different categories of ecosystem services and mapping the research trends on the observed inter-disciplinarily within the scientific research on mangroves.

2. Materials and Methods

2.1. Data Collection and Dataset Preparation

For this analysis, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to document systematic literature reviews as shown in Figure 1. We performed a systematic literature review using the Scopus database (https://www.scopus.com/, assessed on 8 April 2021) to collect existing literature on mangrove ecosystem services. The keywords used for the search query were in the order, KEY (mangroves) AND KEY (ecosystem AND services) AND KEY (assessment) OR KEY (monitoring) OR KEY (modelling). Considering that the concept of ecosystem services emerged in the first half of 2000 and became popular after the publication of the Millennium Ecosystem Assessment (2005), the search was limited to publications in the English language, which were published in and after 2000. The full text of all articles was retrieved from the Scopus database using the defined search criteria (n = 90) and these articles were manually screened. Articles not meeting any of the screening criteria were excluded from further analysis, i.e., (1) articles, which were not available or accessible, (2) articles, which were not relevant to the research questions, i.e., did not articulate any specific ecosystem services. After the manual screening, 76 articles fulfilled the criteria, which were considered for further analysis.

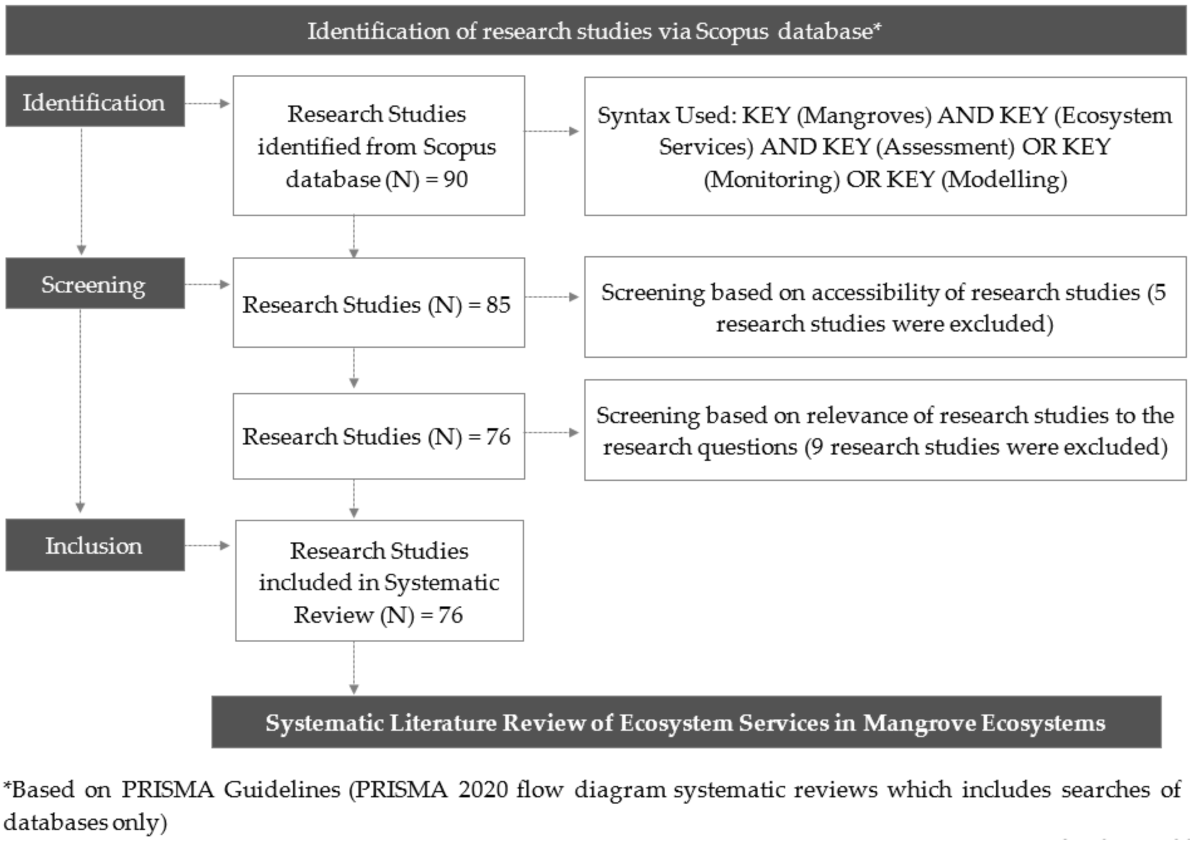


Figure 1. Methodology and search criteria used in systematic literature review for identification of research articles.

2.2. Data Analysis

At first, we tabulated the papers in a master spreadsheet and extracted the year and type of publication, the geographic origin, and the methods and models used to assess different types of mangrove ecosystem services. They were organized into four categories based on the ecosystem services classification framework of Millennium Ecosystem Assessment (2005), namely provisioning, regulating, supporting, and cultural services. Additionally, we evaluated the direct and indirect linkages between the mangrove ecosystem services and SDGs. Due to the complex dimensionality of interactions between ecosystem services and SDGs when viewed socially, economically, and environmentally, we used a thematic segregation framework based on the criteria specified in Table 1. Nonetheless, these subjective classifications might vary a little according to the location and extent of mangrove forests and their underlying relationship with the local communities.

Table 1. Description of linkages of SDGs with Mangrove Ecosystem Services.

SDG	Description of Linkage with Mangrove Ecosystem Services
Goal 1: No Poverty	The less advantaged coastal communities depend on mangrove ecosystem services especially provisioning ESs for their livelihood.
Goal 2: Zero Hunger	Dependence of local communities on mangrove forests for provisioning of food products, such as fish, crab, honey, etc.
Goal 3: Good Health and Well-being	Health, including the physical and mental well-being of communities which are dependent on the mangrove ecosystems for their livelihood.
Goal 4: Quality Education	Promote environmental education programs directed to relevant stakeholders and communities to inform them about the benefits that they receive from mangrove forests.
Goal 6: Clean Water and Sanitation	Sea-level rise causes salinization of groundwater which poses a challenge to the water supply.
Goal 8: Decent Work and Economic Growth	Enhanced risk on the livelihood opportunities for coastal communities due to the impact of climate change on mangrove ecosystems and the services received from them.
Goal 9: Industry Innovation and Infrastructure	Reducing CO_2 emissions and pollutants emitted from steel and petrochemical industries located near estuarine systems through technology development.
Goal 11: Sustainable Cities and Communities	Building resilient coastal communities through community engagement for disaster resilience, coastal protection and mangrove forest management.
Goal 12: Responsible Consumption and Production	Conversion of mangrove forests to competing land uses, e.g., aquaculture, rice and oil plantation, coconut plantation, salt ponds, more extensive shrimp cultivation, etc., emphasizes sustainable production patterns.
Goal 13: Climate Action	Impact of climate change on the health of mangrove ecosystems and role of mangrove forests as sources and sinks of C and their potential role in climate change mitigation strategies.
Goal 14: Life below Water	Relationship between mangrove ecosystems and fisheries as a key driver of decisions about investment in environmental restoration; protection of breeding ground of various fish species from unsustainable cultivation and production practices.
Goal 15: Life on Land	Degradation of mangrove forests due to anthropogenic activities affects species dependent on the canopy of mangrove forests for their habitat, mangrove forest conservation and rehabilitation practices.
Goal 17: Partnerships for the Goals	Collaboration of various organizations, e.g., IUCN and WWF at the global and regional level; and global policies, such as Reduced Emissions from Deforestation and Degradation (REDD+) that calculate net carbon savings by avoided mangrove deforestation.

The relative geographic distribution of sites mentioned in research studies was classified according to the countries of origin. Lastly, the mangrove extent base map was retrieved from the World Atlas of Mangroves (Ocean Data Viewer, 2018) and we used QGIS (3.16 Hannover) to plot the existing studies onto the base map.

Bibliometric network analysis was performed using VosViewer™ software (Version 1.6.16) for the creation, visualization, and exploration of maps based on the bibliometric network data. From the Scopus search results, we created two types of maps based on (1) the co-occurrence of keywords represented through network visualization and (2) its relationship to yearly trends, which is represented through overlay visualization. The 'Full counting method' was used and the minimum number of occurrences was set to five [40–42]. Based on the above criteria, out of 1549 keywords that were identified from the database, 78 keywords met the threshold. Each network map that was generated from the analysis contains nodes, i.e., keywords with varying sizes that determine the 'total link strength' and the thickness of the lines connecting these nodes was based on the 'link strength'.

Lastly, to identify the correlation between categories of mangrove ecosystem services, we conducted a Spearman's rank correlation test using IBM SPSS™ (Version 28.0). Spearman's Correlation Coefficient for non-parametric correlations was calculated after appropriate conversion of data into an ordinal form, wherein the correlation was considered significant at 0.05 level (2 tailed) and 0.01 level (2 tailed).

3. Results and Discussions

3.1. Spatio-Temporal Distribution and Typology of Mangrove Ecosystem Services Studies

The yearly occurrence of research studies on mangrove ecosystem services and their categories is shown in Table 2, wherein the frequency of research studies is demonstrated through a heat map. Previous studies identifying global mangrove ecosystem services [33,43] have listed 17 specific ecosystem services, [35] have identified 22 ecosystem services whereas [4] has enlisted 52 ecosystem services. The difference is most likely because some studies have provided a comprehensive list of ecosystem services whereas some focused on rather broad types of ecosystem services. It is also due to the difference in spatial scale and information availability [44]. However, in this study, based on their recurrence from various research, we observed a total of 26 specific ecosystem services that were used under the "ecosystem services" terminology. These were further synthesized into the four types of ecosystem services, i.e., provisioning, supporting, regulating, and cultural ecosystem services.

Overall, the ability of mangrove forests to store carbon was considered by 43 per cent (n = 33) of the research studies. Furthermore, coastal protection (n = 25), their contribution to nursery and breeding grounds (n = 24), and habitat for terrestrial and marine fauna (n = 23) are among the most evaluated mangrove ecosystem services. Importantly, it was observed that regulating mangroves' services remains well-articulated as compared to other ecosystem services. It is possibly due to the exceptional ability of mangrove ecosystems to hold carbon in greater magnitude compared to the tropical rainforests and other forest types [45,46], which has enhanced the inquisitiveness of researchers to have a better understanding of such climate regulating services. Additionally, it is important to understand the linkage between land-use and land-cover change and carbon flux [35,45] as a lack of proper land-use management practices can result in the degradation of mangrove ecosystem services.

It was also observed that since the year 2010, the focus has been more on regulatory ecosystem services, which can be related to the increasing global awareness about climate change and the need for climate mitigation measures. This may also be due to a series of high-intensity coastal hazards, and extreme climate events that took place starting from the Indian Ocean Tsunami in 2004 and in the following years, where mangroves played an important role in coastal protection and hazard reduction. On the contrary, studies on the cultural ecosystem services of mangroves were almost inexistent until 2010. Likewise, ecosystem services, such as biomass production, reducing eutrophication, medicines, freshwater, water transport, construction material, and prevention of soil water intrusion were not very common until 2010.

Overall, there has been a general consistency in the observed number of research studies on mangrove ecosystem services over the last decade- except in 2015-which shows a significant rise in number. This perhaps signifies the renewed global attention toward mangrove ecosystems, as a result of the adoption of the SDGs (which were adopted by world leaders in September 2015 at a historic UN Summit) (United Nations, 2015), the Sendai Framework of Disaster Risk Reduction (SFDRR) as well as the Paris Agreement in 2015.

Table 2. Frequency of research studies that developed for mangrove ecosystem services for each ecosystem service category over time. *(Note: Colour represents the number of research studies).*

	Classification	**2001**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Total**
Supporting	S1. Nutrient cycling																	18
	S2. Nursery and breeding ground																	24
	S3. Biomass production																	9
	S4. Habitat (Terrestrial and marine fauna)																	23
	S5. Reducing Eutrophication																	2
Provisioning	P1. Food Products																	16
	P2. Fuel Wood																	14
	P3. Timber Products																	17
	P4. Charcoal Production																	6
	P5. Medicines																	6
	P6. Fresh Water																	1
	P7. Fishing and Aquaculture practices																	17
	P8. Water Transport																	3
	P9. Construction Materials																	3
Regulating	R1. Climate Regulation and mitigation																	10
	R2. Coastal protection																	25
	R3. Sequester and store carbon																	33
	R4. Flood protection																	14
	R5. Storm protection																	24
	R6. Wastewater bioremediation																	14
	R7. Prevention of saltwater intrusion																	4
Cultural	C1. Tourism or Eco-Tourism																	15
	C2. Nature-based Recreation																	12
	C3. Aesthetic value																	7
	C4. Cultural Amenities																	4
	C5. Education																	4
	Total	6	8	4	3	3	19	13	23	29	55	18	28	32	39	29	16	325
	Number of research studies		1		2		3		4		5							

After elucidating the relative geographic distribution with a focus on mangrove ecosystem services, as shown in Table 3, it was found that the majority of research studies have been carried out in Asia (n = 34) and have focused on regulating ecosystem services. The high number of studies from Asia generally corresponds to the global distribution of mangroves as Asia enjoys nearly 40% of the mangrove extent. In addition, the voluminous literature on the mangrove ecosystems of Asia substantiates the strong concern of researchers and policymakers to study the protective nature of mangrove forests against the catastrophic effects of coastal risks and hazards [47]. Furthermore, Southeast Asia is the epicentre of anthropogenic mangrove deforestation, and a lot of its mangrove ecosystems are estimated to be severely impacted by sea-level rise over the next century [48]. Concerning the regional distribution of research studies, 20 per cent (n = 15) did not mention any specific region. The geographic distribution of the remaining 80 per cent (n = 61) of research studies plotted on a world map shown in Figure 2 reflects in general, 56 per cent (n = 34) of research studies concentrated in Asia. This is justifiable because approximately 40 per cent of the world's mangrove forests exists in Asia [49].

Table 3. Relative geographic distribution focused on each ecosystem services by region.

Continent	Number of Research Studies	Types of ESs							
		Supporting		Provisioning		Regulating		Cultural	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
Asia	34	24	39%	21	34%	24	39%	15	25%
Africa	6	3	5%	3	5%	5	8%	0	0%
South America	4	2	3%	1	2%	4	7%	1	2%
North America	10	7	11%	3	5%	8	13%	5	8%
Australia	5	2	3%	2	3%	5	8%	1	2%
Europe	1	0	0%	0	0%	1	2%	0	0%
Multi-regional	1	0	0%	0	0%	1	2%	0	0%

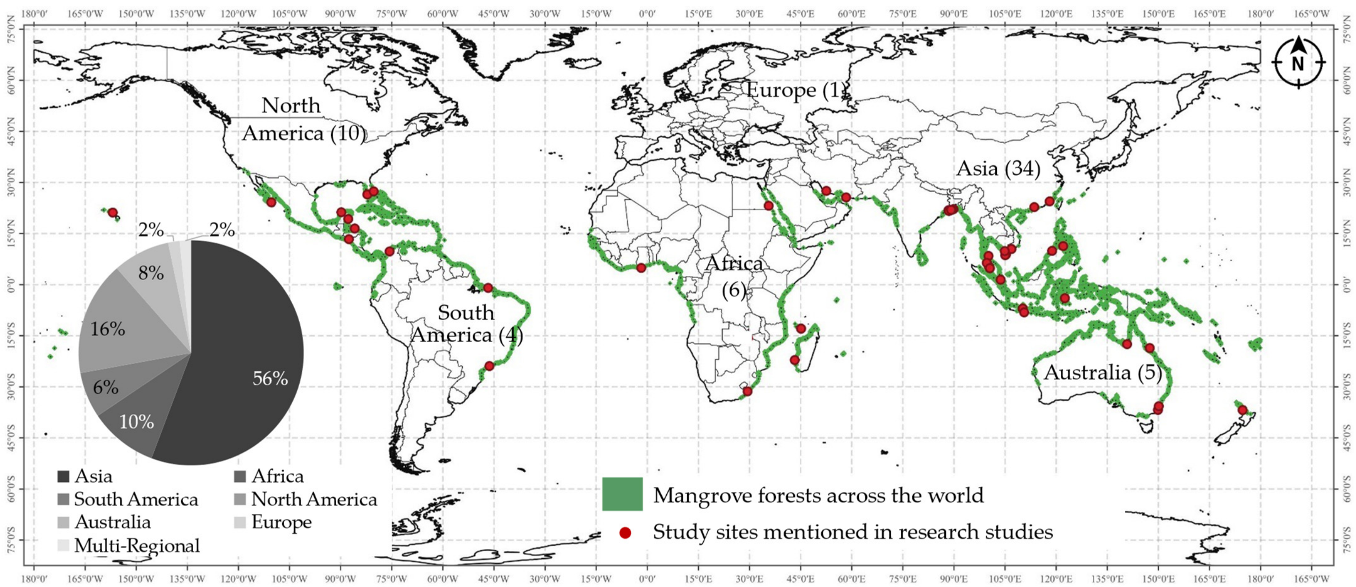


Figure 2. Geographic distribution of study sites mentioned in research studies.

3.2. Contribution of Mangrove Ecosystem Services for Localized Implementation of SDGs

We identified the linkages between mangrove ecosystem services and the 17 SDGs using a quasi-quantitative approach, using the general assumption specified in Table 1. Undeniably, the SDGs have encouraged countries across the world to achieve a better and more sustainable future. Biospeheric goals are relevant because economic, resilience and global peace relies on them. Overall, the mangrove ecosystem services contribute to 13 SDGs, but disproportionately. In particular, SDGs that exhibit close interrelationships with mangrove ecosystem services were SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) [insufficient publications] and SDG 15 (life on land), as shown in Figure 3 (see the Table S1 in Supplementary file). For instance, a good number of research studies (*n* = 30) have discussed the important role mangrove ecosystems play in climate change adaptation and mitigation, which corresponds to SDG 13, because of their adaptive capacity to climate-related hazards and natural disasters. Mangrove forests are extremely efficient at carbon sequestration; protecting them is critical to mitigating climate change. In ongoing international climate discussions conserving existing natural forests including mangroves have received immense recognition to address the Nationally Determined Contributions (NDCs) hence, protecting and restoring them can help address global climate as well as restoration targets and promises including the Bonn Challenge for Forest Landscape Restoration (FLR) and the UN Decade on Restoration, 2021.

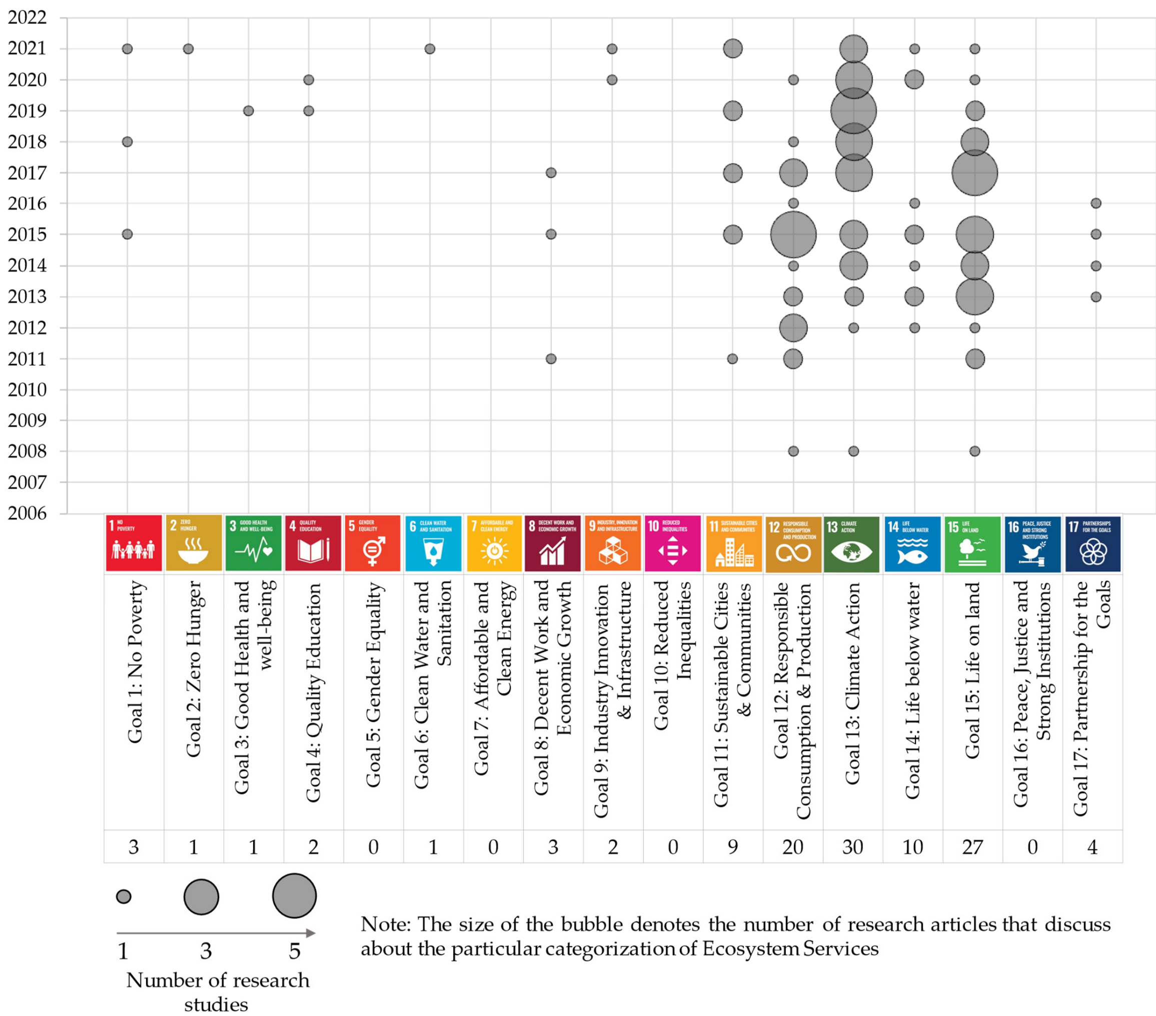


Figure 3. Research studies that demonstrated linkages with Sustainable Development Goals (SDGs) over time.

Further, in the context of SDG 15, some research studies (*n* = 27) mentioned that the degradation of mangrove ecosystems is largely driven by anthropogenic activities, such as coastal development, deforestation for agriculture activities, and the wide expansion of aquaculture practices. Lastly, another good number of research studies (*n* = 20) demonstrated that a strong relationship exists between coastal economic development activities, such as port and jetty, chemical factories, thermal power projects, intensive shrimp aquaculture, palm oil plantation, which is responsible for almost 35% of the total mangrove loss [50,51], that is against SDG 12, which aims at sustainable consumption and production patterns, especially target 12.1, i.e., sustainable management and efficient use of natural resources. For example, the vast expansion of aquaculture practices for the livelihood and income of local communities more or often compromises the delivery of diverse mangrove ecosystem services. Similarly, large scale coastal development for national or corporate interest comes at expensive cost of mangrove degradation and land use changes leading to enhanced destruction that enhances the intensity of damage due to extreme climate events and sea level rise. Nonetheless, our findings also have a significant association with SDG 14 (life below water). However, the current ecosystem studies primarily contribute to the localized implementation of three SDGs, namely SDG 12 (responsible consumption and production), 13 (climate action), and 15 (life on land) and have so far ignored or have insufficiently assessed the impact of mangrove ecosystem services on other pertinent SDGs.

3.3. Bibliometric Analysis and Correlation between the Categories of Mangrove Ecosystem Services

As shown in the network visualization diagram (Figure 4), 'mangrove' had the highest occurrences (*n* = 82) and maximum total link strength, i.e., 757 followed by 'ecosystem services' (occurrence: 63, link strength: 581) and 'ecosystem' (occurrence: 37, link strength: 387). Additionally, an overlay visualization map was created to understand the yearly trend of these linkages, as shown in Figure 5. The overlay visualization superimposes time on the keyword co-occurrence network wherein the different colours correspond to the year in which the keyword appears the maximum number of times. The keywords "carbon", "forestry", "remote sensing", "carbon sequestration", etc., were focused on the research studies as late as the year 2017. In contrast, certain keywords e.g., "climate change", "aquaculture", "coastal zone", etc., mainly appeared in 2014.

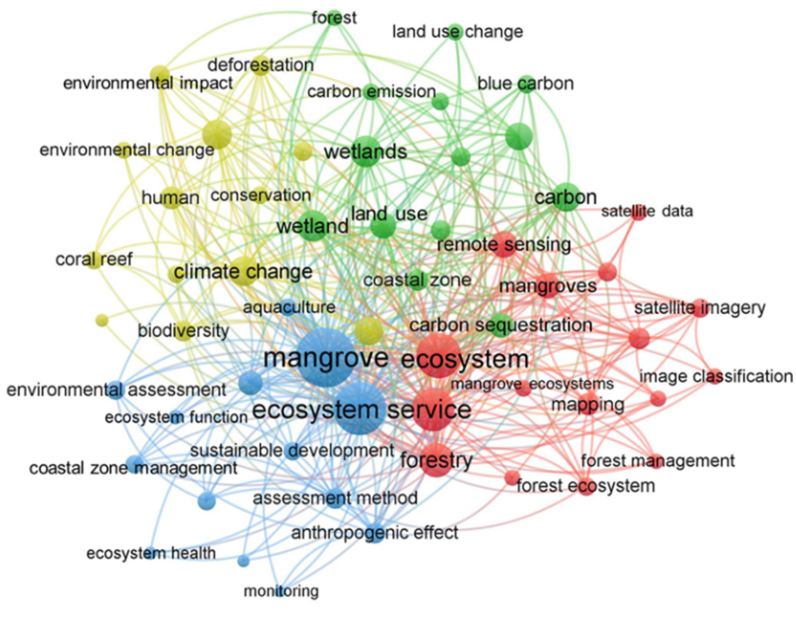


Figure 4. Network visualization denoting the keywords, which have highest number of co-occurrences through nodes, and line width connecting these nodes varies according to link strength.

The Venn diagram shown in Figure 6 demonstrates overlaps between the categories of ecosystem services. It was evident that numerous research studies discussed more than one category of ecosystem services (see Tables S2 and S3 in the Supplementary Material). As such, researchers have evaluated regulating ES (*n* = 62) more as compared to supporting ES (*n* = 52) or provisioning ES (*n* = 37) or cultural ES (*n* = 24). It can also be observed that the research studies which mention supporting and regulating ecosystem services have a maximum intersection (*n* = 42) and maximum number (*n* = 12) of research studies have exclusively discussed regulating ecosystem services.

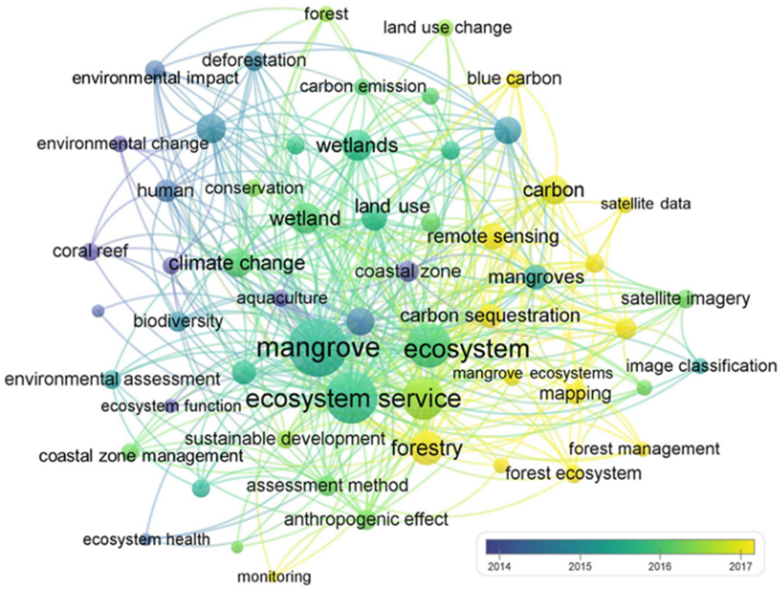
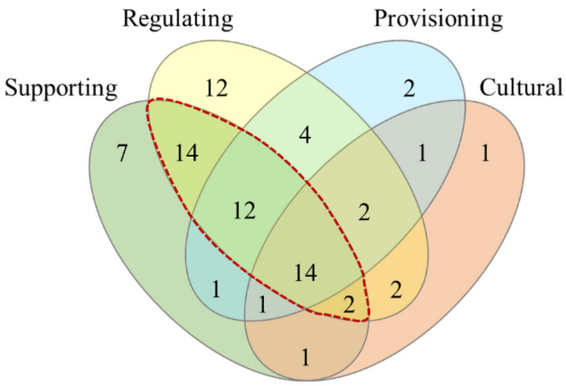


Figure 5. Overlay visualization superimposing time on keyword co-occurrence network.



Ecosystem Services	Number of research studies
Supporting (S)	52
Regulating (R)	62
Provisioning (P)	37
Cultural (C)	24
S ∩ R	42
R ∩ P	32
P ∩ C	18
C ∩ S	18

Figure 6. Overlap between the types of ESs.

All combined, the research studies reported a total of 325 individual ecosystem services (n = 325) (e.g., if a study discussed three types of regulating ecosystem services and two types of provisioning ES, then we counted it as five ecosystem services). The number of research studies that mention each sub-category of mangrove ecosystem services is shown in Table 2. To have an in-depth understanding of the degree of relationship between the sub-categories of mangrove ecosystem services, Spearman's correlation coefficient (r) was calculated as shown in Table 4. The correlations were evaluated based on the likely trade-offs and synergy among the ecosystem services across the sub-category level. The trade-off can be defined as a situation when the uses of one ES directly or indirectly decrease or affects another ES, whereas synergy is a situation when the use of one ES is increasing the benefits of another ES [33]. In this case, a negative correlation between two ecosystem services demonstrates a trade-off scenario and a positive correlation demonstrates a synergistic relationship between the two ecosystem services. The two sub-categories of regulation ecosystem services, i.e., coastal protection (R2) and sequestration and storage of carbon (R3) exhibited the strongest positive correlation (r = 0.963) whereas freshwater (P6) and water transport (P8) demonstrated the strongest negative correlation (r = −0.400). The first case can be explained as the case of co-benefits, e.g., a healthy vegetation offers best protection while also supports carbon sequestration.

Table 4. Spearman correlation coefficient showing degree of relationship between mangroves ecosystem services.

	Supporting					**Provisioning**									**Regulating**							**Cultural**				
Spearman Correlation Coefficient (r)	**Nutrient Cycling**	**Nursery and Breeding Ground**	**Biomass Production**	**Habitat (Terrestrial and Marine Fauna)**	**Reducing Eutrophication**	**Food Products**	**Fuel Wood**	**Timber Products**	**Charcoal Production**	**Medicines**	**Fresh Water**	**Fishing and Aquaculture Practices**	**Water Transport (Ports)**	**Construction Materials**	**Climate Regulation and Mitigation**	**Coastal Protection**	**Sequester and Store Carbon**	**Flood Protection**	**Storm Protection**	**Wastewater Bioremediation**	**Prevention of Salt Water Intrusion**	**Tourism or Eco-Tourism**	**Nature-based Recreation**	**Aesthetic Value**	**Cultural Amenities**	**Education**
	S1	**S2**	**S3**	**S4**	**S5**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**C1**	**C2**	**C3**	**C4**	**C5**
S1																										
S2	0.661 **																									
S3	0.543 **	0.616 **																								
S4	0.743 **	0.934 **	0.560 **																							
S5	0.175	−0.261	−0.148	−0.174																						
P1	0.634 **	0.833 **	0.548 **	0.752 **	−0.223																					
P2	0.617 **	0.744 **	0.155	0.753 **	−0.253	0.768 **																				
P3	0.717 **	0.871 **	0.476 *	0.828 **	−0.281	0.872 **	0.893 **																			
P4	0.489 *	0.611 **	0.045	0.572 **	−0.238	0.543 **	0.824 **	0.799 **																		
P5	0.566 **	0.393 *	0.158	0.489 *	−0.158	0.583 **	0.638 **	0.504 **	0.415 *																	
P6	0.029	0.107	−0.218	0.100	−0.123	0.207	0.366	0.172	0.198	0.145																
P7	0.803 **	0.765 **	0.634 **	0.857 **	−0.117	0.663 **	0.550 **	0.653 **	0.362	0.671 **	−0.036															
P8	0.356	0.165	0.489 *	0.275	−0.174	0.103	−0.087	0.071	−0.175	0.378	−0.400 *	0.563 **														
P9	0.110	0.557 **	0.491 *	0.411 *	−0.272	0.628 **	0.370	0.527 **	0.165	0.002	0.162	0.160	−0.145													

Table 4. *Cont.*

Spearman Correlation Coefficient (r)	Supporting					Provisioning									Regulating								Cultural			
	Nutrient Cycling	Nursery and Breeding Ground	Biomass Production	Habitat (Terrestrial and Marine Fauna)	Reducing Eutrophication	Food Products	Fuel Wood	Timber Products	Charcoal Production	Medicines	Fresh Water	Fishing and Aquaculture Practices	Water Transport (Ports)	Construction Materials	Climate Regulation and Mitigation	Coastal Protection	Sequester and Store Carbon	Flood Protection	Storm Protection	Wastewater Bioremediation	Prevention of Salt Water Intrusion	Tourism or Eco-Tourism	Nature-based Recreation	Aesthetic Value	Cultural Amenities	Education
R1	0.870 **	0.595 **	0.373	0.722 **	−0.097	0.564 **	0.691 **	0.726 **	0.601 **	0.678 **	−0.036	0.757 **	0.443 *	−0.005												
R2	0.746 **	0.899 **	0.761 **	0.878 **	−0.242	0.815 **	0.599 **	0.767 **	0.353	0.502 **	0.050	0.891 **	0.422 *	0.511 **	0.629 **											
R3	0.656 **	0.860 **	0.783 **	0.813 **	−0.281	0.744 **	0.491 *	0.679 **	0.293	0.446 *	0.000	0.861 **	0.463 *	0.481 *	0.520 **	0.963 **										
R4	0.711 **	0.921 **	0.601 **	0.859 **	−0.243	0.818 **	0.744 **	0.912 **	0.629 **	0.333	0.072	0.659 **	0.210	0.561 **	0.693 **	0.825 **	0.768 **									
R5	0.611 **	0.914 **	0.767 **	0.823 **	−0.222	0.838 **	0.595 **	0.831 **	0.447 *	0.215	0.050	0.632 **	0.145	0.739 **	0.492 *	0.857 **	0.821 **	0.917 **								
R6	0.897 **	0.728 **	0.696 **	0.753 **	−0.010	0.746 **	0.552 **	0.761 **	0.477 *	0.522 **	−0.129	0.831 **	0.458 *	0.226	0.821 **	0.802 **	0.730 **	0.770 **	0.726 **							
R7	0.284	0.642 **	0.128	0.622 **	−0.199	0.450 *	0.620 **	0.637 **	0.595 **	0.043	0.081	0.243	−0.136	0.571 **	0.350	0.399 *	0.347	0.688 **	0.601 **	0.294						
C1	0.669 **	0.767 **	0.808 **	0.687 **	−0.263	0.746 **	0.413 *	0.649 **	0.270	0.474 *	−0.130	0.804 **	0.568 **	0.410 *	0.568 **	0.891 **	0.919 **	0.743 **	0.771 **	0.817 **	0.256					
C2	0.838 **	0.668 **	0.349	0.765 **	−0.098	0.616 **	0.709 **	0.722 **	0.627 **	0.682 **	0.036	0.780 **	0.390 *	0.080	0.931 **	0.663 **	0.588 **	0.715 **	0.535 **	0.810 **	0.481 *	0.604 **				
C3	0.510 **	0.597 **	0.252	0.706 **	−0.286	0.377	0.530 **	0.496 *	0.507 **	0.568 **	−0.102	0.735 **	0.438 *	−0.005	0.660 **	0.571 **	0.570 **	0.494 *	0.348	0.508 **	0.474 *	0.473 *	0.778 **			
C4	0.439 *	0.311	0.294	0.420 *	−0.212	0.102	0.302	0.385	0.321	0.129	−0.193	0.318	0.459 *	0.029	0.653 **	0.284	0.231	0.508 **	0.313	0.412 *	0.501 **	0.256	0.623 **	0.554 **		
C5	0.319	0.085	0.080	0.199	−0.218	0.086	0.233	0.112	0.193	0.699 **	−0.176	0.502 **	0.519 **	−0.379	0.496 **	0.214	0.228	0.006	−0.131	0.316	−0.146	0.257	0.543 **	0.682 **	0.313	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). If $r = 1$, the correlation is said to be perfect positive. If $r = -1$, the correlation is said to be perfect negative. If $r = 0$, the variables X and Y are said to be uncorrelated. If $0 < r \geq 0.4$, low correlation. If $0.4 \leq r < 0.7$, moderate correlation. If $0.7 \leq r < 1$, high correlation. [52].

Ecological interactions suggest that there is a connectivity between various constituents of coastal ecosystems which impact the availability and/or quality of ecosystems services for human well-being. Hence, it is important to take into consideration the synergistic characteristics of ecosystem services for their comprehensive assessment [21]. Over the past few decades, numerous research studies have been carried out for the economic valuation of mangrove ecosystem services; nonetheless, there are very few research studies that have evaluated the synergies and trade-offs between types of ecosystem services. The Spearman correlation coefficient calculated in the study demonstrated not only a synergistic relationship between the categories of ecosystem services but also a trade-off relationship, such as a decrease in the capability of mangrove forests to reduce eutrophication has a significant impact on ecosystem services, e.g., timber production, carbon sequestration and aesthetic value of mangrove forests. However, these correlations also exhibit spatio-temporal variations, which were not examined in our research study. For example, if a region focuses on improving the provisioning services (e.g., food) through the use of chemical fertilizers and pesticides, will result in economic benefits but will result in a long-term trade-off between regulating ecosystem services and provisioning ecosystem services [53]. This trade-off will be significant as it can hamper the health of the ecosystem and may also lead to the collapse of natural mangrove ecosystem services.

4. Limitations of the Study

Although we attempted to synthesize a large number of research studies on mangrove ecosystem services, the results should be interpreted with some caution. First, the selection criteria excluded the research studies not directly related to mangrove ecosystem services, which might have overlooked some literature that did not specifically use the term "ecosystem services". Additionally, scrutinizing the identified research studies (n = 90) from the Scopus database, we identified that although some studies mentioned the keywords, they were not exclusively relevant to the research questions. Further, using the Scopus database as the only data source has also caused some limitations, as only selected journals are integrated into the database. Excluding all non-English literature from our study is also one of the limitations. Further, the evaluation of research studies for the sub-categorization of ecosystem services and their linkages with SDGs were based on the quasi-quantitative approach and can vary based on the observer's outlook. Moreover, the Spearman correlation coefficient determined in the study does not consider the spatio-temporal variations of sub-categories of ecosystem services. Being familiar with the limits of our approach, we nevertheless believe that, regardless of the bias mentioned above, our dataset is robust enough to represent the existing state of the research landscape on mangrove ecosystem services, synergies and trade-offs and their potential to localize SDGs.

5. Conclusions

The attempt to map the research landscape of mangrove ecosystem services by synthesizing the contemporary scientific literature yielded a better perspective and understanding on the context. Considering the complex dimensionality of socio-ecological interactions between the mangrove ecosystem services, categorizing them into 26 ecosystem services gave a broader overview regarding nature's contributions for human well-being. The evaluation helped to understand the inter-connectedness of ecosystem services in terms of synergies and trade-offs. Present synthesis clearly reflects the dominant bias of existing research studies towards regulating ecosystem services. Whereas, in contrast, cultural ecosystem services have been somewhat overlooked as high economic benefits were not directly linked to it. The quasi-quantitative approach adopted for the evaluation of research studies clearly demonstrated that a strong relationship exists between mangrove ecosystem services and their role in localizing SDGs, particularly for SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land). However, though not documented in research papers it is clear that in achieving SDG 12, 13 and 15 mangroves ecosystem services will help in achieving in other SDGs viz. SDG 1 (no poverty), SDG 5 (gender equality), SDG 8 (decent work and economic growth), SDG 10 (reduced inequality), etc. Lastly, the Spearman correlation coefficient (r) calculated to have an in-depth understanding of the degree of relationship between the sub-categories of mangrove ecosystem services, and demonstrated that a strong synergistic relationship (r = 0.963) exists between coastal protection and carbon sequestration. In contrast, the strongest negative correlation (r = −0.400) exists between freshwater provision (P6) and water transport (P8). Since this research does not consider the spatio-temporal variations while evaluating the correlation between categories of ecosystem services, more research is needed to understand such spatial association between types of ecosystem services. Nonetheless, the synthesis of knowledge provided in this paper can be of immense benefit for policymakers to advocate decisions at the local level and mainstream mangrove benefits and their participatory conservation for localizing SDGs. This study can further act as the basis for decision-making to promote sustainable forest management, mangrove restoration, and rehabilitation for the well-being of marginalised coastal communities in light of sea level rise and increasing extreme climate events in coastal areas.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141912051/s1, Table S1: Number of research studies that have linkages with Sustainable Development Goals; Table S2: Number of research studies that mention about each sub-category of mangrove ESs; Table S3: List of research studies based on categorization of ESs.

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