Global Ocean Accounts Partnership

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Ecosystem Services Factors

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Table of Contents

List of Figures

List of Tables

Summary

This report consists of mainly two aspects: 1) compilation of coastal ecosystem services factors at a global level, which is expected to enable a more coherent measurement of ocean services and the production of ocean accounts; and 2) a set of stepwise guidance for users/policymakers on how to use the data compilation as part of the development, maintenance, and use of ocean accounts.

Purpose of the Report

The objectives of this report are:

1. Identifying the coastal ecosystem services factors (particularly on mangroves, coral reef, and seagrass) and documenting the measurement or valuation methods and assumptions under which the factors or indicators were made.
2. Developing a process guide that will support the selection and use of appropriate ecosystem services factors for the compilation of a supply and use table for ocean services.
3. Engaging key stakeholders to ensure relevance of work is practically doable and to consult data gaps if needed.

The objectives above are relevant under the following conditions:

- Accounting for ocean services in physical terms will require mapping of those ecosystem types and the Ecosystem Services Factors to estimate the quantities of services provided per unit. Currently, there are no comprehensive global databases of such factors readily available.
- In addition, using these factors in ocean accounting will require an understanding of how to apply them. Since each factor was produced based on specific assumptions about the ecosystem type, the extent, the condition of the extent, the service being measured, the method being applied and the conditions under which the measurement was made.

Methodology

Framework for analysis

A literature review, including peer-reviewed papers and grey literature, will be a key strategy for achieving the main goal of this report. The framework for compilation of ecosystem services factors has been developed in line with GOAP Technical Guidance on Ocean Accounting as to provide consistency with such existing work.

The document highlights the types of services for mangroves, coral reef, and seagrass – respectively based on the following ecosystem service classifications: provisioning, regulating and cultural. The list of information presented in the Appendix 5 of this report is as follows:

- Coastal ecosystems: mangrove, coral reef, and seagrass.
- Ecosystem service classification: provisioning, regulating, and cultural
- Ecosystem service types: e.g., carbon sequestration, fisheries-related service, cultural, tourism, etc. The types are aligned with the GOAP Technical Guidance on Ocean Accounting and other recent and relevant literatures.
- Method: information on the methodology used for calculating the ecosystem service factors.

- Indicator: a physical quantity or factor that represents a unit of ecosystem service. For example: ton of CO2 equivalent per hectare per year (tCO2 eq/ha/year) for carbon sequestration, trip/year for recreation/tourism.
- Unit factor: the number of ecosystem service physical quantities/factors per unit, for corresponding ecosystem (mangrove/coral reef/seagrass). For example, in one hectare of living mangrove biomass may provide 50 tons pf CO2 equivalent of carbon sequestration per year. In this case, the "value" of carbon sequestration is 50. The corresponding "unit" is tCO2eq/ha/year.
- Value: information on the number of physical factors from the study assessed.
- Assumptions: information on any key assumptions explicitly mentioned.
- Location: the specific location or country in which the ecosystem service study is conducted.
- Sources: link containing the corresponding data which can be cited, including website.

Data collection

There are two major data sources involved in the data collection process. The first consideration is the available database (if any) on various websites. The second category consists of peer-reviewed research articles and technical reports on coastal ecosystem valuation, specifically those that discuss the biophysical indicators in the study.

The sources extracted from the websites are listed in the data compilation table in the Appendix. The following is a list of relevant websites:

1. IUCN Tools for measuring, modelling, and valuing ecosystem services. This page is more of a guide on measuring, collecting, and estimating the value of any ecosystem service, not just coastal ecosystem services. The guidebook can be downloaded for free. It's useful for anyone who needs help choosing a measurement or modelling tool to assess their sites for biodiversity and nature conservation, such as Key Biodiversity Areas (KBAs), natural World Heritage Sites (WHS), and protected areas like Marine Protected Areas (MPAs). This publication is a valuable resource for valuing services in coastal ecosystems, even though it does not expressly give case studies or references about the physical elements of coastal ecosystems. It contains a conceptual explanation of why we need to measure, model, or value ecosystem services and which tool suits a specific site. The document provides a more detailed description of each tool, along with the case studies.
2. ValuES is a global project that assists decision-makers in our partner countries in recognizing and integrating ecosystem services into policy development, planning, and implementation of specific projects. It offers a variety of instruments as well as training courses. This project also offers technical assistance and aids in the planning and decision-making processes. It has a wide range of valuation techniques based on the assessment purpose. For example, the Q technique is recommended for estimating ecosystem service valuation from the standpoint of users. Even though this website does not provide case studies or references on physical factors affecting coastal ecosystems, it does contain some case studies that are useful to users. This website also links to other relevant websites, such as The Economics of Ecosystem and Biodiversity (TEEB), Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES), Sub-Global Assessment (SGA) Network, Ecosystem Services Partnership (ESP), World Resources Institute (WRI), DFID Topic Guide on ecosystem services and development (2014). From the users' perspective, it is interesting to check the stepwise approach to integrate ecosystem services into plans, programs, and concrete development-related decisions.
3. Canadian Ecosystem Services Toolkit. This is the official website of the Canadian government, containing a technical document that will assist in the assessment and analysis of ecosystem services. It is a comprehensive document that includes an interdisciplinary toolset for managers and analysts, as well as a conceptual and analytical framework, including

steps to perform an ecosystem services assessment. It discusses a case study of ecosystem services valuation in Canada. However, when it comes to the coastal ecosystem, this document lacks case studies or references to physical factors. This document demonstrates how to use ecosystem services analysis in a range of policy contexts such as spatial planning, environmental assessment, and wildlife management. The technical guideline document is available for free download.

4. Environmental Valuation Reference Inventory. This website has a searchable database of empirical studies on its economic value, including physical factors, as well as human health consequences. However, there is no physical factor in coastal ecosystems. Over 4600 studies of ecosystem services value are included in the database. It's worth noting that the database does not provide clear monetary value estimates per coverage area, such as value unit per hectare. Registration is required to access the database information on this website. Information that can be extracted from this website are, for example, study location, type of environmental assets being valued, methodological approaches and the estimated monetary values of the specific studies. Log in is required to search for specific study on coastal ecosystems. After logging in, the most recent research is presented immediately. There is no specific option for coastal ecosystems in the database. In fact, some keywords related to coastal ecosystem such as coral, seagrass and mangrove, are not immediately found in the search box (search by keywords).
5. Ecosystem Services Valuation Database. This website contains data on the economic welfare values of ecosystem services expressed in monetary units. Despite its emphasis on monetary value, physical factors relating to the coastal ecosystem, for example, hectares of mangrove area, are available for a particular study. We can narrow down our search according to some categories including type of ecosystem, a specific country or continent, the status of biodiversity or area, and status based on TEEB ES services and CICES. In addition, references to the study, for example title, year of publication, and authors, are also presented in the database. Our search can be downloaded as a CSV file. Logging in is required to search for specific study on coastal ecosystems. Over 6,700 value records from over 950 studies are presently stored on the website across all biomes, ecosystem services and geographic regions. Note that this summary of values is for illustrative purposes only and is meant to provide an impression of the order of magnitude of the values obtained from the literature and to identify data gaps. It is not advised to use these summary statistics for value transfers since they reflect the underlying ecological and socio-economic contexts of diverse (but not necessarily representative) study sites.
6. TNC Mapping Ocean Wealth. This website provides information gathered through scientific publications, communications, and policy work. The website was conceptualized and incubated in partnership with the World Bank, led by The Nature Conservancy. Information according to the type of ecosystem services, for example, carbon storage and sequestration, coastal protection, fisheries, and tourism, is available with interactive maps for some countries. Selection of a country depends on data availability. There are five ecosystem services provided on the website: carbon storage and sequestration, coastal protection, filtration, fisheries, and recreation and tourism. Coastal ecosystems, including coral reefs, mangrove, seagrass, and other type of habitats are provided. The database information from this resource could be applied in the field of, for example, mangrove restoration plan, marine spatial planning, marine protected areas, restoration, financial instrument, estimation of fish production, and decision support tools. To extract relevant information regarding physical factor, for example, total coral reefs area and fish biomass, references cited on this website become useful sources that need to be checked. References are not limited to scientific publications; they also include policy briefs. Particularly to this report, there are some technical reports under the "science publication by ecosystems" category, including in the compilation

table in the Appendix. The reports are mostly based on The Nature Conservancy and Wetland International work on several of their project sites.

7. WRI resource watch platform. This website provides data and information that policymakers need to make better-informed decisions about sustainable ocean management. The website is still in a Beta version; thus, a detail information is not yet accessible. Further examination needs to be done to determine what kind of physical factor could be extracted from this website. There is no specific data about coastal ecosystems. Some aggregate data could be extracted from three categories: ocean and climate change, ocean biodiversity, and marine protected areas. Selection of several coastal locations is available by selecting a country, for example: Indonesia. However, the data that is displayed on the website is insufficient to be justified in contributing to this study. It only depicts a large summary of figures without describing the methodological approach that has been applied in obtaining the data.

In addition to the aforementioned data sources, a literature review focused on the physical valuation of coastal ecosystem services was conducted to fill remaining gaps in value. The main source is a research paper titled: The value of estuarine and coastal ecosystem services (Barbier, E.B., et al., 2011), this includes cited references on coastal ecosystem valuation (including mangrove, seagrass, coral reef).

The criteria for identifying screening relevant studies are:

- Publication types include journal articles, working papers, conference papers, technical reports, policy briefs, NGO reports, and other grey literature.
- Year of publication is not older than year 2000, except for the grey literature.
- Geographic location focuses on tropical countries and for a meta-analysis study is at a global or regional level.
- Ecosystems focus only on coral reefs, mangrove, and seagrass.
- Ecosystem services includes all sub-services under provision, regulating and cultural types of services.
- Valuation metric in physical unit as a priority, however, if relevant the monetary units could be included.
- Valuation method focuses on a primary method, including qualitative, quantitative, mixed, modelling, and laboratory work that can be adopted by practitioners
- Assumption given in the reference should help users understand the context of their case

A snowball search strategy is implemented to collect references. In principle, a snowball literature review strategy executed in several steps: first, identify and start reviewing the main sources; second, continue reviewing the literature that is cited in our main sources (looking backwards); third, continue reviewing the literature that is cited in our main sources (looking forwards); fourth, combine and iterate the step 2 and 3 as necessary until saturation is attained. This strategy was modified from Fielke, Taylor, and Jakku (2020) approach.

It started with a few relevant articles resulting from a quick traditional search with a Boolean keyword strategy. The relevant literature was searched according to the Boolean keyword strategy, mostly from the Ecosystem Services journal on Science Direct specifically within the category of research and review articles. Some examples of the Boolean keywords that have been used in this review are coral OR reef AND mangrove AND seagrass AND ecosystem AND services AND factor OR indicator AND physical AND asset OR value AND valuation NOT monetary. PRISMA protocol was used to guide the selection, resulting in 13 papers. To complete the papers resulting from the PRISMA protocol, there are an additional 8 papers as the seed papers. The seed papers are relevant papers that we select, according to the same selection criteria mentioned above, from the references list of the GOAP Technical Guidance on Ocean Accounting document, including for example studies authored by Alongi, D. M., et al (2016) and Barbier, E. B., et al (2011). Eventually, there are 21 papers called as the initial set of papers to enter snowball literature search approach. Please see the appendix (Boolean search protocol and snowball literature scheme) for the selection procedure. The 21 papers are as follows:

1. Beck, M.W., Losada, I.J., Menéndez, P. et al. The global flood protection savings provided by coral reefs. Nat Commun 9, 2186 (2018). https://doi.org/10.1038/s41467-018-04568-z
2. Andreas J. Andersson, Fred T. Mackenzie and Abraham Lerman. Coastal ocean and carbonate systems in the high CO2 world of the Anthropocene. American Journal of Science November 2005, 305 (9) 875-918; DOI: https://doi.org/10.2475/ajs.305.9.875
3. Pet-Soede, C., van Densen, W. L. T., Pet, J. S., & Machiels, M. A. M. (2001). Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. In Fisheries Research (Vol. 51, Issue 1, pp. 35–51). Elsevier BV. https://doi.org/10.1016/s0165-7836(00)00236-8
4. Brander, L. M., Van Beukering, P., & Cesar, H. S. J. (2007). The recreational value of coral reefs: A meta-analysis. In Ecological Economics (Vol. 63, Issue 1, pp. 209–218). Elsevier BV. https://doi.org/10.1016/j.ecolecon.2006.11.002
5. Estimating reef-adjacent tourism values in the Caribbean. Spalding, M., Longley-Wood, K., Acosta-Morel, M., Cole, A., Wood, S., Haberland, C., Ferdana, Z. Published by The Nature Conservancy (2019).
6. Murdiyarso, D., Purbopuspito, J., Kauffman, J. et al. The potential of Indonesian mangrove forests for global climate change mitigation. Nature Clim Change 5, 1089–1092 (2015). https://doi.org/10.1038/nclimate2734
7. Alongi, D.M., Murdiyarso, D., Fourqurean, J.W. et al. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecol Manage 24, 3–13 (2016). https://doi.org/10.1007/s11273-015-9446-y
8. Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193. https://doi.org/10.1890/10-1510.1
9. Wahyudi, A.J., Rahmawati, S., Irawan, A. et al. Assessing Carbon Stock and Sequestration of the Tropical Seagrass Meadows in Indonesia. Ocean Sci. J. 55, 85–97 (2020). https://doi.org/10.1007/s12601-020-0003-0
10. Lavery, P. S., Mateo, M.-Á., Serrano, O., & Rozaimi, M. (2013). Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. In J. F. Valentine (Ed.), PLoS ONE (Vol. 8, Issue 9, p. e73748). Public Library of Science (PLoS). https://doi.org/10.1371/journal.pone.0073748
11. Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J., & van Belzen, J. (2014). The role of seagrasses in coastal protection in a changing climate. In Coastal Engineering (Vol. 87, pp. 158–168). Elsevier BV. https://doi.org/10.1016/j.coastaleng.2013.11.005
12. Jänes, H., Carnell, P., Young, M., Ierodiaconou, D., Jenkins, G. P., Hamer, P., Zu Ermgassen, P. S. E., Gair, J. R., & Macreadie, P. I. (2021). Seagrass valuation from fish abundance, biomass and recreational catch. In Ecological Indicators (Vol. 130, p. 108097). Elsevier BV. https://doi.org/10.1016/j.ecolind.2021.108097
13. Bandaranayake, W. Traditional and medicinal uses of mangroves. Mangroves and Salt Marshes 2, 133–148 (1998). https://doi.org/10.1023/A:1009988607044
14. Pascal, N., Allenbach, M., Brathwaite, A., Burke, L., Le Port, G., & Clua, E. (2016). Economic valuation of coral reef ecosystem service of coastal protection: A pragmatic approach. In Ecosystem Services (Vol. 21, pp. 72–80). Elsevier BV. https://doi.org/10.1016/j.ecoser.2016.07.005
15. Marshall N, Marshall P, Curnock M, PertP, Smith A, Visperas B (2019) Identifying indicators of aesthetics in the Great Barrier Reef for the purposes of management. PLoS ONE 14(2): e0210196. https://doi.org/10.1371/journal.pone.0210196

16. Uddin, M. S., de Ruyter van Steveninck, E., Stuip, M., & Shah, M. A. (2013). Economic valuation of provisioning and cultural services of a protected mangrove ecosystem: A case study on sundarbans reserve forest, Bangladesh. Ecosystem Services, 5, 88–93. https://doi.org/10.1016/j.ecoser.2013.07.002
17. Reduction of Wind and Swell Waves by Mangroves. McIvor, A. L., Möller, I., Spencer, T., and Spalding, M. Natural Coastal Protection Series: Report 1: The Nature Conservancy and Wetlands International. (2012)
18. Badola, R., & Hussain, S. (2005). Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation, 32(1), 85-92. https://doi.org/10.1017/S0376892905001967
19. de la Torre-Castro, M., & Rönnbäck, P. (2004). Links between humans and seagrasses—an example from tropical East Africa. Ocean & Coastal Management, 47(7–8), 361–387. https://doi.org/10.1016/j.ocecoaman.2004.07.005
20. Balzan, M. V., Potschin-Young, M., & Haines-Young, R. (2018). Island ecosystem services: insights from a literature review on case-study island ecosystem services and future prospects. International Journal of Biodiversity Science, Ecosystems Services & Management, 14(1), 71–90. https://doi.org/10.1080/21513732.2018.1439103
21. Langle-Flores, A., & Quijas, S. (2020). A systematic review of ecosystem services of Islas Marietas National Park, Mexico, an insular marine protected area. Ecosystem Services, 46(101214), 101214. https://doi.org/10.1016/j.ecoser.2020.101214

Once the initial papers are decided, it continued with reference tracking (backward looking) and citation tracking (forward looking). Reference tracking means that we checked the reference list of the seed paper to identify the next paper to review. In addition, citation tracking looks by identifying which papers are citing the seed paper in their study. A feature known as citation tracking (available in Google Scholar and other large online databases) helps with this step (Greenhalgh, T., Peacock, R., 2005). The list of the final set of articles for review is available in the Appendix 4, in compilation table of all ecosystems.

Findings: Compilation of factors

The final set of articles for review consists of 66 studies, 59 peer-reviewed article and 7 grey literatures (technical report). There are 20 studies of coral reefs ecosystem, 25 studies of mangrove ecosystem, 16 studies of seagrass ecosystem, and 5 studies of coastal ecosystem as a focus of the study. Most of the studies discussed the regulating services (30 studies), followed by the provisioning (16 studies) and cultural services (15 studies). Figure 1 below depicts a portion of the study regarding the type of services per ecosystem in this report.

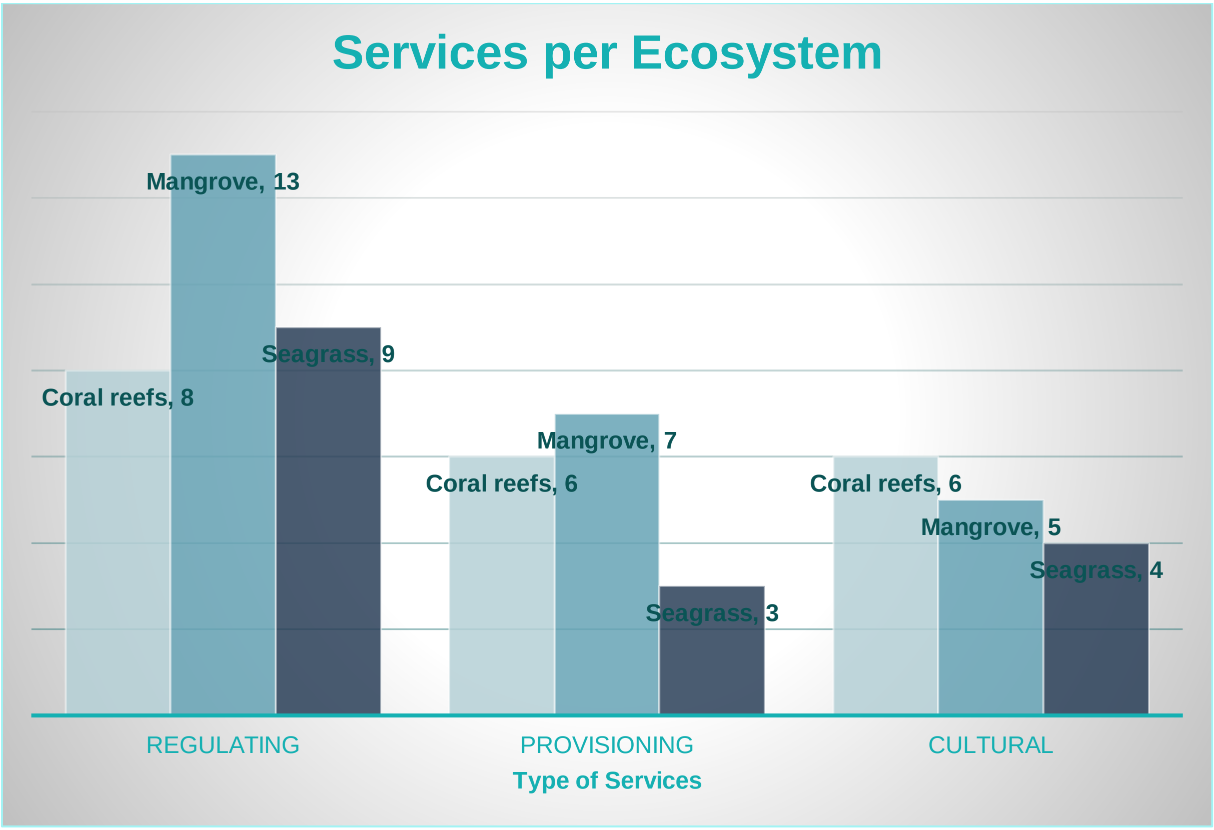


Figure 1. Type of service per ecosystem

Mangrove ecosystem service factors

Mangrove is a coastal vegetation located in brackish water that is influenced by low and high tidal areas. Usually, mangrove ecosystems exist in the tropics and will diminish in the subtropics throughout the world. This ecosystem has provided numerous services for centuries, including direct and indirect use of mangrove. In this report, 25 studies have been reviewed to improve our understanding particularly of the biophysical indicator. The studies include both peer-reviewed papers and grey literature such as project technical reports.

In summary, regulating type of services is dominant in comparison to provisioning and cultural services. There are 13 studies on regulating services in this report. The services are, for example: blue carbon or carbon stock valuation, purifying water, and coastal protection from hurricane, storm, and flood. In addition, some provisioning services are mangrove function in improving fisheries production, and raw materials provision for traditional and medicinal use. Finally, from a cultural perspective, several studies have been conducted about mangrove's contribution to tourism, education and research, and social-ecological-economic value.

Physical factors or indicators depend on the type of service, methodological approach, and objective of the respective study. Mangrove's contribution to the blue carbon study is prominent and thus represents a majority in comparison with other studies in this report. Blue carbon-related factors are indicated by the above and below ground organic carbon content (gr C/ha), dried weight (gr), soil sample, and total nitrogen stock (gr N/ha). In addition, mangrove biomass is indicated by its canopy height (meters) and diameter breast height (meters) per plotted sample area.

Coastal protection services provided by mangroves, both directly and indirectly, have been researched in several locations, including the United States, the Philippines, and India. Hurricane, flood, and storm protection research uses a quantitative modelling strategy based on secondary data sets from weather forecast agencies and satellites. As a result, the physical factor for this type of service is quite numerical, and if we want to use it, it must be standardized.

Related to mangrove function to sustain fisheries resources, the physical factor is a biomass production: catch per unit effort or CPUE data (Kg/ha). In addition, some extractive products from mangrove ecosystem could be factored into a product quantity, for example total area (ha) and weight (kg).

Most cultural services related to tourism and educational contributions, have been studied in various methods, ranging from mixed methods, pure qualitative, statistical modelling, and geotagging. Thus, the physical factors to value mangrove cultural services are mostly descriptive per temporal and spatial scale (number per hectare per year, etc).

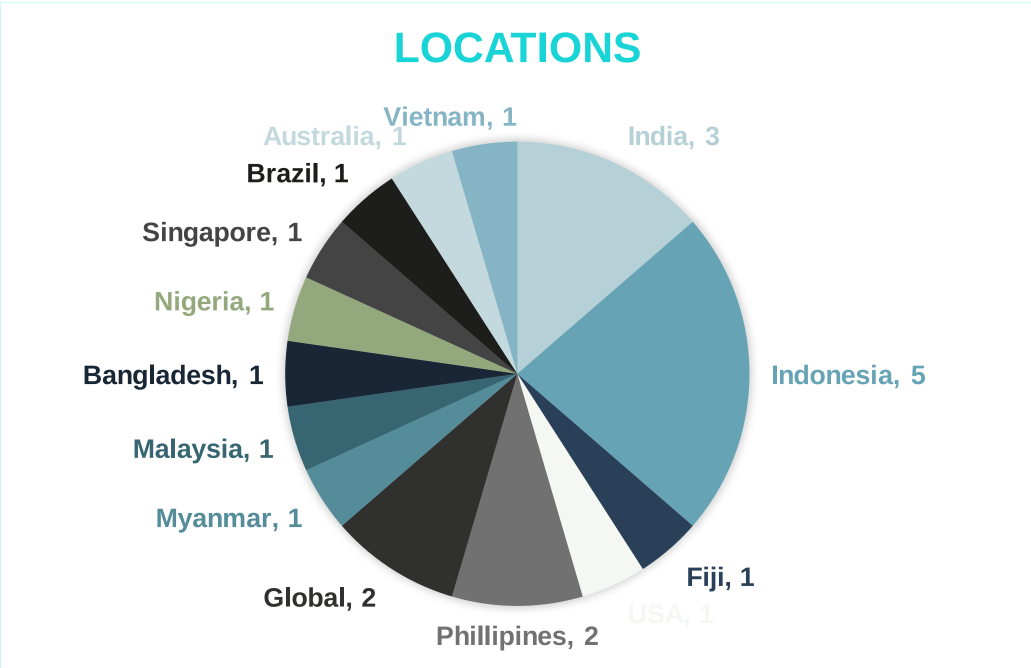


Figure 2. Study location of mangrove ecosystem factor

These 25 studies happened in different countries, such as Australia, India, Vietnam, Singapore, Nigeria, Bangladesh, USA, Malaysia, Myanmar, the Philippines, Brazil, Indonesia, Fiji and at global scale. Years of study are varied from 1993 to 2021. Three studies are a technical report from The World Bank, The Nature Conservancy and Wetlands International. Another 22 studies originate from various peer-reviewed journals, such as Ecological Processes, Marine Policy, Ecosystem Services, Ecological Indicators, etc.

Coral reef ecosystem service factors

Coral reef is another important ecosystem in the coastal area. Among the important ecosystem services provided by this ecosystem are protecting coastal areas and their inhabitants, supporting marine tourism, sustaining fisheries resources, and source of cultural or research inspiration. In this report, 20 studies have been reviewed to improve our understanding particularly of the biophysical indicator. The studies include both peer-reviewed papers and grey literature such as project technical reports.

In summary, regulating type of services is dominant in comparison to provisioning and cultural services. There are 8 studies on regulating services in this report, while of provisioning and cultural services, both are extracted from 6 studies. The regulating services are, for example: carbon sequestration, coastal protection, water purification, nutrient cycling, and pollutant remediation. In addition, some provisioning services are supporting and maintaining fisheries stock and direct use of coral-associated product for medicinal use, for example. Finally, from a cultural perspective, numbers of studies have been conducted about coral reefs contribution to recreational and aesthetic-related value and marine tourism-related activity.

Physical factors or indicators depend on the type of service, methodological approach, and objective of the respective study. Different from blue carbon in mangrove study, study in coral reefs to calculate carbon sequestration depends on laboratory work. The factors are numerical, for example, Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Dissolved Oxygen (DO), inorganic nutrient content, and additional abiotic indicators such as salinity and temperature.

Most of the methods used to assess coral reefs regulating and provisioning services are laboratory work, including defining their contribution to water purification, nutrient cycling, pollutant remediation, and calcification. Thus, it is site-specific and aim-oriented, meaning that biophysical factors should be defined after what objective we want to achieve.

Related to coral reefs services to maintain fisheries stock, the physical factor is biomass production: fish abundance (species per area sampling) and catch per unit effort or CPUE data (Kg/ha). In addition, factors regarding recreational and aesthetic value are mostly descriptive. It depends on the valuation method in the study, for example qualitative data in the form of stakeholder's perception could be used in evaluating the value of recreational value in a particular area. In addition, available statistical data such as value per visit, Gross Domestic Product (GDP), and Purchasing Power Parity (PPP) could be a foundation to determine how coral reefs contributed. Interestingly, social media content is also beneficial to valuing coral reefs from a tourist perspective.

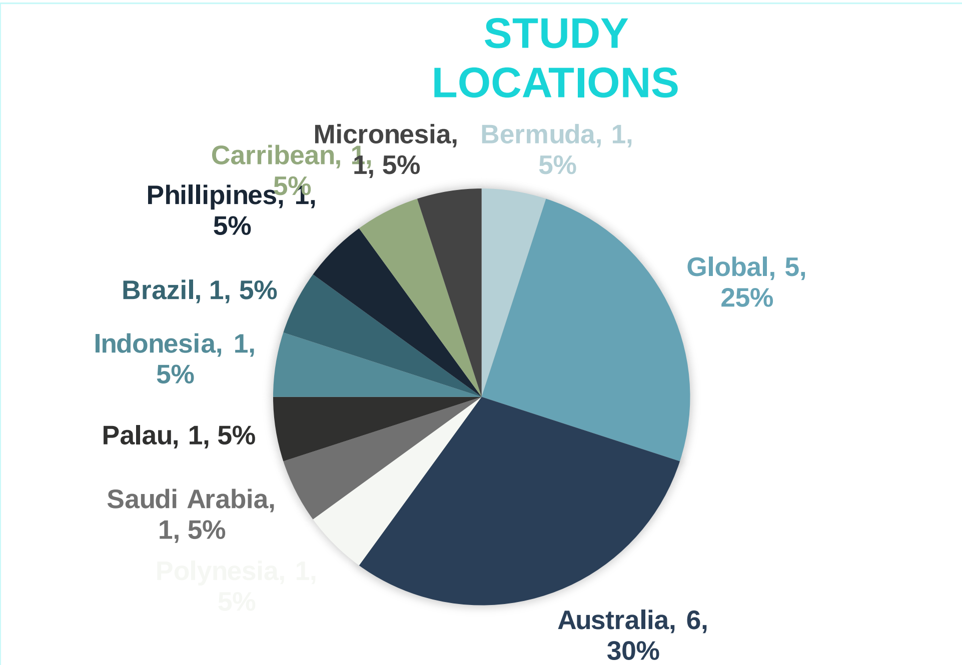


Figure 3. Study location of coral reefs ecosystem factor

These 20 studies occurred in different countries, such as Australia, Indonesia, Polynesia, Bermuda, Saudi Arabia, Palau, the Philippines, Brazil, Caribbean, Micronesia and at global scale. Years of study vary from 2000 to 2021. Two studies are a technical report from The Ocean Wealth website. Another 18 studies originate from various peer-reviewed journals, such as Frontiers in Marine Science, Nature, Ecosystem Services, Tourism Management, Marine Drugs, Fisheries Research, etc.

Seagrass ecosystem service factors

Despite its numerous services, seagrass is perhaps the most understudied among other coastal ecosystems. This ecosystem provides a wide range of services, not only indirect use by storing carbon, purifying water, and trapping pathogens, but also direct function in maintaining fish reproduction, and use of research or religious and cultural practices. In this report, 16 studies have been reviewed to improve our understanding, particularly of the biophysical indicator. All studies are sourced from peer-reviewed papers.

From these 16 studies, the regulating type of service is dominant in comparison to provisioning and cultural services. The seagrass ecosystem regulates three services: the first is carbon sequestration in various locations using various methods; the second is protection from natural hazards and pathogens; and the third is related to water purification and pollutant remediation. The two main provisioning types of service delivered by seagrass are sustaining fisheries resources and pharmaceutical usage. In addition to the cultural types of services, there are studies about recreational, social-ecological, educational, and religious usage.

Physical factors or indicators depend on the type of service, methodological approach, and objective of the respective study. The seagrass contribution in the blue carbon study is prominent and thus is a majority in comparison with other studies in this report. Blue carbon-related factors are indicated by the above and below-ground organic carbon content (gr C/ha), dead or dry weight (gr), soil sample, temperature, and total nitrogen stock (gr N/ha). In addition, the biomass of seagrass is calculated by its depth, leaf width and length, above ground biomass, shoot elongation rate, shoot life span, and rhizome thickness (all in meters or cm). Related to seagrass contribution to maintaining fisheries resources, a physical factor that has been repeatedly used is biomass production (Kg/ha/year). Regarding pathogen protection, the physical factors are the abundance of certain types of bacteria analysed in the laboratory. For recreational-related activities, the indicator of measurement is based on the result of seagrass residency index and expenditure value, both of which are numerical.

These 16 studies occurred in different countries, such as Australia, Indonesia, United Arab Emirates, Portugal, Italy, India, Mediterranean, Tanzania, some EU countries, and at a global scale. Years of study are varied from 2009 to 2022. All studies originate from various peer-reviewed journals, such as PLoS ONE, Marine Pollution Bulletin, Wetlands Ecology and Management, Ocean & Coastal Management, Ecological Indicators, etc.

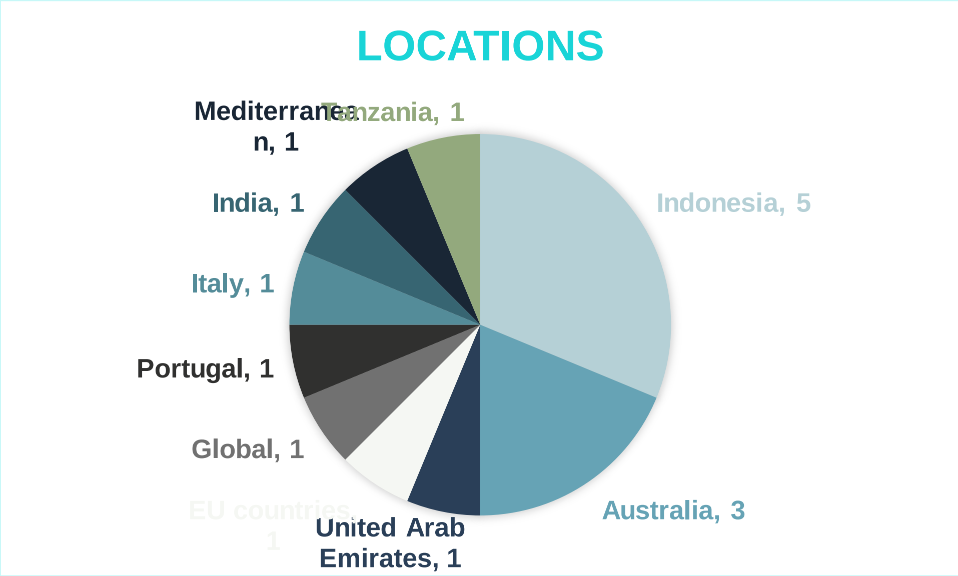


Figure 4. Study location of seagrass ecosystem factor

Process guidance: selection & use of coastal ecosystem service factors

Four practical steps

Coastal ecosystems are very different from other types of ecosystems because they cover areas that are influenced by high and low tides and are between the land and the water. Physically, the condition of coastal ecosystems may be different in different parts of the world because many factors play a role. It is also more difficult to put it in the context of coastal governance, which has a lot of different people involved. In other words, ocean accounting requires both detailed planning and careful attention to detail when it comes to doing it.

We came up with four practical steps of process guidance on the selection and use of coastal ecosystem service factors. These four steps can be integrated into a general stepwise guidance for preparing ocean accounting, where the preparation of ocean accounts can refer to the compilation data table as a reference for assessing coastal ecosystem services. The general stepwise guidance, as well as the process of how these four steps are integrated into it, have been compiled in Appendix 3. It will assist users in developing a comprehensive, usable ocean account analysis using the compilation table included in this report (see Appendix 5). To minimize confusion, each step in this section should begin with a letter. The steps are as follows:

- Step A: Selecting a coastal ecosystem to study and the services provided by that ecosystem. This step is be completed in Step 2 (Vision), see Appendix 3. Three coastal ecosystems are referenced in the compilation table (coral reefs, mangrove, and seagrass). In addition, the GOAP technical standard offers three broad kinds of ecological services: providing, regulating, and cultural. As a result, the structure for compiling data in this report adheres to the GOAP standard. Carbon sequestration, coastal protection, and water purification are all examples of services provided by the mangrove ecosystem. Other services include the maintenance of fisheries stocks and extracted raw materials (provisioning), as well as cultural uses such as tourism, aesthetic, educational, and traditional practices (cultural). The complete list of coastal ecosystem services is available in the compilation table included in Appendix 5.

- Step B: Obtaining data on the extent of the related coastal ecosystem in the unit of area. This phase is completed in Step 3 (Identification), see Appendix 3. The data table demonstrates that most ecosystem service unit values are calculated in terms of ecosystem extent area, e.g., hectare. For instance, some data indicate that the carbon sequestered by seagrass is measured in *tC/ha/year* (tons carbon per hectare per year) – denoting how much carbon may be sequestered annually by a hectare of seagrass in a particular area. Another example is assessing nursery habitat value and quantifying fish biomass production in *kg/ha/y* (kilograms per hectare per year). By having the extent area information of coastal an ecosystem in a certain area of interest, this unit value can be used as the basis for a quick/back-of-the-envelope calculation of the aggregated service value associated with the total extent.
- Step C: Understanding the data compilation table. This step is completed in Step 3 (Identification), see Appendix 3. Please refer to the framework analysis section for specific instructions on how to read the table. In summary, there are three kinds of data tables, each of which begins with a header indicating the type of coastal ecosystem: mangrove, coral reef, or seagrass. Users should organize information about ecosystem service factors by ecosystem type. There are eight columns in the table that describe: 1) the service type; 2) the technique; 3) the indication; 4) the unit factor; 5) the value; 6) the assumption; 7) the location; and 8) the sources.
- Step D: Considering carefully to a specific characteristics and aspect of data prior to select and use the ecosystem service factors and values from the compilation table. Regarding the qualities and elements of data, Barbier, et al (2011) emphasized the importance of accounting for a variety of factors to increase the dependability of coastal ecosystem service value. We consider using this reference as a proxy framework for elaborating on things to consider when picking the ES factors data in the table based on thorough observation of the compiled data. This assumes that the factors that contribute to the reliability of coastal valuation studies (as outlined in Barbier, et al (2011) are equivalent to the factors that contribute to the reliability of data selection from existing coastal valuation studies. This also considers that most of the aspects detailed below are also location-specific (e.g., spatial; ecosystem pressure; etc.) – which may help users determine whether they can select and use the compiled data in accordance with the coastal conditions in their own countries or project locations. This step is also performed in Step 3 (Identification), see Appendix 3.

In addition to the additional steps indicated previously, there are other characteristics of ecosystems that users should carefully evaluate. Users are advised to carefully evaluate these characteristics/aspects when selecting data, if applicable (notice that some of the assembled data points may include one or more of these characteristics/aspects, while others may not, depending on the study's elaboration). The next section contains more information about ecosystem characteristics.

Table 1. Characteristics of coastal ecosystems

No	Characteristic	Description	Examples
1	Spatial	It relates to the extent to which magnitudes of values may vary spatially over the extent of coastal ecosystems. It has become increasingly clear that spatial variation should be considered when assessing benefits within the realm of coastal ecosystems. Barbier, E. B. (2017) discussed how an enormous length of mangrove fringe has benefited local fisheries productivity in the Gulf of California,	Jänes, et al (2021) denotes variation of fish abundances and biomass on seagrass beds in Port Phillip Bay, Melbourne, Australia-ranging from 51- 432/Kg/ha/year. They highlight that 80% of the spatial patterns of fish abundances on seagrass beds were explained by three predictors: “average current speeds, wave orbital velocity and sea surface temperature”.

		Mexico. Additionally, another example involves the amount of mangrove habitat that should be converted to shrimp aquaculture and the geographic diversity of coastal storm protection along the coastline.	Pet-Soede, et al (2001) highlights annual catch of reef fisheries in two areas in Indonesia: Spermonde (Sulawesi Island) and Komodo (East Nusa Tenggara). The two locations have similar annual catch in ton/km^2, whereas Catch per Unit Effort (CPUE) in Spermonde is 8 times lower than Komodo. They denote challenge in spatially comparing fish community structure across these areas, due to oceanographic and geographic features: “Up-welling currents in Komodo cause a lower water temperature than in Spermonde, which could affect the growth of fish. Colder water is associated with lower natural mortality rates and hence larger mean lengths than in warmer water.” Pascal, N., et al (2016) discussed that less quantity of coral reefs would reduce up to 57-66% of coral function in wave energy dissipation, while a normal condition could contribute up to 75-85%. This was a study in Saint Croix, Virgin Islands.
2	Temporal	It relates to where the magnitude of values may have temporal variation across the extent of the coastal habitats, e.g., the influence of seasonality. Particularly for the coastal protection services, temporal variation should result in different outcomes depending on when extreme events occur. For example, Barbier, et al (2011) mentioned that the peak of seagrass biomass in the summer (April-June) would contribute differently to storm protection when compared to similar events that occur in the fall (July-September).	Luisetti, T., et al (2013) discussed that it should be noted that carbon stock in seagrass beds is vary significantly both temporally and spatially, and thus future data on this variance would allow a more accurate estimation. Wahyudi, A.J., et al (2020) mentioned that number and type of data vary among locations depending upon the technical and temporal conditions during the study. Uddin, M. S., et al (2013) in their study about economic value in tourism sector, in Bangladesh Sundarbans Reserve Forest (SRF) mentioned that the number of tourists has been doubled over the study period and revenue increased by four times in the same period. The result caused by the present of

			international tourist by five times over the same period.
3	Valuation method	It refers to situations where the method used to value certain ecosystem services may be affected by practical constraints, so it should be used with care.	Pascal, et al (2016) compares two methods in calculating coastal protection value of coral reefs: avoided damage, and replacement cost. Replacement cost method tends to produce extremely high estimates, up to 10 times greater than the lower-bound estimate calculated using the damage approach. Muller-Karanassos, et al (2021) calculated fish biomass in Palau using stereo-DOV systems method as opposed to other method such as applied by Pet-Soede, et al (2001). They reflect that: "stereo-DOV methodology could result in lower biomass estimates than UVC surveys due to differences in the swimming speed of the transect".
4	Interlinkage of coastal ecosystems	As the location of coastal ecosystems in the land–sea interface suggests (potentially) a high degree of ‘‘*interconnectedness*’’, leading to the linked provision of one or multiple services by more than one ecosystem types. We all aware that coastal ecosystems do not live in isolation but are connected via habitats ranging from mangrove to seagrass to shallow coral reefs. Consequently, many services are interdependent.	Arguably, the function of every coastal ecosystem in maintaining fish stock is a clear example how these coastal ecosystems support each other. In addition, regarding a service of purifying water and trapping sediment, the quality and quantity of healthy coral reefs habitat would influence a function of seagrass and mangrove to do similar service. Finally, coastal protection service needs a strong and solid quality of all coastal ecosystems. The interconnected coastal ecosystem’s function, habitat-fishery linkages, water purification and sediment control, and coastal protection (Barbier, E. B., 2017), indicated that it is crucial for the users to carefully determine what, how and why such services need to be assessed as an integrated perspective.
5	Ecosystems dynamic and anthropogenic pressure	As some factors e.g., anthropogenic and/or natural may influence the condition/health of certain coastal ecosystems and may accordingly impact the relevant	White et al (2000) highlights that in Philippines, the "use of dynamite or cyanide for fishing" leads to coral reef degradation – impacting the

	ecosystem services factors. According to Barbier, E. D., (2017), anthropogenic activities have a negative impact on the environment through eutrophication, overharvesting, sediment runoff, hostile fishing, and aquaculture practices. Among other examples of a natural stressor is its effect on climate change. All stresses have the potential to degrade the viability of coastal ecosystems, for example, the disappearance of most seagrasses in Long Island, USA, in the 1930s led to the collapse of the scallop industry (Orth, et al., 2006 cited in Barbier, E. D., 2017)	reduction of reef fish production from 20 to 4 ton/km^2/year. Pet-Soede, et al (2001) highlighted blast fishing practice in Spermonde leading to “Malthusian over-fishing…where, as a result of human population growth, ecosystem over-fishing occurs, and destructive fishing practices are applied with increasing frequency”. Catch per Unit Effort (CPUE) in Spermonde during the time of their research was 8 times lower than Komodo (5.8 vs 48 kg/trip)

Mock-up example

By using the table compilation, we can use certain research as a mock-up for this additional stage. It is critical for users to keep in mind that they should grasp their practical situation and ecosystem features as described in the table above. After considering the qualities, users should begin applying steps A through D.

To begin (step A), users should mutually agree on the sort of ecosystem and service they wish to study, without necessarily referring to the compilation table. Second (step B), after determining the type of ecosystem and its function, users should be informed about the scope of the ecosystem or the physical data, including the unit area, that must still be collected. Thirdly (step C), users can utilize the compilation table by carefully scanning the columns for pertinent information. As mentioned earlier in this report, there are eight columns that can inform users about the following: the type of coastal ecosystem and its service, the data collection method, the physical indication, the unit factor, the value, the assumption, and the location. Finally, in step D, users can decide if they want to use the study as a reference.

For instance, in step D, if users want to research carbon sequestration in seagrass ecosystems, the compilation table has three references. As a mock-up, let us look at a study by Wahyudi, A., J., et al., 2020. The study is classified as focusing on carbon stock and sequestration (service type) in seagrass ecosystems (ecosystem selection) across different sites in Indonesia. Regarding data on the ecosystem's extent and unit area, readers should be aware that data samples were taken from 28 locations spanning the western to eastern Indonesian seagrass habitats between 2010 and 2018. Additionally, the assumption used in this work is that to assess the seagrass carbon stock and sequestration potential, at least three basic data points must be gathered: (1) the amount of biomass (i.e., standing stock), (2) the carbon sequestration capacity, and (3) the extent of the seagrass meadows. Generally, the data was categorized into two different variables: seagrass- and carbon-related data. In addition, the seagrass- related variables are comprised of coverage (%), density (shoot/ha), biomass (ton/ha), and area (ha); whereas carbon-related variables are comprised of above-ground carbon stock (AGC; gC/m2), below-ground carbon stock (BGC; gC/m2) and carbon sequestered (tC/ha/year).

Additionally, users should be alerted about the study's circumstances to determine whether it is a good reference for their situation and condition. For instance, this investigation discovered that:

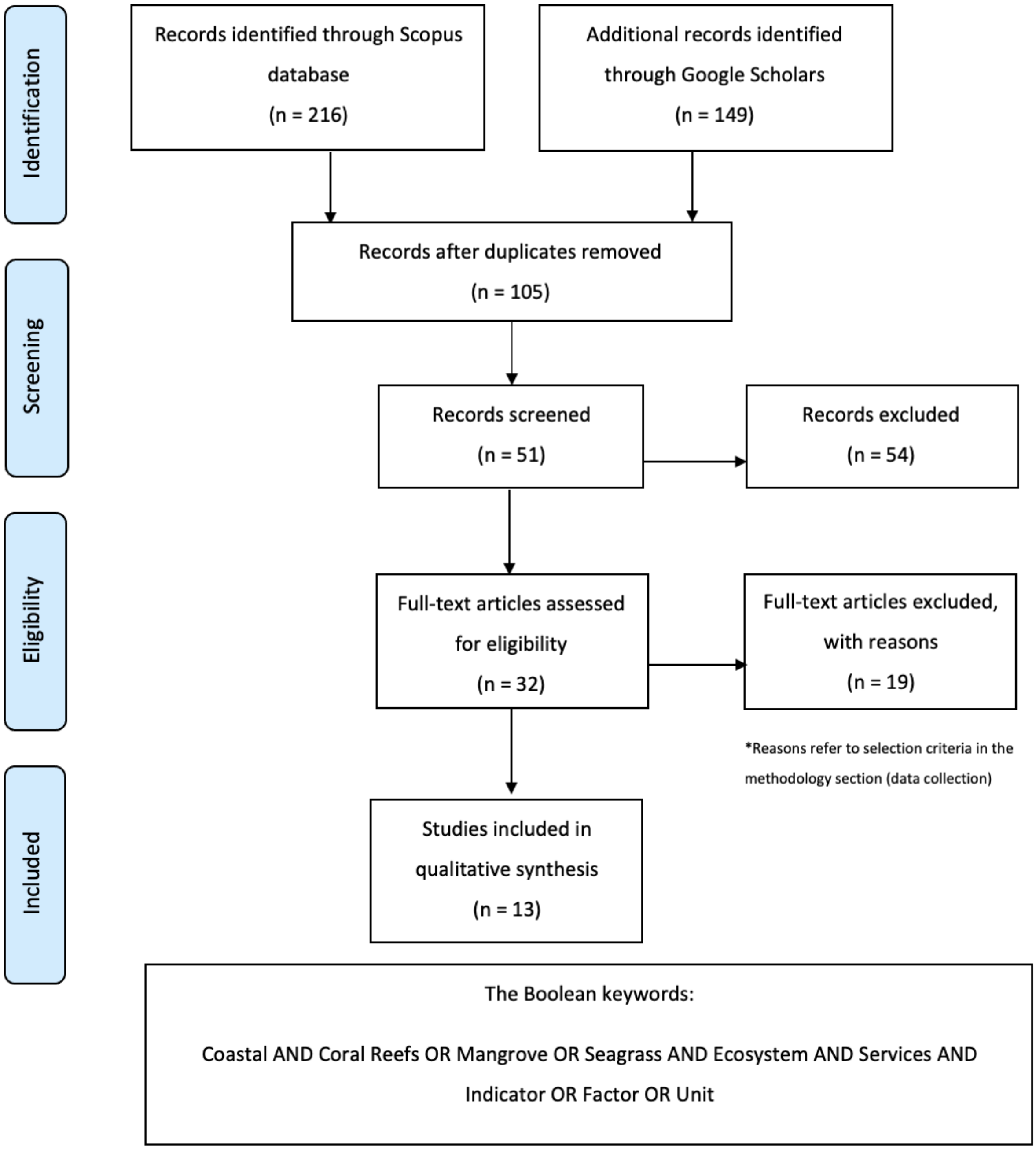
- The carbon sequestration capacity was determined by measuring the Net Primary Production (NPP), mainly for Enhalus acoroides and Thalassia hemprichii, using the leaf marking method (Short and Duarte 2001).
- The seagrass meadows area was identified through satellite imageries and validated by ground-truthing in the designated areas. This was done to estimate the total seagrass area in kilometer square or hectare.
- The areal extent of the seagrass meadows was then estimated using remote sensing and GIS (Geographic Information System) techniques (Hernawan et al. 2017; Sjafrie et al. 2018). Statistical analyses were only applied to 13 locations where all data of seagrass-related variables were complete (Table 1), for detail please see the full paper.
- The 13 locations were treated as independent replicates, whereas other sites were treated as nested factors within the locations, ca. 1–35 sites per location. Data analysis for formula selection was performed using R software with the following packages: robustlmm (Koller 2016) for rLMMs analysis, and glmulti (Calcagno and de Mazancourt 2010) for formula selection. Above-ground carbon, below-ground carbon, standing carbon, and carbon sequestration of the seagrass meadows in Indonesian waters were not significantly different among all scenarios ($p > 0.05$), ca. 27.40 1–35.84 gC/m2, 66.93–79.42 gC/m2, 94.33–114.71 gC/m2, and 5.62–8.40 tC/ha/year, respectively (Figs. 2–5).
- Under the fourth scenario, the highest values of above-ground carbon, below-ground carbon, standing stock carbon, and carbon sequestration of seagrass meadows located at Selayar were respectively, ca. 32.52 gC/m2, 78.51 gC/m2, 111.03 gC/m2, and 8.90 tC/ha/year (Fig. 5, Scenario 4 map).
- The highest values of above-ground carbon, below-ground carbon, standing carbon, and carbon sequestration of seagrass meadow were located at Wakatobi Islands, with ca. 3.2 ktC, 7.9 ktC, 11.1 ktC, and 719.45 ktC/year, respectively. This might be because Wakatobi has the largest seagrass meadows compared to other locations in Indonesian waters.

Finally, after having understood the data available in the study, it is concluded that “considering the total area of seagrass meadows in Indonesian waters (i.e., 293,464–875,967 ha; Sjafrie et al. 2018), the above-ground carbon, below-ground carbon, standing stock carbon, and carbon sequestration values of seagrass meadows in Indonesian waters were ca. 80–314 ktC, 196–696 ktC, 276–1,005 ktC, and 1.6–7.4 MtC/year, respectively.” The users can then determine whether the study is relevant to their objectives prior to beginning data collection in their specific project area. In this example from Wahyudi, A., J., et al., 2020, at least three ecosystem aspects are considered: geographical (28 locations spanning the western to eastern Indonesian seagrass habitats), temporal (2010 and 2018), and the valuation method applied. Such a study could serve as a basis for people to build their own.

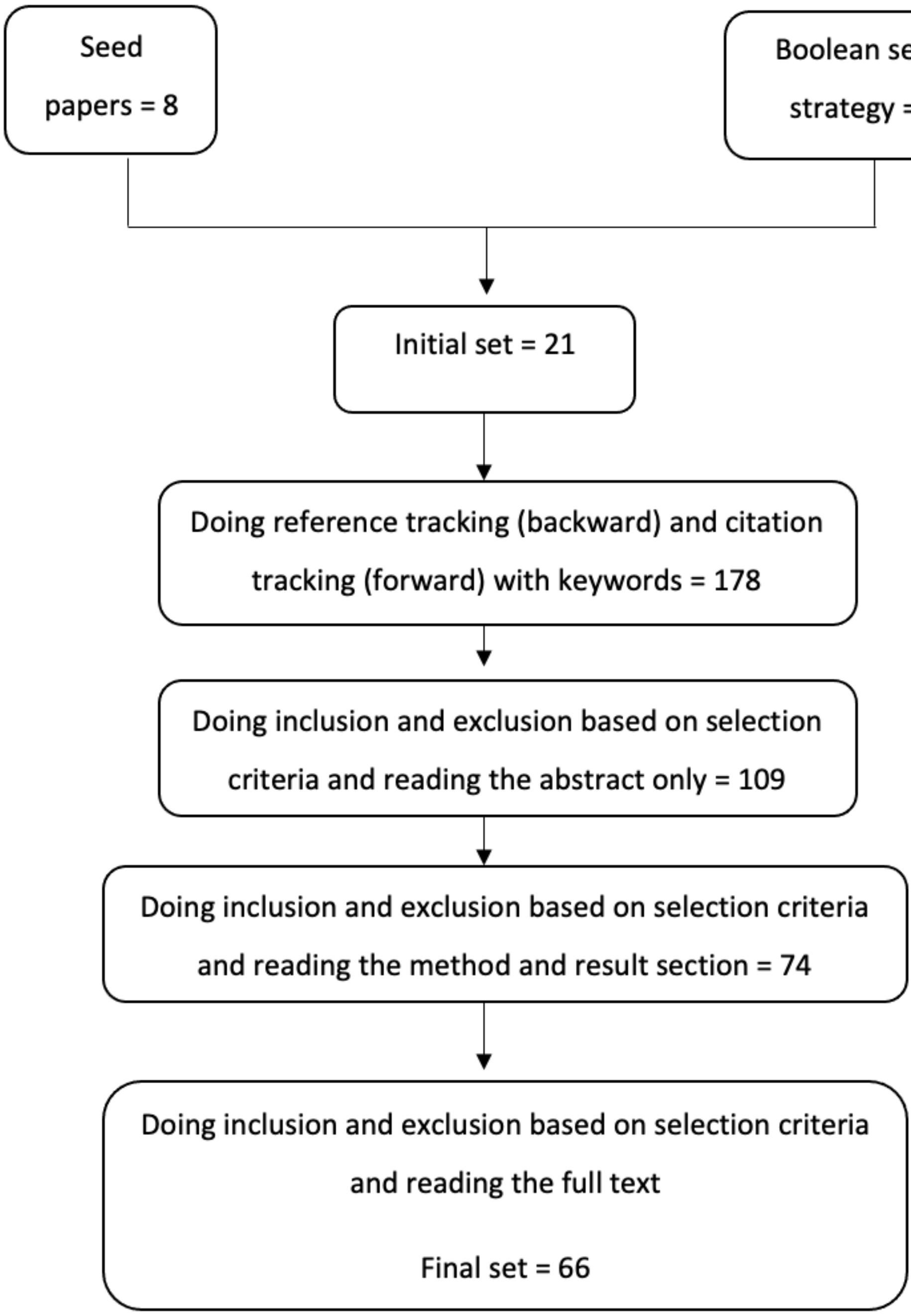
Appendix

1. Boolean search strategy using PRISMA protocol

PRISMA Flow Diagram



2. Snowball literature search scheme



3. Seven general steps

Below is a proposed stepwise guide for developing ocean accounting based on an adaptive assessment and management toolkit (McDonald, G., *et* al., 2018). The proposed steps are a circular process, so when the users finish the very last step, they could iterate the steps for another study or for monitoring and evaluation purposes. It should also be able to be used in a variety of ways so that people can start at any point based on their own circumstances and needs. Below is the illustration of all the steps:

Figure 5. Seven steps guideline to conduct coastal ecosystem factor study

More explanation is available in the below table.

Table 2. General 7-steps guidance

No	Steps	Description
1	Proposition	A clear statement that covers common goal and understanding prior doing an ocean accounting in a specific coastal ecosystems area.
	Output	A common understanding of the terms in ocean accounting, particularly in the context of coastal ecosystems. It is important to determine the objective and interest that would be achieved mutually among the stakeholders involved. Some terminologies could be understood differently by several stakeholder groups, for instance, the misinterpretation of benefit and service in coastal resource utilization.
	Questions	1. What are the issues/interests/needs of different stakeholders being considered and the rationale for the services valuation? 2. Why do we need the valuation study? 3. Who are the stakeholders to be involved with? 4. How is the funding?

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		5. What are the agreed policy objectives/priorities that can be accommodated with the proposed ocean account system?
2	Vision	The overall idea of what, who, when, where and how is the ocean accounting will be going. Vision can be mutually agreed upon after a common understanding about ocean accounting is established.
	Output	A target focus and execution strategy. The prioritizing scope area and type of services in each coastal ecosystem are discussed at this stage. If available, national program-related Ocean Accounting could serve as a reference.
	Questions	1. What ecosystem is the focus? 2. What type of service is the focus? These first two questions are related to the initial steps of the four practical steps mentioned above, particularly Step A. 3. When will the valuation be started? 4. Where will the valuation take place? 5. What approach or coordinating strategy across relevant stakeholders is applicable to conduct the valuation?
3	Identification	Any inventory action regarding list of agencies and the available data, including manpower/expert, infrastructure, and data gap. It is important in this step to agree upon who is the lead institution to organize ocean accounting-related activities.
	Output	Definitive lead institution and reviewed resource plus data available. Including here are checking the relevancy, quality, quantity, data collection method and interpretation of the available data.
	Questions	1. Which institution should take the lead? 2. What national program should be aligned with it? 3. What is the status of the valuation? Is the existing data adequate or is a primary data collection required? 4. What is the baseline data available? This includes if the baseline data contains information regarding the coastal ecosystem extent and is available. This step links to the four practical steps mentioned above, particularly Step B to pick a relevant reference in the coastal ecosystem factor compilation table in Appendix 5. 5. What is the change described in the data? 6. What is the remaining data gap? This includes if the remaining data gap is associated with the coastal ecosystem extent, this question should link to the four practical guidance mentioned above, particularly Step B. 7. How reliable and accurate is the data? To reflect on this question, users could connect it with Step C in the four practical guidance mentioned above. 8. What methods are available to be learnt from the available data? 9. Who collected the data? 10. When and where is the data being collected? 11. Is there data available on the dynamics of coastal ecosystems and the relevant anthropogenic pressure? 12. What kind of technology that has been used to collect and analyze the data?

		13. What are the characteristics of the coastal ecosystem services that need to be carefully considered? Users could reflect on table 1 (characteristics of coastal ecosystem service) mentioned above.
4	Data gap execution	An official assessment to know the status of data and develop a strategy or approach to perform ocean accounting in the selected coastal ecosystems, particularly to fulfill data gaps from (if any) the previous relevant study.
	Output	The status of data and a written strategy to complete the necessary information. Here, under the coordination of the lead institution, stakeholders examine and decide whether additional data and information collection is needed. If that is the case, additional data collection planning is required. Data collection planning includes, for example, budget planning, data collector, method, data storage, analysis, and interpretation.
	Questions	1. In event that additional data collection is required, 2. What methods are applicable and doable? 3. How is the funding? 4. What are the data points? 5. Who will collect the data? 6. How will the data be stored and managed? 7. What kind of technology is needed?
5	Evaluation	An official judgement is established by a core team under the lead institution.
	Output	The updated status after additional data collection and stakeholder coordination. The activities, are for example, analysing physical factors, converting the physical unit to monetary value, drafting reports, and integrating the output into an account table.
	Questions	1. What are the outputs from data collection? 2. Who is responsible for writing the valuation report? 3. Who is accountable for publishing the valuation report?
6	Consultation	An official public hearing session to discuss the outcome of ocean accounting in specific coastal ecosystems. It includes activities like, for example, disseminating the account table and evaluating the report or output from an account table.
	Output	A final consultation report, including a monitoring and evaluation plan to sustain the implementation.
	Questions	1. When and where will the consultation be held? 2. What part of the results are going to be publicly consulted?
7	Adaptation	An adaptive strategy to improve and sustain ocean accounting in the future. Input from a consultation activity will benefit the development of the strategy.
	Output	The written strategy document for the next performance of ocean accounting, includes: 1) a scalable plan to be implemented in different locations; 2) addressing different ocean accounting priorities in the same location, for example, the first iteration is on tourism and the second iteration could be on fisheries, and then blue carbon, etc. This written

	strategy integrates lessons-learned from the previous ocean accounting activity.
Questions	1. What are the lessons learned? 2. How to make the study scalable? 3. What is it that needs to be followed up on?

As a note, this proposed 7-steps guidance uses a circular process approach. It means that users can reiterate and adjust to their needs or conditions when adopting all the steps. Additionally, users could also start directly from Step 2, Step 3 or even Step 7, depending on the condition. Furthermore, the outputs from this study could be fed into the next valuation study. It is also important to highlight that with the output from the complete steps, users could use the result of the study to mainstream the coastal ecosystem services valuation approach in the decision-making process among stakeholders. Mainstreaming ocean accounting needs momentum, and the complete steps that resulted in important findings should raise awareness and meet the needs of stakeholders.

4. The final set of articles

Table 3. Final set of articles for review

No	Citation
1	Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193. https://doi.org/10.1890/10-1510.1
2	WAVES project, Pilot Ecosystem Account for Southern Palawan-Technical Report 2016. www.wavespartnership.org
3	Langle-Flores, A., & Quijas, S. (2020). A systematic review of ecosystem services of Islas Marietas National Park, Mexico, an insular marine protected area. Ecosystem Services, 46(101214), 101214. https://doi.org/10.1016/j.ecoser.2020.101214
4	Balzan, M. V., Potschin-Young, M., & Haines-Young, R. (2018). Island ecosystem services: insights from a literature review on case-study island ecosystem services and future prospects. International Journal of Biodiversity Science, Ecosystems Services & Management, 14(1), 71–90. https://doi.org/10.1080/21513732.2018.1439103
5	Basa T. Rumahorbo, Baigo Hamuna, Henderina J. Keiluhu, Alianto. (2020) Identifying and Quantifying the Economic Value of Coastal Ecosystem Services According to the Perceptions of Papuan Indigenous Peoples in Jayapura City, Papua Province, Indonesia. International Journal of Environmental Science, 5, 197-206
6	Hernández-Blanco, M., Costanza, R., & Cifuentes-Jara, M. (2021). Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology. Ecosystem Services, 49(101258), 101258. https://doi.org/10.1016/j.ecoser.2021.101258
7	M. Brander, L., J. Wagtendonk, A., S. Hussain, S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. Ecosystem Services, 1(1), 62–69. https://doi.org/10.1016/j.ecoser.2012.06.003
8	UNEP, 2011. Economic Analysis of Mangrove Forests: A case study in Gazi Bay, Kenya, UNEP, iii+42 pp. https://wedocs.unep.org/20.500.11822/7948
9	Beck, M. W. , S. Narayan, D. Trespalacios, K. Pfliegner, I. J. Losada, P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, F. Fernandez, S. Abad, P. Mucke, L. Kirch. 2018. The global value of mangroves for risk reduction. Summary Report. The Nature Conservancy, Berlin. http://dx.doi.org/10.7291/V9930RBC
10	Harishma, K.M., Sandeep, S. & Sreekumar, V.B. Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecol Process 9, 31 (2020). https://doi.org/10.1186/s13717-020-00227-8
11	Navarro, A., Young, M., Allan, B., Carnell, P., Macreadie, P., & Ierodiaconou, D. (2020). The application of Unmanned Aerial Vehicles (UAVs) to estimate above-ground biomass of mangrove ecosystems. Remote Sensing of Environment, 242(111747), 111747. https://doi.org/10.1016/j.rse.2020.111747
12	Murdiyarso, D., Purbopuspito, J., Kauffman, J. et al. The potential of Indonesian mangrove forests for global climate change mitigation. Nature Clim Change 5, 1089–1092 (2015). https://doi.org/10.1038/nclimate2734

13	Cameron, C., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). High variance in community structure and ecosystem carbon stocks of Fijian mangroves driven by differences in geomorphology and climate. Environmental Research (Vol. 192, p. 110213). Elsevier BV. https://doi.org/10.1016/j.envres.2020.110213
14	Alongi, D.M., Murdiyarso, D., Fourqurean, J.W. et al. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecol Manage 24, 3–13 (2016). https://doi.org/10.1007/s11273-015-9446-y
15	Costanza, R., Pérez-Maqueo, O., Martinez, M. L., Sutton, P., Anderson, S. J., & Mulder, K. (2008). The Value of Coastal Wetlands for Hurricane Protection. Ambio, 37(4), 241–248. http://www.jstor.org/stable/25547893
16	Menéndez, P., Losada, I. J., Beck, M. W., Torres-Ortega, S., Espejo, A., Narayan, S., Díaz-Simal, P., & Lange, G.-M. (2018). Valuing the protection services of mangroves at national scale: The Philippines. In Ecosystem Services (Vol. 34, pp. 24–36). Elsevier BV. https://doi.org/10.1016/j.ecoser.2018.09.005
17	Reduction of Wind and Swell Waves by Mangroves. McIvor, A. L., Möller, I., Spencer, T., and Spalding, M. Natural Coastal Protection Series: Report 1: The Nature Conservancy and Wetlands International. (2012)
18	McIvor, A.L., Spencer, T., Möller, I. and Spalding. M. (2012) Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41. Published by The Nature Conservancy and Wetlands International. 35 pages. ISSN 2050-7941. URL: http://www.naturalcoastalprotection.org/documents/storm-surge-reduction-by-mangroves
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21	Lebata, M., Hazel, J., Vay, L. L., Primavera, J. H., Walton, M. E., & Biñas, J. B. (2007). Baseline assessment of fisheries for three species of mud crabs (Scylla spp.) in the mangroves of Ibajay, Aklan, Philippines. Bulletin of Marine Science, 80(3), 891-904. http://hdl.handle.net/10862/2064
22	Doetinchem,Nina. 2020. Nipa Palm Products in the Ayeyarwady Region – Insight Brief © World Bank. https://pubdocs.worldbank.org/en/502551611143196249/Insight-Brief-Nipa-Palm-Products-in-the-Ayeyarwady-Region
23	Bennett, E. L., & Reynolds, C. J. (1993). The value of a mangrove area in Sarawak. In Biodiversity and Conservation (Vol. 2, Issue 4, pp. 359–375). Springer Science and Business Media LLC. https://doi.org/10.1007/bf00114040
24	Bandaranayake, W. Traditional and medicinal uses of mangroves. Mangroves and Salt Marshes 2, 133–148 (1998). https://doi.org/10.1023/A:1009988607044
25	Rizal, A., Sahidin, A., & Herawati, H. (2018). Economic value estimation of mangrove ecosystems in Indonesia. Biodiversity International Journal, 2(1), 98-100. http://dx.doi.org/10.15406/bij.2018.02.00051

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28	Sari, A. N., Bhaskara, C., Bimantara, A., 2020. The Suitability of Mangrove Ecotourism Based on Its Biophysical Condition in Hamadi Beach, Jayapura City. Journal of Indonesian Tourism and Development Studies. Vol 8 No 3. https://jitode.ub.ac.id/index.php/jitode/article/view/402/310
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5. Coastal ecosystems services compilation table

Table 4. Coastal ecosystems services compilation table: Mangrove

Services	Method	Indicator	Unit factor	Value	Assumption	Location	Sources
Regulating							
Biomass and carbon stock	Further information about 1) Aboveground and belowground biomass carbon stocks calculation, 2) Soil sample collection, 3) Soil analysis, 4) Soil carbon stocks, is available in the full paper.	Biomass Carbon stock	t/ha t C/ha	The mean biomass stored in mangrove vegetation of Kerala is 117.11 ± 1.02 t/ha (ABG= 80.22 ± 0.80, BGB = 36.89 ± 0.23 t/ha). Six mangrove species were found distributed in the study area. Among the different species, *Avicennia marina* had the highest biomass (162.18 t/ha) and least biomass was observed in *Sonneratia alba* (0.61 t/ha). The mean ecosystem carbon stock of mangrove systems in Kerala was estimated to be 139.82 t/ha, equivalent to 513.13 t CO_2 e/ha with the vegetation and soil storing 58.56 t C/ha and 81.26 t C/ha respectively. The lowest biomass was observed in central Kerala (48.55 t/ha) with a recruit density of 1690 trees/ha. The southern zone had a mean biomass of 56.25 t/ha with a recruit density of 2210 trees/ha. Earlier studies by Vinod	Although mangrove forests in this region are protected by the Kerala Forest Department, they have been frequently facing illegal encroachment, prawn cultivation, and coastal erosion Three levels of canopy density were considered for sampling using a spherical crown densitometer: (i) canopy density of above 70% (very dense), (ii) canopy density between 40 and 70% (moderately dense), and (iii) canopy density between 10 and 40% (open).	Kerala, southwest coast of India	Harishma, K.M., Sandeep, S. & Sreekumar, V.B. Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecol Process 9, 31 (2020). https://doi.org/10.1186/s13717-020-00227-8

et al. (2018) have reported 236.56 t/ha of biomass from Kadalundi mangroves (Northern Kerala) and 132.83 ± 97.5 t C/ha from the central zone.

The average vegetation carbon stock of Kerala mangroves was found to be 58.56 ± 0.51 t C/ha (Table 4). Species contribution of the different mangrove species to the average carbon stock was in the order of A. marina > R. mucronata > A. officinalis > B. cylindrica > R. apiculata > S. alba. The biomass carbon stock of the northern region of Kerala was estimated to be 123.28 ± 1.36 t C/ha and was found to be the most carbon-rich mangrove region indicating a positive correlation between tree density and biomass and carbon storage.

In the southern region, the total carbon stock estimated was 28.13 ± 0.10 C/ha, and species such as A. marina, R. apiculata, and S. alba contributed 26.98 t C/ha, 0.85 t C/ha, and 0.31 t C/ha respectively to the total estimated stocks. The central zone was the least carbon-rich area with a total carbon stock of 24.28 ± 0.08 t

A total of 30 sampling plots (10 plots in each zone) of size of 10m × 10m was established for non-destructive determination of biomass and soil carbon stock as well as species composition. The total sampling area covered was 3 ha. To mark the exact location of each sampling site, a global positioning system, GPS (Garmin Etrex 10), was used and the spatial location of each quadrant was recorded.

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				C/ha. The contribution of species to the carbon stock in this region was in the order of A. officinalis > B. cylindrica > R. mucronata. The soil carbon content in the top 30 cm was comparatively higher than the lower layers. Soil organic carbon stored in the upper 60 cm depth of the mangrove sediment was estimated to be in the range of 36.71–124.99 t C/ha with an average soil carbon stock of 81.26 ± 10.16 t C/ha. The higher carbon contents in the mangrove systems compared to forest (55.40 t C/ha), rubber (43.73 t C/ ha), home gardens (37.78 t C/ha), coconut (26.42 t C/ha), and rice paddy (17.74 t C/ha) indicated the higher potential of mangrove soils to act as a better carbon reservoir than other common land uses in the region.			
Biomass estimation	Unmanned Aerial Vehicles (UAVs). We used a low-cost UAV and the in-built RGB	Height (H), Crown Area (CA)	Meter	An average of 250 images per hectare were used to generate the dense point clouds using SfM-MVS procedures. An orthomosaic image, DSM, DTM and CHM were generated for every survey site with an average pixel resolution of 3.2 cm (Fig. 4). The geometric	We manually identified and marked the GCPs in all available images for high precision geo-referencing of all products. This allowed for the corners of the	Australia	Navarro, A., Young, M., Allan, B., Carnell, P., Macreadie, P., & Ierodiaconou, D. (2020). The application of Unmanned Aerial Vehicles (UAVs) to

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sensor to detect and measure the structural characteristics of individual trees within mangrove ecosystems in southeastern Australia. Detail data collection procedure is available in the full paper			accuracies of the scene reconstructions averaged an RMS horizontal error (x, y) of 1.0 cm and RMS vertical error (z) of 1.2 cm. DTM generation averaged a RMSE vertical error of 6.3 cm for WP, 9.0 cm for RRE (rehabilitated areas) and 44.7 cm for RRE (natural areas) when compared to GCPs. Mangrove trees in WP showed a homogeneous profile of heights due to the slow growth rate characteristic of temperate climates, with trees ranging from 1 to 3.5 m (Vandervalk and Attiwill, 1984, Fig. 4d). This disposition allowed for almost all trees to be visible from UAV imagery, with only saplings and 5% of adult trees under the main canopy not recorded. On the other hand, mangrove trees in RRE showed a more heterogeneous profile of heights, especially in rehabilitated areas where two differentiated canopy stories can be found (Fig. 5). This variation in canopy heights results in a relatively large percentage of the mangrove	on-ground survey plots to be located with high precision for posterior comparison of tree metrics and above-ground biomass estimates. Mangrove tree density and height, canopy diameter and AGB medians estimated from the UAV-SfM were compared to field data at the plot level using linear regression models. A Shapiro-Wilk test (Shapiro and Wilk, 1965) was used to test for normality of mangrove tree height, canopy diameter and AGB distributions at the region level. This study has demonstrated the ability of UAV-SfM data to estimate AGB of mangrove ecosystems. Low-cost UAV imagery was used for the creation of orthomosaic images, DSM, DTM		estimate above-ground biomass of mangrove ecosystems. Remote Sensing of Environment, 242(111747), 111747. https://doi.org/10.1016/j.rse.2020.111747

GOAP

trees from the lower canopy story not observable from the UAV (up to 30% in some rehabilitated areas). Even though this is a large percentage of trees not being detected by the UAV-SfM method, these trees only hold an average of 9.1% of the total plot-level AGB.

Results of the validation work that consisted of comparing onground measured tree densities to UAV-SfM derived tree densities for each of the 41 plots can be seen in Fig. 6. When considering only the top canopy (Fig. 6b), the method performed well at low tree densities (< 0.8 trees per m^2), but oversaturated at higher tree densities, following an exponential relationship with an adjusted coefficient of determination of 0.82 and p-value < 0.001.

The mangrove tree height, mean canopy diameter and biomass data measured in the field and from the CHMs are summarized in Table 2.

In WP, the tree heights from the on-ground measurements ranged between 0.77 and 3.70 m, with a median height of 1.80 m. For the

and CHMs for nine survey sites in the south-eastern coast of Australia using Structure from Motion procedures. There was a close correspondence between UAV-SfM derived tree heights, average canopy diameters, tree density and ultimately AGB estimates with those measured in the field. Other studies have found that UAV-SfM data can be used as a tool for the retrieval of vegetation structure characteristics (Dandois and Ellis, 2010; Messinger et al., 2016; Panagiotidis et al., 2017; Zarco-Tejada et al., 2014).

However, very few have attempted to estimate AGB of mangrove ecosystems from UAV-SfM derived CHMs due to the high tree density and

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				CHM-based measurements, tree heights ranged between 0.71 and 3.33 m, with a median height of 1.80 m. Estimated AGB based on the UAV-SfM data in WP and natural areas of RRE was consistently lower (between 10 and 20%) than that generated from the field data at each survey site (Table 2). We observed the opposite pattern in the rehabilitated areas of RRE, where AGB estimates from UAV-SfM data were consistently higher (~10%) than those from field measurements when only the top canopy was considered (Table 2). In WP, the estimated tree AGB median from the on-ground measurements was 0.74 Kg. This value was not significantly different than the value obtained from the CHM-based measurements (0.66 Kg; Wilcoxon Rank-Sum test, p-value = 0.924).	overlap of these ecosystems (Navarro et al., 2019; Otero et al., 2018). Moreover, the use of UAV imagery is less expensive than on-ground measurements (Table 3), manned flights imagery (Dustin, 2015; Matese et al., 2015) and LiDAR systems (Sankey et al., 2017) while maintaining forest biomass estimation accuracy.		
Carbon sequestration	Differences in C stocks among sites were analysed using	Carbon storage Soil bulk density (BD)	MgC/ha	It has been reported that C stocks in the Indo-Pacific region contain on average 1,023 MgC/ha. Here, we estimate that Indonesian mangrove C stocks are 1,083 ± 378 MgC/ha.	Scaled up to the country-level mangrove extent of 2.9 Mha (ref. 3), Indonesia's mangroves contained on average 3.14 PgC.	Indonesia, in 39 mangroves ecosystem located	Murdiyarso, D., Purbopuspito, J., Kauffman, J. et al. The potential of Indonesian mangrove forests for

GOAP

	analysis of variance. For detail method, please see Table 3 in the supplementary information	Soil C content Soil C density Soil C pools		Although there was variation in how ecosystem C stocks were partitioned across sites, the majority (78%) of C was stored in the soils. Smaller pools of C were stored in living trees and roots or biomass (20%), and in dead or downed wood (2%). This finding is like many other mangrove ecosystems worldwide.	In three decades Indonesia has lost 40% of its mangroves, mainly because of aquaculture development. This has resulted in annual emissions of 0.07–0.21 Pg CO_2. Annual mangrove deforestation in Indonesia is only 6% of its total forest loss, however, if this were halted, total emissions would be reduced by an amount equal to 10–31% of estimated annual emissions from land-use sectors at present.	in eight sites spanning longitudes of 105°–140° E	global climate change mitigation. Nature Clim Change 5, 1089–1092 (2015). https://doi.org/10.1038/nclimate2734
Carbon stock	Plots transect; Within each transect, up to 6 plots of 7 m radius (154 m^2) were established at ~50-m intervals.	Organic soil carbon stock Canopy height Diameter at breast height	Total carbon stock (Mg C/ha) Canopy height (meters)	Average biomass contained in Rewa's forests is over twice the average reported for mangroves in other parts of the Indo-Pacific (Donato et al. 2011), it is still ~50–90 Mg C/ha lower than the mangroves of Sembilang (Sumatra) and Bintuni (West Papua) of Indonesia (Murdiyarso et al. 2015, Table 7) despite similar species dominance of	Allometric equations were used to estimate above and below ground biomass using both species specific equations (where available) and common (mangrove generic) equations. A list of the allometric equations used and sites in which species were recorded	Fiji's largest island, Viti Levu: Ba Province, Nadroga-Navosa Province, and in the Rewa Delta, which	Cameron, C., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). High variance in community structure and ecosystem carbon stocks of Fijian mangroves driven by differences in geomorphology

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The carbon content of biomass was calculated by multiplying by a factor of 0.464 for above-ground biomass and 0.39 for below-ground biomass. Samples were air dried in the field before analysis of carbon and nitrogen concentrations using an elemental analyzer (LECO TruMac) was conducted at the Commonwealth Science and Industry	(DBH, measured at 1.3 m above the ground); Mass of dead and downed wood debris (DDWD); Soil cores	DDWD (%) Total nitrogen stock (Mg N/ha) Species dominant (%)	all three forests (*Bruguiera gymnorrhiza* and *Rhizophora spp.*). Biomass in mangroves declines with increasing latitude (Alongi, 2009; Siikamäki et al., 2012; Hutchison et al. 2014) with higher biomass occurring in those forests closer to the equator, and both Sembilang and Bintuni are about 16◦ further north than Rewa. We scaled our ecosystem carbon storage results to the total estimated area of mangroves in Fiji (65, 243 ha, Cameron et al. 2020) and delineated mangrove estate by coarse scale estimates of geomorphic units. In this analysis, a further 3, 582 ha of mangroves on Vanua Levu (in addition to the Rewa, Ba and Tuva deltas) are classified as deltaic and assumed to have similar composition to the Tuva Delta. Within a global context, Fiji's deltaic systems appear at the lower end of the scale in terms of average ecosystem carbon stocks reported for estuarine mangroves (1073.9 Mg C/ha) in the Indo–	is available in the Supplementary materials; The mass of dead and downed wood debris (DDWD) was calculated through a modified version of the planar line intercept technique (Van Wagner, 1968; Brown, 1971) adapted for mangroves (Kauffman and Donato, 2012). Soil cores to a depth of 1.5 m were extracted near the center of each plot using an open faced, semi–circular tapered auger. Differences in geomorphic settings and biophysical variables, principally precipitation, freshwater influx and tidal range drive the high levels of variability	spans the Rewa and Tailevu Provinces	and climate. Environmental Research (Vol. 192, p. 110213). Elsevier BV. https://doi.org/10.1016/j.envres.2020.110213

	Research Organization, Adelaide, Australia.			Pacific (Donato et al. 2011, Table 5).			
Blue carbon (carbon sink)	Method to analyse data followed the published sources obtained using literature values and augmented by unpublished data, when available. Different data sources invariably use different methods, but we treated all data equally and standardized all nomenclatur	C_{org} content of living biomass and C_{org} content and dry bulk density (DBD) of soils	Mg C ha^{-1}	Recent calculations (Donato et al. 2011; Pendelton et al. 2012; Alongi and Mukhopadhyay 2014) indicate that the global destruction of mangrove carbon stocks at the current deforestation rate of 1 % results in an annual release of 90–970 Tg C $years^{-1}$ to the atmosphere/ocean pools and add an additional 10 % to global CO2 release from deforestation of tropical terrestrial forests. This estimate reflects the fact that mangroves store more carbon (956 t C ha^{-1}; Alongi 2014) than other ecosystems, such as rainforests (481 t C ha^{-1}) and salt marshes (593 t C ha^{-1}); mangrove carbon is stored mostly (75 %) below-ground as it is in seagrass meadows (>90 %) The data from all forest plots (Fig. 4) showed asymmetric distribution especially for above-ground carbon biomass (AGCB) with very few values greater than 350 Mg C ha^{-1}. AGCB ranged from 8.2 to 478.4 Mg C ha^{-1} with a median of	Summing the median AGCB, BGCB and soil pools (limited to 1 m depth), we derive a median carbon storage value for an Indonesian mangrove forest of 950.5 ± 29.9 Mg C ha^{-1}. Extrapolating this value to the total area of mangroves (31,894 km^2) results in a total mangrove carbon storage in Indonesia of 3.0 ± 0.1 Pg C. One empirical estimate indicates carbon sequestration (estimated from sediment accretion using surface elevation tables) in mangroves in Bali of 2.2 ± 0.6 Mg C ha^{-1} $years^{-1}$ (Sidik 2014) which is very close to the global mean burial rate of 1.7 Mg C ha^{-1} $years^{-1}$.	Indonesia, from 37 different mangrove forests in Sumatra, Sulawesi, Java, West Papua and Kalimantan	Alongi, D.M., Murdiyarso, D., Fourqurean, J.W. et al. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecol Manage 24, 3–13 (2016). https://doi.org/10.1007/s11273-015-9446-y

GOAP

e across the data.

159.1 and a mean (±1 SE) of 191.2 ± 20.2 Mg C ha^{-1} (Table 2). Below-ground carbon biomass (BGCB) was less than AGCB at all locations, ranging from 2.5 to 58.6 Mg C ha^{-1} with a median of 16.7 and a mean (±1 SE) of 21.1 ± 2.7 Mg C ha^{-1}(Table 2). The largest reservoir was the soil pool, ranging from 18.8 to 1569.3 Mg C ha^{-1} with a median of 774.7 and a mean (±1 SE) of 761.3 ± 73.6 Mg C ha^{-1} (Table 2). In one Sumatran Forest growing atop a relict coral reef, the largest C pool was the mangrove forest canopy (Alongi et al. 2008b). Mangrove AGCB and BGCB correlated positively (Pearson's $r = 0.436$; $P < 0.007$) but neither biomass pool correlated with soil carbon.

Mean (±1 SE) above-(AGCB) and below-ground carbon (BGCB) biomass and soil carbon storage in various mangrove forests throughout Indonesia, for detail number please see the full paper.

Using the Bali estimate, this means that approximately 7 Tg of carbon is buried in mangrove soils throughout Indonesia annually.

Given the continuing mangrove deforestation rate of 1 % of area annually, and assuming that 88 % of the entire carbon store in above- and below ground biomass as well as in soil to a depth of 1 meter is oxidized to CO_2 during the destruction process (Kauffman et al. 2014), the amount of CO_2 returned annually to the atmosphere/ocean pools is roughly 26,400 Gg CO2 or 29,040 Gg CO_2 if we make the identical assumptions for seagrasses (see Kennedy et al. (2014) for level of uncertainty and validity of these assumptions). This estimate is equivalent

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					to about 3.2 % of the annual CO_2 emissions associated with forest and net forest and peatland conversion (906,874 Gg CO_2 years^{-1}) in Indonesia (FAO 2012), which is roughly proportional to the total area of coastal wetlands to forest area (World Bank 2012). Our emissions estimate is only a small proportion of the 0.15–1.02 Pg CO_2 that may be released by land-use change of all the world's coastal wetlands (Pendleton et al. 2012).		
Hurricane protection	Using ordinary least squares (OLS) we fit nine alternative multiple regression models using the natural logs of wind speed and	Data combination on the tracks of the US hurricanes and their wind speeds with data on storm	Population GDP/ km^2 Total damage	The results also allow straightforward assessments of the impacts of changes to wetlands. For example, Louisiana lost an estimated 480 000 ha of coastal wetlands prior to Katrina (2005) and 20 000 ha during hurricane Katrina itself (6). The value of the lost storm protection services from these wetlands can be estimated as the average value per hectare in Louisiana	We would expect mangroves to have a significant storm protection effect, relative to inland riparian forest. Since mangroves occur in the US to a significant extent only in southern Florida, their positive effect was no doubt outweighed by the lack	combined data on the tracks of the US hurricanes and their wind speeds with data on storm damages	Costanza, R., Pérez-Maqueo, O., Martinez, M. L., Sutton, P., Anderson, S. J., & Mulder, K. (2008). The Value of Coastal Wetlands for Hurricane Protection. *Ambio*, *37*(4), 241–248.

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	area of coastal herbaceous and forested wetlands as the independent variables and TD/GDP as the dependent variable. Detail formulation please see the full paper.	damages and spatially explicit data on gross domestic product (GDP) and coastal wetland area in each storm's swath.	(Million)	(USD 1700/ha/year from Table 3) times the area, yielding approximately USD 816 million/year for services lost from wetlands lost prior to Katrina and an additional USD 34 million/year for wetlands lost during the storm. Converting this total of USD 850 million/year to present value terms using a 3% discount rate implies a lost value for just the storm protection service of this natural capital asset of USD 28.3 billion, and the lost storm protection value due to wetlands lost during Katrina of USD 1.1 billion.	of effect of riparian forested wetlands elsewhere. In future studies we hope to obtain better data that can differentiate mangroves from riparian forested wetlands.	and spatially explicit data on gross domestic product (GDP) and coastal wetland area in each storm's swath	http://www.jstor.org/stable/25547893
Flood protection	Risk assessment methods In this work we describe and pilot a multistep modelling framework to estimate the economic value of the coastal	Mangrove coverage Benefits Temporal data	Hectare US$ year	We successfully apply the multi-step methodology to estimate the flood protection service of mangroves for all the Philippines. By combining several data sources and models, we show that existing mangroves reduce flood damages significantly, from tropical cyclone surge events as well as daily flooding from large waves. Mangroves throughout the Philippines have historically provided – and continue to provide – annual coastal	Using this modelling framework, we estimate the consequences of mangrove loss for different climate conditions in terms of Annual Averted Flood Damages or Expected Annual Benefits. The contribution of mangroves for risk reduction, expressed in	Philippines	Menéndez, P., Losada, I. J., Beck, M. W., Torres-Ortega, S., Espejo, A., Narayan, S., Díaz-Simal, P., & Lange, G.-M. (2018). Valuing the protection services of mangroves at national scale: The Philippines. In Ecosystem Services (Vol. 34, pp. 24–36).

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	protection ecosystem services from mangroves in a way that can be readily included into national wealth accounting systems. The analytical framework scheme is in the full paper. Detail formulation, please see the full paper.			protection benefits to people, property, and infrastructure greater than typical costs of restoration. We also show that these benefits are highly spatially variable, with mangroves being providing far more benefits in some areas than in others. Without mangroves, flooding and damages to people, property and infrastructure in the Philippines would increase annually around 25%. These habitats reduce flooding to 613,500 people/year, 23% of whom live below the poverty line. They also avert damages to 1 billion US$/year in residential and industrial property. If mangroves were restored to their 1950 distribution, there would be additional benefits to 267,000 people annually, including 61,500 people below poverty and an additional 453 mill. US$ in avoided damages. Currently, mangroves prevent more than 1.7 billion US$ in damages for extreme events (1-in-50-year). The benefits provided by mangroves in the Philippines total	terms of expected annual monetary benefits and people protected, is obtained by means of the differences in damage across three mangrove habitat scenarios – 1950s extent (historical), 2010 extent (current) and no mangroves (loss). Understanding the annual, national economic value of the coastal protection service provided by mangroves requires a rigorous assessment that is consistent in flexible methodology and approach, across the country, that can be adapted to any other country or global scale analysis. Some main uncertainties resulting from the implementation of the methodology are: 1)		Elsevier BV. https://doi.org/10.1016/j.ecoser.2018.09.005

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				approximately 1 billion US$ in annual savings and 613,461 people protected against flooding, 142,427 of whom are vulnerable people living below poverty. The loss of mangroves would also affect road networks and an additional 76 kilometres of public roads would be flooded. More detail number of expected annual benefits per hectare is provided in Table 2, please see the full paper.	The difficulty to find global bathymetry data accounting for shallow structures, such as coral reefs; 2) the estimation of the roughness coefficients assigned to coral reefs and mangroves; 3) Due to technical and computational limitations, several simplifications have been made for modelling hazards and obtaining Flood Heights at national scale with the highest resolution as possible.		
Wind reduction	Modelling the dissipation of wave energy, including the Wave Propagation in Mangrove Forest (WAPROMAN) and Simulating Waves Nearshore	Factors affecting wave are available in the section 3 in the full report	Numerical	Case study 1: Predicting wave attenuation behind a mangrove island. Narayan et al. (2010) used the modified SWAN model of Burger (2005) and Suzuki et al. (2011) to estimate wave attenuation at Dhamra port behind Kanika Sands mangrove island, Orissa, India, for cyclone-induced wind waves of varying return period. For a wave height with a return period of 25 years and an incident	To understand the level of protection provided by mangroves, and to plan how to increase it, the passage of waves through mangroves has been modelled numerically using both a standard wave model used by coastal engineers called SWAN (Simulating WAves	India, Vietnam	Reduction of Wind and Swell Waves by Mangroves. McIvor, A. L., Möller, I., Spencer, T., and Spalding, M. Natural Coastal Protection Series: Report 1: The Nature Conservancy and Wetlands International. (2012)

(SWAN) model. Detail formulation and model is available in the full report			wave angle of 90º, a wave reduction of nearly 50% was observed at the port due to the effect of the mangrove island; attenuation within the island was nearly 90%, but a relatively sharp recovery of wave heights was seen beyond the island, partially because of the island's shape (Fig. 11). Because of the presence of the mangrove vegetation on the island, 2.5 m waves have a calculated return period of 60 years at Dhamra Port, compared to a return period of 20 years if the mangrove island was not present. Case study 2: Determining the required width of a mangrove belt. Bao (2011) studied the reduction in wave height in mangrove forests in Vietnam and created a statistical model relating wave attenuation to initial wave height, cross-shore distance, and mangrove forest structure (as described in section 4.4). Bao used the model to calculate the minimum mangrove band width that would provide adequate protection from waves, and how	Nearshore) (Suzuki et al., 2011), as well as a model developed specifically for waves in mangroves called WAPROMAN (WAve PROpagation in MANgrove Forest) (Vo-Luong and Massel, 2008). These models are able to predict typical levels of wave attenuation given a knowledge of the mangrove characteristics, the wave parameters and the local bathymetry and topography. A statistical model has also been developed to explore the relationship between some standard forest measurements (tree height, tree density and canopy closure) and wave attenuation with distance (Bao, 2011). This model has been able to predict wave reduction within the Vietnamese mangroves	

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				this would vary for mangroves with different forest structures. All studies have found that mangroves are able to attenuate wind and swell waves. The level of wave attenuation varies between 0.0014 /m and 0.011 /m (Table 2). These attenuation rates suggest that over 500 m of mangrove forest, wave height would be reduced by 50 to 99%. However, most studies have measured the attenuation of only relatively small waves (wave height < 70 cm), and further research is needed to measure the attenuation of larger wind and swell waves by mangroves.	where it was developed and could be used to determine the width of mangrove belt needed to deliver a predefined level of protection from waves.		
Storm surge reduction	Numerical model: a numerical storm surge model has been proposed by Sheng et al. (2012). They propose a three-dimensional numerical	Factors affecting storm surge reduction: mangrove width, mangrove vegetation characteri stics, topograph y, bathymetr	Cm, Km, %	These studies measured reductions in peak water levels of 5 to 50 cm per kilometre of mangrove. This implies that a mangrove belts several kilometres wide is needed to significantly reduce storm surge water levels. By reducing wave height, mangroves are expected to reduce wave set-up and run-up, which contribute to the raised water levels, inundation and damage caused by storm surges. Mangroves also buffer the water	The model allows them to vary the height, density, and width of the vegetation, and they find that increases in height, density and/or width result in a reduction in inundation volume. Their model is yet to be applied to mangrove vegetation. One limitation of the current numerical	Global scale, not specific	McIvor, A.L., Spencer, T., Möller, I. and Spalding. M. (2012) Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41. Published by The Nature Conservancy and Wetlands

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model of storm surges based on the coupled CH3D-SWAN (Curvilinear-Hydrodynamics 3D – Simulating Waves Nearshore) model	y, size and speed of cyclone and storm surge, wind speeds		surface from winds that would otherwise cause larger wind waves to form on the surge water surface. The ability of mangroves to reduce storm surges also depends on the storm surge forward speed, the height of the storm surge and the cyclone intensity. Numerical models suggest that mangroves will be more efficient at reducing surge height for fast-moving surges. Extreme events, with very strong winds or surges many meters high, may damage or destroy mangroves, reducing their ability to reduce surge height. The threshold at which such damage occurs is likely to depend on mangrove species and height (Lacambra et al., 2008). The most appropriate use of mangroves in coastal defense is likely to be in combination with other risk reduction measures. For example, sea walls and levees placed on the landward side	models is their inability to include spatial variation in mangrove characteristics, such as mangrove density. It is very likely that the ability of mangroves to reduce peak water levels depends on mangrove characteristics, with sparse, fragmented, or channelized areas reducing storm surge water levels less effectively than dense mangrove vegetation. Currently, mangroves are represented in numerical models as an increase in surface roughness, and a single value for the roughness coefficient is used for all mangroves areas (Xu et al., 2010; Zhang et al., 2012).		International. 35 pages. ISSN 2050-7941. URL: http://www.naturalcoastalprotection.org/documents/storm-surge-reduction-by-mangroves

				of mangrove forests are likely to experience reduced water levels and wave energy during storm surges, greatly reducing the likelihood of the wall being overtopped or damaged during a storm surge, this could significantly reduce the design specifications and therefore the cost of the sea wall (such combinations are sometimes referred to as 'hybrid engineering').			
Strom protection function	We used the damage cost avoided approach (Bann 1998) to value the storm protection function of the Bhitarkanika mangrove ecosystem. Socio economic data pertaining to local demography	Monetary value	US$	Total losses in monetary terms were calculated for each of the households in the three villages by combining the values of the cost of repair and reconstruction (CR), damage to other personal property such as boats, fishing nets and household goods (DPP), damage to livestock (DL) and loss of agricultural products (i.e. difference in total paddy production between 2001–1999, taking the area cultivated in 1999 as the basis). The loss incurred per household (TML) was highest in Bandhamal (US$ 153.74) followed by Singdi (US$ 44.07) and Bankual (US$ 32.31) (Tables 3 and 4).	With a view to valuing the uses and ecological services provided by the Bhitarkanika mangrove ecosystem, quantifying the dependence of local communities on it, identifying marginalized stakeholders, and examining the attitudes of local communities towards present management, we set out to value the storm protection functions of the Bhitarkanika mangrove forests. This was based on the perceptions of local	Bhitarkanika, India	BADOLA, R., & HUSSAIN, S. (2005). Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation, 32(1), 85-92. https://doi.org/10.1017/S0376892905001967

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and economic conditions were collected from 35 villages.

We conducted a door-to-door survey and sampled

100% of the selected households to assess the socio-economic status of the villages, the actual damage to houses, livestock, fisheries, trees and other assets owned by the people and the rate, level and duration of flooding.

In the mangrove-protected village, variables had either the lowest values for adverse factors (such as damage to houses), or the highest values for positive factors (such as crop yield). The loss incurred per household was greatest (US$ 153.74) in the village that was not sheltered by mangroves but had an embankment, followed by the village that was neither in the shadow of mangroves or the embankment (US$ 44.02) and the village that was protected by mangrove forests (US$ 33.31).

people regarding the services provided by mangrove forests and

their attitudes towards these forests generally. We aimed to measure the economic losses attributed to the cyclone relative to the prevailing socio-economic conditions of the study villages.

To assess the type of damage caused to houses, we developed a composite score or damage rating (DR) for each of the households surveyed in the three villages. The scores were in the range of 0–19 depending on the intensity of damage to the house.

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Erosion control	*Further studies are needed*						
Water purification	The estimated value of each form of culture (Vc) in US$/year was added together and divided by the area of mangrove forest in hectares (A_m), resulting in the potential value of mangroves use for aquaculture (V_a) at US$/ha/year For comparison with other works, given by: $V_a=\Sigma V_c/A_m$. Detail formulation,	Nutrient's stock: phosphorus and nitrogen Stock in sediment Stock in trees Estimated loads in sewages Time to reach	Kg, year	The estimated loads stored in the sediments (E_s) and in the trees (E_b) for the forest area dominated for the *R. Mangle*, equivalent to about 920 ha, 62% of mangrove wetland area around the Potengi estuary (1488 ha), summed up 418,400 kg of P and 4,447,800 of N. The loads of P and N released per year (Load $_{kg/year}$) in the corresponding heights of tides that flood the mangrove forest, were estimated at 85,137.50 kg / year of P and 304,062.50 of N. The time the charges of P and N released from sewage in the estuary would take to be equivalent to those stored in the sediments would be 4.9 years for P and 14.6 years for N, equivalent to treatment time (t) of the loads of P and N in years in a Water Treatment Plan (WTP) with stabilization ponds. Considering the mangrove area (A_m) of 920 ha, the value of the service of holding the loads of N and P which are stored in the mangrove ecosystem ($V_\$$) was	Considering in this case some conditions to estimate the valuation of the capacity of estuarine water purification by the mangrove forest were assumed: a) that the estuary is a closed system to the exchange of P and N with the ocean; b) the loads of N and P from sewage available to mangroves refer to only those on tide heights that flood the mangrove forest, given the fact that only the influence of the tide can provide nutrients to the mangrove forest (Ramos e Silva 1996); c) that the tides that flood the forest are semi-diurnal, given by their daily peaks where each peak occurs at intervals of 06 h. It is also considered that the tidal heights that	The Potengi estuary, Rio Grande do Norte in northeastern Brazil	Souza, F. E. S., & Ramos e Silva, C. A. (2011). Ecological and economic valuation of the Potengi estuary mangrove wetlands (NE, Brazil) using ancillary spatial data. Journal of Coastal Conservation, 15(1), 195–206. http://www.jstor.org/stable/41506513

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	please see the full paper			about US$ 7,200.00/ha, and for the service of renewal rate of the loads P and N ($V_{a\$}$) was about US$ 72.00/ha/year. Based on the cost of the trips in the Potengi estuary applied to the perimeter of the mangrove forest used for this purpose (Table 3), and based on the tracks made in the Potengi estuary (Fig. 4) showed that aggregate potential values reach about US$ 2.50 per kilometer of mangrove forest used as a the scenario of direct and indirect uses tourism uses. More detail about scenarios in the full paper.	flood the forest (from 0.4 m) were obtained from topographic profile in the study area, where the level reference was the neap (0.0), and its incidence given by the average annual frequency according to the tide boards to the Port of Natal in 1995, 1996 and 1997 (DHN. Marinha do Brasil 2004); d) and that the loads are evenly diluted in the volume of water of the estuary and entirely retained by the mangrove forest, having the volume at the tide height of (0.0 m) at the Potengi estuary of 18,607,200 m^3 (CAERN 1995).		
Nutrient cycling	*Further studies are needed*						
Waste remediation							
Pollutant remediation							
Provisioning							

Maintenance of fisheries (mud crab)	All catches were recorded for a period of 43 months (April 2002–November 2005, except January 2004). From May 2005, sampling was only on the first spring tide of the month. Size at sexual maturity was estimated following Jennings et al. (2001).	Mud crab CPUE, biomass	Monthly mean CW (mm), BW (g), CPUE (number and biomass), and yield (kg) were each correlated with time, temperature, and salinity	The mean monthly yield from all traps deployed was 17.0 kg, varying between 8–48 kg or 0.34 kg ha^{-1}, giving an annual fishing yield of 4.1 kg ha^{-1} (Fig. 5). Catch per unit effort (CPUE) was analyzed monthly using only bamboo trap catches to allow comparison of the entire survey period with consistent fishing effort (Fig. 6). Mean monthly CPUE for number ranged from 0.32 ± 0.02 (April 2003) to 1.02 ± 0.16 crabs $gear^{-1}$ d^{-1} (April 2002). In terms of biomass, CPUE ranged from 32.0 ± 3.0 to 94.5 ± 17.7 g $gear^{-1}$ d^{-1}. A decreasing trend was observed for CPUE in both number and biomass from the start of the sampling in April 2002–December 2003. CPUE in terms of both number and biomass more than doubled in February 2004, increased until June 2004, then started to drop again.	Each fisher was trained to record data for type and number of gears used, percentage of traps containing crabs, deployed time and duration, crab species, sex, sexual maturation of females, carapace width, and body weight (noting missing limbs). All analyses were performed using the Minitab software package (version 14).	Naisud and Bugtong Bato village, municipality of Ibajay, in Aklan province, central Philippines	Lebata, M., Hazel, J., Vay, L. L., Primavera, J. H., Walton, M. E., & Biñas, J. B. (2007). Baseline assessment of fisheries for three species of mud crabs (Scylla spp.) in the mangroves of Ibajay, Aklan, Philippines. Bulletin of Marine Science, 80(3), 891-904. http://hdl.handle.net/10862/2064
Extractive: Nipa Palm Products	Cost benefit analysis	Nipa palm operational	Farm area (ha), produ	On average, the leaf-selling farmers reported a productivity of 1,109.5 bundle/ha/year with an average farm size of 3.64 ha. The	Nipa palm sap can also be processed into bioethanol, which has an outstanding	Ayeyarwady Region of Myanmar	Doetinchem,Nina. 2020. Nipa Palm Products in the Ayeyarwady Region

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	information	ctivity of leaves (bundle/ha/year), Gross income-operational cost-net income (MMK/year),	average price per bundle observed was 540 MMK. On average, farmers reported an estimated annual income from the sale of nipa leaves of around 1,400,000 MMK, equivalent to around USD 1,000. In terms of operational costs, no input costs were reported; maintenance costs consisted of weeding and cutting the stump of the palm border; while labor costs reflected the opportunity cost of the farmer, given the time and effort required to fully carry out the activity; and finally, transportation costs were reported. The average annual net income for these farmers is positive, with a net margin and benefit to cost ratio reflecting a profitable economic activity. Based on 2013 data, production of bioethanol was capable to contribute a net income of 6,095,274 – 42,039,360 IDR/ha/year (around 500 – 3,400 USD/ha/year). Evaluations showed that the labor recruitment on the utilization of nipa palm sap into bioethanol	importance in economies that are seeking to fulfill their energy requirements and/or substitute the utilization of fossil fuels. As a reference point, with a nipa sap tapping period of 100 days/year (under Traditional management), and with a density of 1,000 palms per ha, an annual sap yield of 50,000-100,000 L/ha/year can be harvested. Consequently, the annual ethanol yield estimated is around 4,550-9,100 L/ha/year (Hidayat, 2018). Compared to other sources, sugarcane can yield (fuel-alcohol) 3,350-6,700 L/ ha/year, cassava 3,240-8,640 L/ha/year, sweet potato 6,750-18,000 L/ha/year, and coconut sap 5,000 L/ha/year. It		– Insight Brief © World Bank. https://pubdocs.worldbank.org/en/502551611143196249/Insight-Brief-Nipa-Palm-Products-in-the-Ayeyarwady-Region

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				was able to generate up to 3.69 people/ha/month.	takes 13 liters of sugar-rich nipa palm sap to produce around 1 liter of bioethanol		
Cultivated resources extracted	Case study with secondary data from internal Sarawak Mangroves Forest Reserve	Mangrove products	Number of poles and percentage US$	The mangroves support marine fisheries worth US$21.1 million p.a. and up to 3000 jobs, timber products worth US$123,217 p.a., and a tourist industry worth US$3.7 million p.a. If the mangroves were to be damaged, all of the fisheries and timber and many of the tourism benefits would be lost. Table 6. provides the products percentage derived from dependency on mangrove. In summary: fish and prawns (48%), firewood (26%), nipa fronds for roofing materials (13%), nibong poles for prawn traps (19%), and bakau poles (47%). Please check the full paper for detail information.	Mangroves directly provide the major source of subsistence, revenue, and employment for all of the villages in the area. Any alternative form of land use would have to provide jobs for at least 600 households if people in the area were not to suffer immediate hardship. Table 7. provides summary of costs which could be expected if the area were to be converted to an alternative form of land use	Sarawak Mangroves Forest Reserve, Malaysia	Bennett, E. L., & Reynolds, C. J. (1993). The value of a mangrove area in Sarawak. In Biodiversity and Conservation (Vol. 2, Issue 4, pp. 359–375). Springer Science and Business Media LLC. https://doi.org/10.1007/bf00114040
Traditional and medicinal materials extracted	Literature review	It describes how people have and are using	Descriptive	The economical uses of products from mangrove ecosystems are many and varied. Traditionally, the mangroves have been exploited for firewood and charcoal. Use has also been found for mangroves in the	A knowledge of the biological activities and/or chemical constituents of plants is desirable, not only for the discovery of new therapeutic agents, but	Global	Bandaranayake, W. Traditional and medicinal uses of mangroves. Mangroves and Salt Marshes 2, 133–148 (1998).

		mangroves on a traditional basis		construction of dwellings, furniture, boats and fishing gear, tannins for dyeing and leather production. The mangroves provide food and wide variety of traditional products and artefacts for the mangrove dwellers. Extracts and chemicals from mangroves are used mainly in folkloric medicine (e.g. bush medicine), as insecticides and piscicides and these practices continue to this day. However, the extraction of novel natural chemical compounds from mangroves, in addition to those already known to the pharmacopoeia of the people is in its infancy.	because such information may be of value in disclosing new sources of already known biologically active compounds. It is of further value to those interested in "deciphering" the actual value of folkloric remedies.		https://doi.org/10.1023/A:1009988607044
Social economic value	Economic value of mangrove ecosystem can be viewed from its functions which are social, ecological, physical and chemical aspects. This functions are	Man/month/hectare/year	US $ of economic value	The benefit of mangrove ecosystem per hectare per year in Indonesia can be value as follows: Direct use value: There are 26 productive identified uses for the mangrove ecosystem in Indonesia varying from timber, firewood, fisheries, and other uses. The economic value of this direct use value ranging from US $19.42 to US $1,687.24.	Social value of mangrove ecosystem can be expressed by how many man/month utilized the resource, Rizal [6] estimated 38 man-month per hectare per year involve in tapping mangrove ecosystem. Using the benefit-cost analysis framework, the analysis showed that	Indonesia	Rizal, A., Sahidin, A., & Herawati, H. (2018). Economic value estimation of mangrove ecosystems in Indonesia. Biodiversity International Journal, 2(1), 98-100. http://dx.doi.org/10.15406/bij.2018.02.00051

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	classified to their uses, namely direct use value (DUV), indirect use value (IUV), option value (OV) and existence value (EV).			Indirect use value: Six indirect use values are considered, varying from food source to storm protection with economic value ranging from US $637.93 to US $24,000.53. Option value: Biodiversity has been selected to refer the different types of biological diversity habitats or traits which exist in any given system. The biodiversity value is US $15.00. Existence value: Existence value is interpreted as value humans gain from simply knowing that an ecosystem or species exists, independent of whether an individual uses it or not. By using the contingent valuation method, the communities valuate the mangrove resources US $ 560.00 to US $ 2,516.40. The cost of using the mangrove is ranging from US $12.71 to US $975.76 per hectare therefore the total economic value of mangrove ecosystem is ranging from US $3.624.98 to US $26,734.61 per hectare per year.	by allocating 80% for mangroves and 20% for aquaculture: tilapia aquaculture resulted in lower NPV (US $10,347.6) compared to sustainable mangrove forest management (US $11,043.2). The management option for sylvofisheries-shrimp aquaculture resulted in a higher NPV (US $15,195.2) compared to sustainable mangrove forests		
Cultural							

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Cultural usage	In this study we develop an indicator of CES usage that is derived from photographs from an image-sharing website,	social media photographs	geo-tagged photographs	In the case of all mangrove sites, the relationship between the number of photographs classified, and the accuracy of the site level characterization was positive and nonlinear, with the rate of improvement slowing to reach an asymptote (Fig. 5a and d). The minimum numbers of photographs necessary to categorize in order to reach 95% agreement with the full dataset were 41 for SBWR, 46 for Berlayer Creek, 56 for Chek Jawa and 64 for Mandai. The maximum time taken to classify the entire dataset of 682 photographs was approximately 5 h, so it should be feasible for one assessor to classify 70 photographs (enough to reach 95% similarity at any of our study sites) in around 30 min.	Singapore is a suitable location to analyze social media photographs due to a high population density of ~7600 people per km^2 and high rate of mobile phone usage, smartphones that are capable of capturing and uploading geo-tagged photographs	Singapore	Richards, D. R., Friess, D. A. (2015). A rapid indicator of cultural ecosystem service usage at a fine spatial scale: Content analysis of social media photographs. Ecological Indicators. https://doi.org/10.1016/j.ecolind.2015.01.034
Tourism/recreation	'Direct' valuation methods	Economic value	US$ per year	The economic value of cultural services of Sundarbans, in terms of revenue collected from tourists, was estimated to be US$ 42,000 per year during the period of 2001–2002 to 2009–2010. On average each year 80,375 tourists visited Sundarbans, of which 98% were domestic and 2% were foreigners. The number of tourists has been doubled over the study	The economic value of the provisioning services including timber, fuel wood, thatching materials, fish, crab, and honey was estimated using the aggregate of annual revenue earned by Forest Department from all types of	Bangladesh Sundarbans Reserve Forest (SRF)	Uddin, M. S., de Ruyter van Steveninck, E., Stuip, M., & Shah, M. A. (2013). Economic valuation of provisioning and cultural services of a protected mangrove ecosystem: A case study on sundarbans

period (Fig. 4) and revenue increased by 4 times in the same period. This is because of increase of international tourist by five times over the same period. It indicates that there is a high potential to increase economic benefit from tourism in the Sundarbans.

The average annual extraction of timber from Sundarbans was about 3567 m3 during 2001–2002 to 2009–2010, which is obviously much lower than the timber extraction at the pre-moratorium stage (nearly 300,000 m3 in 1987–1988) reported in a previous study (FAO, 1998). It indicates that the economic benefit from timber extraction could be much higher than present value if we could maintain sustainable production from the forest. Fuelwood production followed the same declining trend as timber, and generated low revenue compared to other products.

provision services of the Sundarbans over a fiscal year. Historical records of revenues earned from each of the provisioning services were retrieved from the sales documents maintained by the FD for the financial years 2001–2002 to 2009–2010. Total stock of different types of provisioning services such as timber, fish, is not evaluated in this study because two reasons: one is unavailability of realistic information on the stocks; the other reason is that the estimated economic value of the total stock would not give any indication how much economic benefit the SRF can provide to FD annually, whereas possible annual yield of resources would be more important to FD to determine the

reserve forest, Bangladesh. Ecosystem Services, 5, 88–93. https://doi.org/10.1016/j.ecoser.2013.07.002

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					potential economic benefit from SRF.		
Ecotourism suitability	Quantitative descriptive with survey method. Data collection techniques of this research are observation, interview, and documentation. The research was conducted in March - August 2019. Detail data collection is available in the paper	Data collection about the biological condition of mangrove forests includes mangrove density, mangrove types, and biota types in the mangrove forest	five parameters. mangrove length (m), mangrove density (ind.ha^{-1}), mangrove species, tidal (m), and biota	The highest Ecotourism Suitability Index (ESI) value is in Site I that is 87.18%, then followed by Site III for 79.49%, while the lowest is in Site II for 66,67%. The average value of the three sites is 77.78%, so that the mangrove forest area in Hamadi Beach, Jayapura City, is included in the very suitable category to be used as an ecotourism area. Potential natural resources found in Hamadi Beach are mangrove forests, where mangrove length is on average 254 m, mangrove density is high with an average of 12,367 ind.ha^{-1}, and mangrove species found in nine species. Other potential natural resources found are biota, which consists of fish, birds, reptiles, amphibians, mollusca, crustaceans, and insects. Mangrove forests in Hamadi Beach are very suitable to be designated as ecotourism areas. With ESI value of 77.78%, they are categorized as S1 or very suitable.	The suitability mangrove as ecotourism is calculated by considering five parameters. mangrove length (m), mangrove density (ind.ha^{-1}), mangrove species, tidal (m), and biota The supporting documents include Jayapura City Spatial and Regional Planning (RTRW), the profile of South Jayapura District, and tidal data.	Hamadi Beach, Jayapura	Sari, A. N., Bhaskara, C., Bimantara, A., 2020. The Suitability of Mangrove Ecotourism Based on Its Biophysical Condition in Hamadi Beach, Jayapura City. Journal of Indonesian Tourism and Development Studies. Vol 8 No 3. https://jitode.ub.ac.id/index.php/jitode/article/view/402/310

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Education/research	To calculate cultural services carried out by the Travel Cost Method (TCM)	Area	Ha, US$	Total economic value with estimated are of 415.89 ha is 14,762.7 US$	Recapitulation of the total economic value of the mangrove ecosystem of Tangerang District in 2017 based on high (17.46 ha), medium (18.09 ha), and low (380.34 ha) habitat quality ecosystem services.	Tangerang District, Indonesia	Marlianingrum, P. R., Kusumastanto, T., Adrianto, L., & Fahrudin, A. (2021). Valuing habitat quality for managing mangrove ecosystem services in coastal Tangerang District, Indonesia. Marine Policy, 133(104747), 104747. https://doi.org/10.1016/j.marpol.2021.104747
Social valuation	The natural capital of wetland services framework qualitatively measured by combining focus group and household surveys methods	Social valuation variables: therapeutic, amenity, heritage, spiritual and existence values, respectively	Qualitative	When survey participants were asked whether they use materials from the mangrove for spiritual worship, 78% of them responded 'Yes' in Buguma community; while 69% and 35% responded 'Yes' in Burutu and Kuruama communities, respectively. The negative influence of external factors on these social value variables may in the long run erode the significance of the social value of mangroves in the Niger Delta. For example, the advent of Christianity in the	A hectare of mangrove in the region has a potential yield of between \$642/ha – \$2853/ha. The decision to conserve or change mangrove vegetation to alternative usage in the Niger Delta should be determined within economic as well as social value frameworks	Niger Delta, Nigeria	Godstime K. James, Jimmy O. Adegoke, Sylvester Osagie, Saba Ekechukwu, Peter Nwilo & Joseph Akinyede (2013) Social valuation of mangroves in the Niger Delta region of Nigeria, International Journal of Biodiversity Science, Ecosystem Services & Management, 9:4, 311-323, https://doi.org/10.108

				region has gradually diminished the role of mangroves in spiritual worship.			0/21513732.2013.842611
Religious/spiritual/indigenous	*Further studies are needed*						

Table 5. Overall services of mangrove ecosystem

Sources	Context or assumption	Indicator (unit)	Method	Location	Type of service	Value
Hernández-Blanco, M., Costanza, R., & Cifuentes-Jara, M. (2021). Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology. Ecosystem Services, 49(101258),	Due to the public good nature of many of mangrove's ecosystem services, markets for them do not exist and there is limited potential to manage them with conventional markets. Moreover, because of the difficulties in estimating the value of these non-marketed services, mangroves are often undervalued in benefit cost analysis of conservation versus commercial land uses causing their degradation and loss. To overcome some of the limitations of the benefit transfer method, such as providing values only from the demand side and differences in population characteristics (Bergstrom and Taylor, 2006), in July 2018 we conducted a workshop with experts from the government, the	Payment for Ecosystem Services ($million/year) Social Cost of Carbon (SCC) is $/tC Carbon stocks (MgC/ha) Sequestration rate (MgCO2eq/ha/yr)	We applied a hybrid approach to estimate the value of ecosystem services from mangrove forests in the Gulf of Nicoya, using both secondary and primary data. we extracted 67 estimates in per hectare per year units from the Ecosystem Services Valuation Database (ESVD) from The Economics of Ecosystems and Biodiversity (TEEB). Our method consists of traditional benefit transfer and expert modified benefit transfer for 11 ecosystem services, and the	Gulf of Nicoya, Costa Rica	Three of those ecosystem services (exp. climate regulation, fisheries, and coastal protection)	Combining the values of the expert modified benefit transfer with the estimates from the more in-depth and specific methodologies, we calculated the mean total value of the ecosystem services assessed from mangrove forests in the Gulf of Nicoya in $408 million per year, and a median total value of $86 million (Table 11). Using traditional benefit transfer, we estimated the total economic value of ecosystem services of mangroves in the Gulf of Nicoya in $812 million per year (median=$88 million/year), and the total mean value of the ecosystem services provided by all the mangroves in Costa Rica as $1.5 billion per year (median=$160 million/year). By applying the expert modified benefit transfer we estimated that the mean total value of the mangrove forests of the Gulf of Nicoya is $470 million per

101258. https://doi.org/10.1016/j.ecoser.2021.101258

academic sector and NGO's to determine which ecosystem services from our list of 11 are in reality provided by mangroves in the Gulf of Nicoya, as well as to define where these services are benefiting people. Having calculated the area of provision of ecosystem services through a participatory mapping process with the experts, we multiplied it by its respective per ha per year value.

To estimate the economic value of fisheries, we assumed that the marginal and average products of mangrove area are equal for all species harvested since there isn't data for the country on fishing effort (Costanza et al., 1989). This could result in an overestimation because the marginal product is generally lower than average product. However, there is also a compensating underestimation because the market price does not fully capture the value of fishing to society.

As established in the methods section, we assumed that the marginal and average products of

application of more specific methods.

Table 1 provides specific methods for the economic valuation of three ecosystem services from the Gulf of Nicoya: 1) Climate regulation = Social cost of carbon, marginal abatement cost; 2) Food (fisheries) = Production/ha and market price; 3) Coastal protection = Spatial modelling and benefit transfer. Detail formula to each services valuation is available in the full paper.

year, and a median value of $75 million per year. Combining the three different valuation technics, we calculated the mean total value of the ecosystem services from mangrove forests in the Gulf of Nicoya in $408 million per year, and a median total value of $86 million. Considering the median total value of ecosystem services from mangroves, it represents 0.16% of the GDP in Costa Rica in 2015.

We estimated the economic value of the total organic carbon storage in the mangrove forests of the Gulf of Nicoya using the Marginal Abatement Cost of Carbon (MAC) as the value of carbon stock per hectare. MAC represents the costs of eliminating an additional unit of carbon emissions, and "these costs are the benefits forgone when scarce resources are used to avoid the chances of negative impacts of emissions instead of being used in alternative activities" (Jerath, 2012, p35), in other words, MAC represents the opportunity costs. Specifically, we used the estimate that Fisher et al. (2007) produced for the IPCC 4th Assessment Report, with a mean MAC of $125/tC (calculated for the year 2010). The mean estimate for Social Cost of Carbon (SCC) is $177/tC, and $80/tC (calculated for the year 2010) if

GOAP

mangrove area are equal for all species harvested (following Costanza et al. 1989), which results in a catch of 54 kg per hectare of mangrove, and a total value of $222 per hectare.

The Sea Level Rise map that we produced using data from the AVISO + website (www.aviso.altimetry.fr) (Fig. A4.1 from Appendix 4) shows the northern zone of the Gulf to be the one that is experimenting the highest rise, with 2.93 mm/year in the districts of Chomes, Pitaya, and parts of Puntarenas, and 2.88 mm/year in the districts of Manzanillo, Colorado-Abangares, Mansion and Chira Island. In the middle zone of the Gulf, in the districts of El Roble, Espiritu Santo, San Juan Grande, Paquera and the majority of Tarcoles, sea level is rising at a rate of 2.7 mm/year. Finally, the southern zone of the Gulf has the lowest trends of sea level rise, in the district of Cobano is 2.46 mm/year and in Jaco, one of the most populated beaches of the country, 2.32 mm/year.

only peer review papers are considered. We chose the peer reviewed values since they have a higher quality. This value was then converted to 2015 international dollars. Applying the Social Cost of Carbon of 87 $/MgC to a sequestration rate of 6 MgCO2eq/ha/year, the total economic value of the carbon sequestration service is $38,151,655 (Table 6).

The first part of the application of the benefit transfer method, which was the estimation of a per hectare per year value from the ESVD of the ecosystem services provided by mangroves, shows that the ecosystem service with the highest mean value are timber and fuelwood, $17,652/ha/year, followed by biodiversity protection ($10,651/ha/year) and coastal protection ($7,638/ha/year). Other services with high economic value are food ($2,002/ha/year) and raw materials ($1,366/ha/year). Nevertheless, median values provide a different panorama, with coastal protection with the highest value ($2,997/ha/year), followed by timber and fuelwood ($315/ha/year), food ($293/ha/year) and climate regulation ($287/ha/year). We found that one hectare of mangrove can provide average economic benefits of $40,747

GOAP

per year (median=$4,410/ha/year) through the provision of these 11 ecosystem services valued. By multiplying these values by the mangrove cover in the Gulf, we estimated the economic value of 11 ecosystem services of these mangroves is approximately $812 million per year (median = approximately $88 million/year) (Table 2). Using the same method, we estimated the total mean value of the ecosystem services provided by the total extent of mangroves in Costa Rica as $1.5 billion per year (median=$160 million/year). Considering the change in national cover of mangroves from 1980 to 2013 (FAO, 2007), we estimate that Costa Rica lost an average $1.1 billion per year (median=$120 million per year) during that period because of the loss of ecosystem services from mangroves.

Having determined which ecosystem services are provided in reality by mangrove forests in the Gulf of Nicoya, we produced a new set of value estimates (Table 3). According to our modified benefit transfer, the highest mean values of the mangroves of the Gulf of Nicoya comes from biodiversity

GOAP

protection ($212 millions/year), coastal protection ($152 millions/year) and timber and fuelwood ($50 millions/year). The highest median values are from coastal protection ($60 millions/year), food ($5.8 millions/year) and climate regulation ($5.7 millions/year), all three ecosystem services valued in this study as well using specific methods.

Looking at the total catches and economic values by species in 2015 in the Gulf of Nicoya, the queen corvina is the species that is fished in the highest quantities of all species assessed (311,771 kg), as well as having the highest economic value ($1,264,579). The Scalyfin corvina is the second most fished species of all (267,892 kg) but has the third highest economic value ($709,818) since white shrimps are the second most valuable species ($1,082,514) (Table 9). In total, the provisioning service of food (exp. fisheries) in the Gulf of Nicoya has an economic value of $4,613,471.

We estimated through the benefit transfer modified by modelling method that the total mean value of the coastal protection service is $103 million per year, and a median total value of 40 million per year (Table 10).

GOAP

M. Brander, L., J. Wagtendonk, A., S. Hussain, S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. Ecosystem Services, 1(1), 62–69. https://doi.org/10.1016/j.ecoser.2012.06.003	We construct a database containing 130 value estimates, largely for mangroves in Southeast Asia. Values are standardised to US$ per hectare per year in 2007 prices. The mean and median values are found to be 4185 and 239 US$/ha/year respectively. The values of mangrove ecosystem services are highly variable across study sites due to, amongst other factors, the bio-physical characteristics of the site and the socio-economic characteristics of the beneficiaries of ecosystem services. We include explanatory variables in the meta-analysis to account for these influences on estimated mangrove values. A geographic information system (GIS) is used to quantify potentially important spatial variables, including the abundance of mangroves, the population of beneficiaries, and the density of roads in the vicinity of each study site. In order to allow direct comparison of study results, all value estimates are standardised to US$ per hectare per year at 2007 price levels. Values that are	Regarding study site characteristics, we define variables indicating the ecosystem service that is valued and the size of the mangrove in hectares. On theoretical expectations we define three groups of explanatory variables that represent different determina	The selected methodology for estimating the foregone value of ecosystem services due to change in the extent of mangroves in Southeast Asia over the period 2000–2050 is to apply a value transfer approach using a meta-analytic value function combined with spatial data on changes in mangrove area. This approach allows the estimation of spatially variable site or patch specific values that reflect the characteristics and context of each mangrove patch. For the purposes of conducting a meta-analysis of mangrove ecosystem service values, we collected mangrove valuation studies through online journal databases, libraries, online	Southeast Asia	The values that are estimated in this paper using the meta-analytic value function therefore represent a subset of the total economic value from mangroves.	The meta-analytic value function is used to estimate the change in value of mangrove ecosystem services in Southeast Asia under a baseline scenario of mangrove loss for the period 2000–2050. The estimated foregone annual benefits in 2050 are US$ 2.2 billion, with a prediction interval of US$ 1.6–2.8 billion. Table 2 shows the dependent and explanatory variables included in the meta-regression model together with the definition and descriptive statistics for each variable. The average mangrove value in the sample is 4185 USD/ha/annum and the median is 239 USD/ha/annum. This divergence of the mean and median values indicates a skewed distribution with a few very high outliers that is commonly observed for both values and physical variables such as ecosystem area; this is rectified in our meta-regression model through the use of a double log specification which normalizes the distribution. The estimated coefficient on mangrove area is negative and statistically significant, which is evidence of diminishing returns to scale for mangrove size, i.e., the value per hectare is lower in larger mangroves than in smaller mangroves. In other

GOAP

GOAP

reported in currencies other than US dollars are converted using purchasing parity adjusted exchange rates. Values that are initially estimated for other price level years are converted to 2007 price levels using GDP deflators. Estimates that are reported as net present values are converted to annual values using the time horizon and discount rate reported in the study. Total values or values estimated for specified changes in the area of a mangrove ecosystem are divided by the corresponding area in hectares to obtain a value per hectare. Values reported in per person or household terms are converted to a per hectare basis by computing the implied total value, e.g., multiplying the per person value by the relevant population of ecosystem service beneficiaries identified in the study, and dividing by the area of the mangrove study site.

For the bio-physical context characteristics we use spatial data in combination with geographic analysis to define two potentially important spatial variables for the vicinity of each

nts of variation in value, namely the characteristics of each mangrove site, characteristics of the bio-physical context of each mangrove, and the socio-economic characteristics of the population of ecosystem service beneficiaries.

valuation reference inventories and contact with authors. From the 48 selected studies we are able to obtain 130 separate value estimates. Multiple value estimates are taken from single studies if they represent different mangrove sites or services. These are distinctions that are explicitly controlled for in the meta-analysis through the inclusion of explanatory variables that represent differences in site characteristics and services valued. There are 14 estimates for North America, 18 for Latin America, 21 for South Asia, 61 for Southeast Asia, 11 for Africa wetlands, and 5 for Oceania.

words, adding a hectare to a large mangrove is of lower value than adding a hectare to a small mangrove. It is important to understand that the total value of a mangrove increases with its size but at a diminishing rate as the per hectare value decreases. In other words, there is a non-linear (concave) relationship between total area and total value. The estimated coefficient shows an inelastic relationship between area and value, in which a 10% change increase in area results in a 3.4% decrease in per hectare value.

The two variables representing the socio-economic characteristics of beneficiaries both follow prior expectations. The estimated coefficient on the population variable is positive and statistically significant, indicating that mangrove ecosystem service values are higher in areas with larger populations. A 10% increase in population results in a 2.8% increase in mangrove value per hectare. This meta-regression model provides the value function that we use to estimate the change in value of ecosystem services due to the change in the stock of mangroves in Southeast Asia under a business-as-usual scenario.

study site, namely the total area of other mangroves and the density of roads. The variables representing the socio-economic characteristics of the beneficiaries of mangrove services are the population (again defined within 10, 20 and 50 km radii of the centre of each study site) and the gross domestic product (GDP) per capita.

To define a baseline scenario for mangrove change for the period 2000–2050, we make use of the results of the IMAGE-GLOBIO integrated assessment model (Alkemade et al., 2009, PBL, 2010).3 This baseline scenario has previously been used to assess the cost of policy inaction to halt global biodiversity loss (Braat and ten Brink, 2008). Changes in the extent of mangroves are assumed to follow similar patterns to the GLOBIO modelled changes for forests and grasslands for the period 2000–2050. The reasoning behind this assumption is that the population, development and land use pressures that drive changes in the extent of forests and grasslands will also tend to drive

The values of foregone mangrove ecosystem services, aggregated to the country level, are presented in Table 4. Comparing the 2000 stock of mangroves to the projected 2050 stock, the annual value of lost ecosystem services from mangroves in Southeast Asia is estimated to be approximately US$ 2.16 billion in 2050 (2007 prices), with a 95% prediction interval of US$ 1.58–2.76 billion. Assuming a linear time profile of these losses between 2000 and 2050, the present value of the stream of lost ecosystem services is US$ 40 billion using a 1% discount rate and US$ 17 billion using a 4% discount rate. This is the cumulative value of the foregone ecosystem services due to mangrove loss that is expected to occur each year over the period 2010–2050. The loss of ecosystem services is not valued only for the year in which the mangrove area is lost but for every subsequent year up to the time horizon of the analysis (i.e., 2050).

At a country level, the annual value of foregone mangrove ecosystem services in 2050 follows the pattern of loss of area, with Indonesia expected to suffer the highest losses; US$ 1.7 billion per year with a 95% prediction interval of US$ 1.2–2.2 billion. Malaysia

GOAP

	degradation and conversion of mangroves. We recognise, however, that there are differences in the way in which development pressures affect different biomes, and indeed that mangroves face unique pressures.					is estimated to suffer the second highest losses in mangrove ecosystem service values; US$ 279 million per year with a 95% prediction interval of US$ 228–330 million.
UNEP, 2011. Economic Analysis of Mangrove Forests: A case study in Gazi Bay, Kenya, UNEP, iii+42 pp. https://wedocs.unep.org/20.500.11822/7948	The variables are divided into direct use, indirect use and non-use value. Some variables require highly sophisticated research approaches and methods, which are not always affordable or have not even been invented. Regional or local specifications may also influence the valuation. While Spurgeon (2002) derived the value of eco-tourism in Egyptian mangroves to be as high as US$ 130,000 per hectare per year (ha-1 y-1), Kairo et al. (2009) valued the same factor at US$ 9.3 ha-1 y-1 in Gazi, Kenya. The significant difference in value is simply based on the fact that tourism is much more developed around the mangroves of Egypt than in Gazi Bay.	Descriptive	The study quantifies the Total Economic Value (TEV) of the Gazi Bay mangrove forest. It is acknowledged and stressed that this study suffers from research limitations. One reason is the lack of primary data and appropriate peer reviewed studies. Application of the BT should also be considered with caution. It is, however, recognized as one of the most widely used methodologies in the field of environmental valuation and serves as a first approach in determining non-marketable mangrove services. Therefore the	Gazi Bay mangrove forest, Kenya	Direct use values include fishery, timber, eco-tourism, research and education, aquaculture and apiculture. They account for 20 per cent of the TEV. Indirect use values of the	The Total Economic Value (TEV) of the mangroves in Gazi Bay is US$ 1,092.3 ha-1y-1. Direct uses account for around 25 per cent of the TEV. **Fisheries**. Since the result from the study of Aburto-Oropreya (2008) figure is based on accurate background research it is applied here to calculate a more valid figure for the value of mangrove contribution to offshore fishery in Gazi Bay. Assuming a mangroves contribution to fishery of 31.7 per cent in Gazi Bay, the number of fish caught attributable to the mangrove is (69.8*0.0317). The total amount of fish caught in 2010, related to the mangroves in Gazi Bay, is: 22.1538 tons. **Wood**. The annual income from sustainable harvesting was Ksh 216,000 in 2010. Assuming 620 hectares of mangroves, the harvesting income in Gazi is Ksh 348.4 ha-1y-1, which is equivalent to US$ 4.2 ha-1y-1.

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Although research on the African mangroves has a great potential it has been rather low up to now. Kairo et al. (2009) and Spurgeon (2002) added the funds for PhD and MSc students to their valuation. This study assumes that the amount of funding for mangrove research can be applied to quantify the research and education value of the mangroves to some degree. It is acknowledged that more research must be done and various methods applied to finally come up with a more accurate value. There have been several research projects in the Gazi Bay mangroves during the period 2007 and 2010. Funding for those projects was as follows (Kairo, pers. comm.): PhD = 5 * US$ 10,000 / year; Msc = 9 * US$ 6,000 / year; Bsc = 4 * US$ 2,500 / year. TOTAL = US$ 114,000 / year. The funding and research value per year is therefore US$ 114,000 or US$ 184.4 ha-1y-1.

A total of 24 hives were built, each with 9 columns. Each column produces 3Kg of honey in 3 months. This

results of this analysis should be considered as a first step towards quantifying the value of Kenyan mangrove goods and services.

For the valuation of biodiversity in the Gazi mangroves the Benefit Transfer method (BT) was applied. BT included the comparison of the purchasing power parity GDP per capita for Kenya and Sri Lanka. UNEP/GPA (2003) used this approach to calculate the biodiversity value of mangroves in Sri Lanka. Non-use value in this study only consists of the existence value. This study uses BT to value the existence of the mangroves in Gazi Bay.

mangroves are shoreline protection, carbon sequestration and biodiversity. They represent 25 per cent of the TEV. The existence value, which represents the value of mangroves in an unharmed state, accounts for 55 percent

This figure appears to be very low, but considering the tough restrictions for the concessionaire the low value is justifiable. 500 scores per year is equivalent to 10,000 stems. This results in a harvest limit of only 16 trees ha-1y-1. Assuming those 50 people go to collect fuel wood 22 days per month (every day excluding weekends), the annual total amount of collected fuel wood is: 50 collectors * 22 days per month (1 bundle per day) * 12 months = 13,200 bundles / year. The collecting fees are Ksh 100 / month / person. The total fees are therefore Ksh 60,000 / year. Fuel wood can be sold at Ksh 70 per bundle. The total income from fuel wood collection is Ksh 864,000 or Ksh 1,394 per hectare (equivalent to US$ 16.8 ha-1y-1).

Ecotourism. Since 2008 the number of visitors has increased steadily. In 2010 the Boardwalk registered 1673 visitors. The entrance fee is generally Ksh 100 and students usually pay a little less. The women's group also offers food at the entrance to the Boardwalk at a cost of Ksh 200 per person. It is assumed that 50 per cent of the visitors take this opportunity. The total income for the "Gazi Women Boardwalk is therefore: 1,673 x Ksh 100 + 837 x Ksh 200 = Ksh 334,700. Costs for running the

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results in 108Kg of honey / hive / year. The 24 hives are able to produce 2,592Kg of honey in one year. The honey can be sold at Ksh 300/Kg. The total potential annual revenue is therefore: Ksh 777,600 per year. The construction costs were Ksh 122,690 (Hamsa, pers. comm.). Without a protective shade a hive can last 10 years.

Annualizing the construction costs results in annual costs of Ksh 12,269. The potential total annual income is thus: Ksh 765,331 per year or Ksh 1234.4ha-1y-1, which is equivalent to US$ 14.7 ha-1y-1.

Due to climate change carbon sequestration by forests continues to gain in value. Due to their high biomass density and productivity mangroves play a significant role in carbon sequestration. According to Giri et al. (2010) mangroves, including associated soil, could sequester approximately 22.8 million metric tons of carbon each year. Covering only 0.1 per cent of the earth's continental surface, the forest would account for 11 per

of the TEV.

boardwalk are nearly non-existent and the "Gazi Women" do not keep records of their costs. The income from eco-tourism in Gazi in 2010 attributable to the mangroves is Ksh 334,700y-1 or Ksh 540 ha-1y-1, which is equivalent to US$ 6.5 ha-1y-1.

Shoreline Protection. Studies show that 30 trees per 100m2 in a 100m wide belt may reduce tsunami flow rate by as much as 90% (EjF, 2006). Different studies on the impact of the tsunami in 2004 indicated that in an area with an intact mangrove belt only 7 per cent of the villages were severely affected,while in areas where the mangrove forests were degraded, damage reached 80-100 per cent (Dahdouh-Guebas, 2006). Taking 80 per cent as representative, this corresponds to an additional protection of 73 per cent of the villages due to mangroves. Assuming 700 houses (with an average house price of US$ 2,225), 5 per cent likelihood for a severe weather event and an additional protection of 73 per cent, the shoreline protection value of the mangroves can be calculated as follows: Following this approach the value of shoreline protection from any possible severe

GOAP

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cent of the total input of terrestrial carbon into the ocean and 10 per cent of the terrestrial dissolved organic carbon exported to the ocean. Another study calculated net photosynthetic rates of 155 kg C ha-1day-1 in a 22-year-old Rhizophora apiculata forest in Malaysia (Walters et al., 2008). This study assumes a carbon price of US$ 7 per ton and a biomass of 18 t C ha-1y-1. These assumptions limit the validity of the results, since prices change significantly over time.

What valuation studies normally measure is the economic value of ‘biological resources’ rather than biodiversity (Bann, 1997). Other studies suggest that the value of biodiversity should be expressed as or should at least include the value of medicinal and pharmaceutical extracts from the forest (Abeysinghe, 2010). This

indicates that mangroves might be a source of different medicinal properties such as specific antibacterial features. Following this approach Ruitenbeek (1992) came up with a biodiversity value of US$ 15 ha-1y-1, measuring

weather events becomes US$ 91.7 ha-1y-1.

Carbon storage. A number of attempts to measure the ability of Gazi mangroves to sequester carbon have been undertaken. While most of these attempts were rather based on ecological approaches, Kairo et al. (2010) came up with a straightforward result of 18 tC ha-1y-1 carbon benefit potential. Carbon prices change depending on the location of the market, the type of market (e.g. Voluntary market) and supply and demand. This study assumes a price of US$ 7 per ton. These assumptions result in an additional mangrove value of US$ 126 ha-1y-1.

Biodiversity. Due to the relatively low PPP GNP of Kenya the value of biodiversity of the Kenyan mangroves, using BT, is only US$ 5 ha-1y-1. This value might change significantly, if a different methodology, such as WTP, is applied. This requires extensive field work, and it is put forward as a recommendation to confirm the theoretically calculated results.

Existence value. This study uses BT values from Spurgeon (2002) in Egypt. The limitations of the validity of this approach are acknowledged.

GOAP

mainly the pharmaceutical value of the mangroves. UNEP/GPA (2003) used the following benefit transfer formula to calculate the value of biodiversity of mangroves in Sri Lanka (see report).

Differences in environmental settings, society's dependence on mangroves and in the wealth of the population can influence the WTP significantly. It is therefore strongly recommended that contingent valuation should be applied in Gazi Bay to quantify the existence value more accurately. Table D1 and D2 show the estimates for the non-use value of the mangroves in Egypt. The data were obtained from national statistics. People along the Kenyan coastline depend heavily on mangrove products. Therefore, consciousness of mangroves in Kenya can be assumed to be higher than in Egypt. Conclusively the parameter column "high" can be stated as being representative for Kenya. This results in a US$ 524.19 ha-1y-1 mangrove existence value when using the theoretical approach. Gazi Bay is home to around 3,000 inhabitants (Kairo, pers. comm.). On average round about 4,000,000 tourists per year visit the coastline of Kenya (KBS, 2010). Kenya features around 57,000 hectares of mangroves. Since coastline tourists are usually only moderately interested in mangroves and most of them stay in hotels close to Diani Beach or Mombasa, the column "Moderate" is assumed to be appropriate. The existence value of

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						the mangroves for visitors is therefore US$ 70.2 ha-1y-1.
Beck, M. W., S. Narayan, D. Trespalacios, K. Pfliegner, I. J. Losada, P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, F. Fernandez, S. Abad, P. Mucke, L. Kirch. 2018. The global value of mangroves for risk reduction. Summary Report. The Nature Conservancy, Berlin. http://dx.doi.org/10.7291/V9930RBC	This work uses a rigorous integrated hydrodynamic approach to value the flood protection services of mangroves and identifies where mangroves provide the greatest benefits. Vietnam, India, Bangladesh, China, and the Philippines receive the greatest benefits from mangroves in avoided flooding of people. China, USA, India, Mexico and Vietnam receive the most benefits in terms of annual avoided damages to property. In this report Risk is measured by considering Exposure to natural hazards such as floods, and Vulnerability which considers social, economic and governance aspects. The World Risk Index has consistently identified that the most at-risk nations are all tropical, coastal developing nations where habitats such as mangroves and coral reefs can play significant roles in reducing risk.	Number of people and the value of property flooded with and without mangroves.	These results can inform strategies for adaptation and risk reduction, including the development of tools that use the risk reduction benefits of mangroves to pay for their restoration. To value the coastal protection benefits provided by mangroves, this work follows the Expected Damage Function approach, commonly used in engineering and insurance sectors and recommended for the assessment of coastal protection services from habitats (Figure 2). The protection benefits provided by mangroves are assessed as the flood damages avoided by keeping mangroves in place. Hydrodynamic models are used to calculate the	Global	Risk reduction of flooding and erosion.	Mangroves reduce annual flooding to more than 18 million people. Without mangroves 39% more people would be flooded annually, and flood damages would increase by more than 16% and US $82 billion. Mangroves reduce exposure and vulnerability. These combined benefits are most important for countries in West and East Africa, Central America and the South Pacific. Mangrove restoration can be a highly cost-effective strategy for risk reduction. Hundreds of thousands of hectares have already been restored. Mangroves protect coastlines by decreasing exposure to flooding and erosion. The aerial roots of mangroves retain sediments and prevent erosion, while the roots, trunks and canopy reduce the force of oncoming wind and waves and reduce flooding (Figure 1). A 500-meter-wide mangrove forest can reduce wave heights by 50–100%. In low lying areas, even relatively small reductions in water levels can reduce flooding and prevent property damage. Mangroves also decrease vulnerability by supporting livelihoods, ecotourism

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Mangroves are being lost at an alarming rate — 19% of the world's mangroves were lost between 1980-20054 — resulting in more people and property directly at risk from the impacts of storms, floods, erosion, and sea level rise, in part because we have not adequately valued these natural defences. Conventional approaches to measuring wealth focus mainly on built infrastructure. Currently, only a subset of the extractive benefits provided by natural ecosystems are valued. Many critical goods and services, such as flood protection, which rely on keeping ecosystems intact, are rarely valued.

This work combines relevant data for coastal dynamics from IH Cantabria and for assets from various sources. To calculate exposure, data on population and built capital (residential and industrial property) are calculated in 1 km^2 grids globally. The assessment includes global vulnerability damage functions for population and built capital based on HAZUS10 and JRC11. This assessment also identifies where flooding that occurs globally under current mangrove and no mangrove scenarios (i.e., assuming all mangroves are lost). The models calculate flooding under regular storm conditions by analysing more than 30 years of wave and water level data, and also flooding under the most extreme events by analysing the historical data and spatial distribution of 7,170 cyclones. The models also consider the wave reduction effect from adjacent coral reefs.

and trade and providing multiple social and economic services.

Mangroves provide significant flood reduction benefits to people and property in critical 'hotspots' around the world. Protection benefits to people are highest in key areas in the Indian Ocean and East Pacific, protection benefits to property are more evenly distributed globally (Figure 4).

Without mangroves, more than 18 million people would be flooded every year, an increase of more than 39%. The annual damages to property would increase by 16% and US $82 billion (Figure 3).

In the Philippines, mangroves reduce annual flooding to people by 24% providing direct benefits to more than 600,000 people every year, many of whom live in poverty. Mangroves reduce annual damages to residential and industrial property by 28% providing more than US $1 billion in annual averted damages. They also reduce flooding for 766 km of roads annually. One hectare of mangroves in the Philippines provides on average more than US $3200/year of direct flood reduction benefits.

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mangroves provide the greatest overall risk reduction benefits. Data on annual expected benefits from mangroves (exposure reduction) is combined with vulnerability scores from the World Risk Report and Index (see Table 1) to produce a ranking of countries that receive the greatest risk reduction benefits from mangroves overall.

China, USA, India, Mexico and Vietnam receive the most benefits in terms of annual avoided damages to property. Per GDP, Guyana, Belize, Bahamas, Suriname, and Mozambique receive the greatest flood protection benefits for avoided flooding (Table 1).

In addition to reducing flood exposure, mangroves can reduce vulnerability. The countries that receive the greatest overall risk reduction benefits from mangroves are Guinea, Mozambique, Guinea-Bissau, Sierra Leone and Madagascar (Table 1 and Figure 5).

For catastrophic events, such as the 1-in-50-year storm, mangroves avert more than US $1.7 billion in property damages. Based on the Philippines's current population, the mangroves lost between 1950 and 2010 have resulted in increases in flooding to more than 267,000 people every year. Restoring these mangroves would bring more than US $450 million/year in flood protection benefits.

Mangroves provide greater protection for events in regular climate conditions than for tropical cyclones. Though low in intensity of damage, these events are more frequent. If mangroves were lost, 32% more people would be flooded under 1 in 10-year events, and 16% more people would be flooded under 1 in 100 year events.

The study identified the spatial variation in the benefits provided by current and restored mangroves for every 90m^2. These results can inform local and national strategies for adaptation, risk management, and environmental management, and can help prioritize sites for mangrove restoration.

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Table 6. Coastal ecosystems services compilation table: Coral reefs

Services	Method	Indicator	Unit factor	Value	Assumption	Location	Sources
Regulating							
Carbon sequestration	Dissolved Inorganic Carbon (DIC) was measured by a gas extraction/coulometric technique Total Alkalinity (TA) was determined by potentiometric titration with HCl Detail formulation, please see the full paper	Seawater CO_2 from uptake of atmospheric CO_2 and ocean acidification (OA) indicator	Abiotic factor: salinity (‰), temperature (°C), Dissolved Oxygen/DO and inorganic nutrient (%),	Onshore, surface Dissolved Inorganic Carbon (DIC) and partial pressure of CO_2 (pCO_2; >10% change per decade) have increased and OA indicators such as pH and calcium carbonate ($CaCO_3$) saturation state (Ω) decreased from 1996 to 2016 at a rate of two to three times that observed offshore at Bermuda Atlantic Time-series Study (BATS) site. As with anomalies of seawater CO_2–carbonate chemistry discussed in Section Long–term Trends (1996–2016) of Seawater CO_2 –carbonate Chemistry, anomalies of Net Ecosystem Calcification (NEC) and Net Ecosystem Production (NEP) show significant changes over the past two decades.	Data record in few long–term records (>5 years). Surface samples (~2 m deep) for Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA) were drawn from Niskin samplers into clean 500 ml size Pyrex glass reagent bottles, using established gas sampling protocols. This represents an increase in calcification of ~0.7 ± 0.3 g $CaCO_3$ m−2 per decade or about a 31% increase per decade of Bermuda reef calcification.	Harrington Sound, Bermuda	Bates, N. R. (2017). Twenty Years of Marine Carbon Cycle Observations at Devils Hole Bermuda Provide Insights into Seasonal Hypoxia, Coral Reef Calcification, and Ocean Acidification. In Frontiers in Marine Science (Vol. 4). Frontiers Media SA. https://doi.org/10.3389/fmars.2017.00036
Coastal flooding protection	Using process-based flooding	Coastal profile Populatio	N/A	Across reef coastlines (71,000 km), reefs reduce the annual expected damages from storms by more than $4 billion. Without	The without reefs scenarios assume only a decrease of 1 m in the height and	Global scale	Beck, M. W., Losada, I. J., Menéndez, P., Reguero, B. G., Díaz-Simal, P., &

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	models, it estimates the annual expected benefit of coral reefs for protecting people and property globally.	n and assets		reefs, annual damages would more than double (118%) and the flooding of land would increase by 69% affecting 81% more people annually. For 25-year events, reefs reduce flooding for more than 8700 km^2 of land and 1.7 million people and provide $36 billion in avoided damages to build capital (Fig. 3, Supplementary Fig. 2). For 100-year events, the topmost 1m of reefs provide flood reduction benefits that result in $130 billion in avoided damages (Fig. 3). Without reefs, damages would increase by 90% for 100-year events and 141% for 25-year events.	roughness of coral reefs. We estimate the land, population and built capital flooded across all coastlines with coral reefs to a 90 m resolution (Fig. 1). We then derive the annual expected benefit of coral reefs for flood damage reduction from local to global levels.		Fernández, F. (2018). The global flood protection savings provided by coral reefs. In Nature Communications (Vol. 9, Issue 1). Springer Science and Business Media LLC. https://doi.org/10.1038/s41467-018-04568-z
Coastal protection	The avoided damages (see the formula in the full paper) and replacement costs. Comparison of the avoided damages costs	Annual value of coastal protection Area Inhabitants	Area (Hectares) Inhabitants (year of census)	The average value of constructing protective seawalls or dykes in the area was estimated at $352/Ha. This approach did not consider the potential differences of construction and maintenance costs between different types of seawalls and a wide range of seawalls exists, varying in material and orientation. The relative amount of wave energy dissipation of coral reefs in	The proposed method seems appropriate for advocacy with policy makers but appears to be less effective for small scale approaches, such as those required for Payment for ES negotiations or marine spatial planning. The replacement cost	Tobago, New-Caledonia), Saint-Croix (Virgin Islands), Saipan (Northern Mariana Islands), Marine Bohol	Pascal, N., Allenbach, M., Brathwaite, A., Burke, L., Le Port, G., & Clua, E. (2016). Economic valuation of coral reef ecosystem service of coastal protection: A pragmatic approach. In Ecosystem Services (Vol. 21, pp. 72–80). Elsevier BV. https://doi.org/10.101

	approach and the replacement cost method shows that the replacement cost method tends to produce extremely high estimates, up to 10 times greater than the lower-bound estimate, calculated using the damage approach			St. Croixis around 75– 85%. In the absence of corals on the reef crest (exp. friction) the wave energy dissipation function would be 57–66%.	method should be used with caution, in the context of small scales and specific zones. The avoided damage cost approach appears to be better adapted to scales of km and 10s of km. Comparison of the avoided damages costs approach and the replacement cost method shows that the replacement cost method tends to produce extremely high estimates, up to 10 times greater than the lower-bound estimate, calculated using the damage approach.	Triangle (Philippines)	6/j.ecoser.2016.07.005
Wave attenuation	Meta-analysis from literature search	Wave energy Detail variable to each study is available in the	%	Reefs significantly reduced wave energy across all three environments (Fig. 2a and Supplementary Fig. 1a). Reef crests dissipated on average 86% (n ¼ 10; 95% confidence interval: 74–92%) of the incident wave energy (Fig. 2a). Reef flats dissipated 65% of the remaining wave energy (n ¼ 23; 58–71%).	We examined available studies on wave attenuation across three reef environments: the reef crest, reef flat and the whole reef.	Global	Ferrario, F., Beck, M., Storlazzi, C. et al. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nat Commun 5, 3794 (2014). https://doi.org/10.1038/ncomms4794

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	supplementary documents of this study.		The whole reef accounted for a total wave energy reduction of 97% (n ¼ 13; 94–98%; Fig. 2a). Reefs significantly reduced wave height across all three environments (Fig. 2b and Supplementary Fig. 1b). The reef crest reduced wave height by 64% (n ¼ 10; 51–74%). The reef flat reduced wave height by 43% (n ¼ 23; 34–51%; Fig. 2b). The whole reef reduced wave height by 84% (n ¼ 13; 76–89%; Fig. 2b). Reef crests significantly dissipated 70% (n ¼ 4; 43–84%) of the incident swell wave energy, and the whole reef significantly reduced both wind and swell wave energy (Supplementary Fig. 2). Reef flats reduced both wind and swell wave energy, but our analysis of existing studies showed a significant effect only for swell waves (Supplementary Fig. 2). Nonlinear regressions indicated that for reef crests and reef flats, wave energy reduction reached asymptotes of 91% and 67%, respectively (Fig. 3).	We estimate that there are up to 197 million people that live both below 10 m elevation and within 50 km of a reef who may receive risk reduction benefits from reefs (Fig. 6 and Table 3). If we consider only areas within 10 km of a reef (that is, an 80% reduction in distance) and below 10 m elevation, there are still some 100 million people who may receive risk reduction benefits from reefs (Table 3).	

Erosion control	*Further studies are needed*						
Water purification	Coral mucus was collected from the staghorn corals *Acropora millepora, Acropora pulchra,* *Acropora nobilis* and *Acropora aspera.* Individual coral colonies (maximum diameter, 30 cm), anchored with their lower branches in the carbonate sands, were lifted, exposed to air and subsequently released	Acropora mucus Particulate organic carbon (POC)	l/m^2 mmol	Reef rim Acropora can release 4.8 l of mucus per m^2 of reef area per day. This corresponds to 10–21 mmol of particulate organic carbon (POC), 1.5–1.8 mmol of nitrogen and 0.08–0.18 mmol of phosphorus. In reefs with enclosed lagoons, coral reef and lagoon sediments together form a recycling entity linked by coral mucus as an important carrier of energy and nutrients (Fig. 3). By producing and shielding an enclosed or landward lagoon, coral reefs generate a biocatalytic filter system that accumulates and retains energy and nutrients in the reef ecosystem. A coral barrier protecting the lagoon provides the hydrodynamic conditions and tide-induced pressure gradients, which are necessary to increase the volume of water and particles filtered by the lagoon sands and the reef framework. Benthic organisms living on and in the lagoon sands and framework25 can degrade organic matter from the water forced	The adhesive mucus can trap particulate matter from the water and the light-collecting coral surfaces. Mucus and trapped particles are transported over the coral surface by ciliary currents and are released to the water9 at a magnitude such that mucus can dominate suspended matter around reefs. Submerged Acropora released 1.7 l of mucus per m^2 of reef area per day, excluding the rapidly dissolving mucus fraction.	Heron Island, the Great Barrier Reef, Australia	Wild, C., Huettel, M., Klueter, A. et al. Coral mucus functions as an energy carrier and particle trap in the reef ecosystem. Nature 428, 66–70 (2004). https://doi.org/10.1038/nature02344

	0.1–0.3 l of liquid mucus. We discarded the initial 30 s of mucus release containing water and afterwards collected the dripping mucus into a container for 2 min.			through these permeable structures and return nutrients to the water that are essential for autotrophic growth. This tight recycling mechanism and the trapping function of mucus thus counteract the release of almost 50% of the net fixed carbon by the corals2,3 and may contribute to explain the high gross primary production that characterizes coral reefs growing in oligotrophic oceans.			
Nutrient cycling	Biogeochemical box models	CO_2 flux	C/year	Biogenic production of CaCO3 may decrease by 42 percent by the year 2100 and by 85 to 90 percent by 2300 relative to its value of about 24 × 1012 moles C/year in the year 2000	Modelling results show that the carbonate saturation state of coastal sediment pore water will decrease in the future owing to a decreasing pore water pH and increasing CO_2 concentrations attributable to greater deposition and remineralization of land-derived and in situ produced organic matter in sediments.	Statistical data from Bahamas, South Pacific Oceans and elsewhere	Coastal ocean and carbonate systems in the high CO2 world of the Anthropocene Andreas J. Andersson, Fred T. Mackenzie and Abraham Lerman American Journal of Science November 2005, 305 (9) 875-918; DOI: https://doi.org/10.2475/ajs.305.9.875
Calcification	To estimate the	The partial	Salinity (‰),	One of the least considered physical parameters is water flow,	Net calcification of corals and calcifying	Moorea, French	Comeau, S., Edmunds, P. J.,

characteristics of the flow coming into the flumes, we applied the dimensionless Reynolds number (Re) Net calcification rates were measured using the Total alkalinity anomaly method, which is based on the stoichiometric relation of two moles of Analysis of total Alkalinity (A_T) being removed for each mole of $CaCO_3$ precipitated	pressure of CO_2 (pCO_2) pH, salinity, temperature	temperature (°C),	which is surprising considering its strong role in modulating the physiology of reef organisms and communities. In the present study, the effects of flow were tested on coral reef communities maintained in outdoor flumes under ambient pCO_2 and high partial pressure of CO_2 (pCO_2) (1300 μatm). Net calcification of coral communities, including sediments, was affected by both flow and pCO_2 with calcification correlated positively with flow under both pCO_2 treatments. At the community level, calcification was highest during the day in high flow, ambient pCO_2 and lowest in the low flow, high pCO_2. The community net calcification rates in the flumes in the ambient treatment during the day were similar to rates measured for reefs on the north shore of Moorea in 2012 and 2013 (R.C. Carpenter, unpublished data). During the day, there were significant effects of pCO_2 ($p = 0.019$) and flow ($p = 0.040$), and there was no interaction between the two ($p = 0.251$). At night, under three flows	algae, estimated by subtracting the mean calcification rates of the sediments from the total community net calcification for each treatment, was highest at ambient partial pressure of CO_2 (pCO_2) under high flow during the day. Our results show that flow enhanced net calcification at the community level, during both day and night. The strongest effect was detected under high pCO_2 and very low flow (2 cm/s), where dissolution of calcium carbonate exceeded precipitation daily. The effects of water flow on the calcification of *Porites compressa* and whole reef communities maintained in flumes under ambient	Polynesia	Lantz, C. A., & Carpenter, R. C. (2014). Water flow modulates the response of coral reef communities to ocean acidification. Scientific Reports, 4(1), 6681. https://doi.org/10.1038/srep06681

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	when nutrient concentrations are held constant			speeds, net calcification was positive at ambient pCO_2, but negative at high pCO_2. There was a significant interaction between pCO_2 and flow ($p = 0.045$), which was caused by increased dissolution at low flow and high pCO_2. When net calcification was integrated over 24 h, it was positive under all conditions except in the high pCO_2 and low flow. Net calcification integrated over 24 h was affected by pCO_2 ($p = 0.003$) and flow ($p = 0.013$), but the interaction was not significant ($p = 0.138$). Net calcification increased as a function of flow under both pCO_2 treatments	conditions have been tested previously, but in contrast to the present study, no effects on calcification were found.		
Waste remediation	*Further studies are needed*						
Pollutant remediation	In situ experiment	Environmental indicators: water temperature, nitrate, nitrite, ammonium, phosphat	Temperature (°C), reefs area (m^2)	We showed that in situ nutrient enrichment did not directly affect organic C budgets and calcification of coral-dominated communities in their natural environment. In contrast, excess nutrients significantly enhanced productivity, respiration, and caused a dissolution of the carbonate framework in co-occurring algae-dominated	Nutrient enrichment affects coral- and algae-dominated reef communities differently. Nutrient pollution amplifies effects of community shifts on reef ecosystem services.	Abu Shosha reef located in the central Red Sea on the west coast of	Roth, F., El-Khaled, Y. C., Karcher, D. B., Rädecker, N., Carvalho, S., Duarte, C. M., Silva, L., Calleja, M. Ll., Morán, X. A. G., Jones, B. H., Voolstra, C. R., & Wild, C. (2021). Nutrient pollution enhances productivity

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		e, and monomeric silicate		communities of the same reef. These results may have important implications for the competitive relationship of coral- and algae-dominated communities and the ecosystem services these communities can provide. Specifically, on reefs where the two community-types co-occur, algae-dominated communities may have a higher potential for biomass accumulation that can enhance space occupation and rapid succession on bare reef substrates (Roth et al., 2015; Stuhldreier et al., 2015).		Saudi Arabia	and framework dissolution in algae- but not in coral-dominated reef communities. In Marine Pollution Bulletin (Vol. 168, p. 112444). Elsevier BV. https://doi.org/10.1016/j.marpolbul.2021.112444
Provisioning							
Fish abundance on coral reefs habitat	Sampling the fish abundance by Underwater Visual Census (UVC). Sampling effort and outcome of the fishery by catch	Fish abundance Coral reefs area Catch per Unit Effort (CPUE)	Fish density (number of fish/N ha^{-1})	Data from the underwater survey were used to calculate fish biomass for each transect by converting individual length (cm) to weight (g) using length–weight relationships published in FishBase (Froese and Pauly, 1998). The richness of the fish community was estimated by counting the number of taxonomic categories at each transect (Thresher, 1991). Mean fish density, mean fish length and mean fish biomass were estimated for the fish community,	All fish observed within 2.5 m left and right of each transect line were included in the counts (English et al., 1994) and fish smaller than 1 cm that could not be identified during the underwater survey were grouped in the category “others”. After the fish were counted, the same observer swam back along the transect line and	Indonesia, in Spermonde Archipelago off Southwest Sulawesi Island, and in Komodo National Park and its buffer	Pet-Soede, C., van Densen, W. L. T., Pet, J. S., & Machiels, M. A. M. (2001). Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. In Fisheries Research (Vol. 51, Issue 1, pp. 35–51). Elsevier BV. https://doi.org/10.1016/s0165-7836(00)00236-8

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assessment survey (CAS)			for two major fishery groups (commercial and non-commercial), for four major trophic groups (planktivores, herbivores, benthic invertebrate feeders, and piscivores), and for individual taxonomic fish categories. Fish was categorized as commercial if regularly landed at one of the auctions. Taxonomic categories were allocated to trophic groups based on knowledge of their adult feeding habits. Table 1 in the full paper provides detail figures of Fish density (N ha^{-1}) per taxonomic category at reefs in Spermonde and Komodo as observed during UVC, for example *Scarus spp.* (parrotfish) density in Spermonde was 764/ha while in Komodo was only 308/ha. Spermonde and Komodo differed greatly in total fish biomass (REGW $p<0.001$), which was more than four times higher in Komodo (382 g m^{-2}) than in Spermonde (86 g m^{-2}). The annual catch of the reef fishery was estimated 3.2 t km^{-2} reef in Spermonde and 3.1 t km^{-2} reef in Komodo. The mean CPUE	estimated the relative cover (%) of seven different habitat categories in the 5 m wide belt where fish were recorded. These categories included dead coral standing, live hard coral, live soft coral, coral rubble, sand, rock and “other”. The total live substrate cover (LSC) was calculated by summation of the relative cover for live hard coral, live soft coral and “other” for each transect. A monthly CAS was performed in Spermonde to study species and size composition of the catches at sea. At sea four belt transect sampling routes along the most common fishing sites were sailed and total fishing intensity was recorded.	zone between West Flores and East Sumbawa

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				for all reef fisheries combined was 5.8 kg per trip in Spermonde, eight times lower than for Komodo (48 kg per trip) (Table 6). Also, per gear type, catch rates were much lower in Spermonde (Table 6). For detail, see the full paper.	Total catch biomass and individual CpUE in Komodo were assessed during a weekly fisheries monitoring program implemented in 1996 by the Indonesian Department of Forestry and Nature Conservation (PHPA) with support of The Nature Conservancy (TNC)		
Maintenance for fisheries	Mapping of shallow water benthic habitats for Palau was conducted in 2007 by the National Oceanic and Atmospheric Administration (NOAA) using high-resolution, multispectral satellite imagery. While fishery-	Assessed predictor variables of resource fish biomass, see in the full paper.	Reef fish biomass in g m^{-2}	Fish biomass was calculated using the length-based equation: $W=aFL^{b}$ where W is the weight of the fish in grams, FL is the fork length of the fish in cm, and a and b are constant values derived from published biomass-length relationships (Kulbicki et al., 2005; Kamikawa et al., 2015; Gumanao et al., 2016; Cuetos-Bueno and Hernandez-Ortiz, 2017) and FishBase (Froese and Pauly, 2019). Weight was then divided by the area of the transect (transect length*5 m) in order to calculate biomass in g m^{-2}. Fishes were categorized into three trophic groups (piscivores, secondary consumers, and	The number of sites was determined based on the total area of each habitat within the study area and previous sampling efforts for *B. muricatum* and *C. undulatus* in Palau. Sites were then randomly selected using the open-source Geographic Information System (GIS) software QGIS and any selected sites that were < 1 km apart or located inside an MPA were reallocated to another location. MPAs were	Palau	Muller-Karanassos, C., Filous, A., Friedlander, A. M., Cuetos-Bueno, J., Gouezo, M., Lindfield, S. J., Nestor, V., Marino, L. L., Mereb, G., Olsudong, D., & Golbuu, Y. (2021). Effects of habitat, fishing, and fisheries management on reef fish populations in Palau. In Fisheries Research (Vol. 241, p. 105996). Elsevier BV. https://doi.org/10.101

	independent surveys were conducted using a diver operated stereo-video system (stereo-DOV, Goetze et al., 2019), not with Underwater Visual Census (UVC)			herbivores) based on Friedlander et al. (2017) and information from FishBase (Froese and Pauly, 2019). Biomass and abundance were recorded for 106 species (SOM 3). A total of 11,773 fishes were observed during the surveys, with actual length measurements for 5,518 individuals and estimated length measurements for the remaining 6,255. Total fish biomass varied by an order of magnitude across sites from 0.13 to 293 g m^{-2}, with a mean biomass of 17.83 ± 32.09 g m^{-2}. Mean biomass was significantly different between trophic groups (LMM: $p < 0.001$), with significantly lower herbivore biomass (5.39 ± 10.11 g m^{-2}) than piscivore biomass (6.96 ± 27.63 g m^{-2}) ($p < 0.001$). There was no significant difference in biomass between piscivores and secondary consumers (5.47 ± 11.48 g m^{-2}). *Lutjanus gibbus, Caranx sexfasciatus, and Sphyraena qenie* accounted for the highest percentages of total fish biomass observed during the surveys	excluded from this survey since the aim of this project was to assess the status of commercially important fish stocks in locations open to fishing. All statistical analyses were conducted using R version 4.0.3. Linear mixed effects models (LMM) were used to test the effect of predictor variables on fish biomass and to compare biomass between trophic groups using the 'lmer' function in the 'lme4′ package. It is possible that the stereo-DOV methodology used in this study could result in lower biomass estimates than UVC surveys due to differences in the swimming speed of the transect (Goetze et al., 2015). During slower moving and non-instantaneous UVC		6/j.fishres.2021.105996

				(16.12 %, 11.75 %, and 9.47 %, respectively). Biomass is an in-situ measurement of the amount of living organisms on coral reefs and in this case, provides an indication of the availability of commercially important resource fish species across Palau. The results of this study indicate that fish biomass varied considerably across the survey sites, with the highest biomass observed in the Northern Reefs, driven primarily by large schools of piscivores (*S. qenie and C. sexfasciatus*) and secondary consumers (*L. gibbus*). The fore-reefs west of Koror also had a high fish biomass, driven by large schools of piscivores (*C. sexfasciatus*), secondary consumers (*L. gibbus*), and herbivores (*N. lituratus*). Harborne et al. (2018) calculated a potential standing stock of 107 g m^{-2} for the biomass of all reef fishes in Palau.	surveys, there is a greater likelihood of larger mobile species moving into transect boundaries which can lead to overestimates of biomass (Ward-Paige et al., 2010).		
Fish biomass	We calculated and compared community	Biomass	Kg/ha	The UVC based biomass estimates were 788 kg/Ha, which was ~50% greater than those from DOV (500 kg/Ha). Differences between the methods	Our results suggest that community measures of fish biomass from DOV and UVC are broadly	Ningaloo reef (Western Australia)	Wilson, S. K., Graham, N. A. J., Holmes, T. H., MacNeil, M. A., & Ryan, N. M. (2018).

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	level measures of coral reef fish biomass at Ningaloo reef (Western Australia) using both UVC and DOV			were primarily due to DOV measuring the length of only ~40% of fish detected by video, preventing fish specific weight calculations for all fish encountered. When the size of unmeasured fish was assumed to be the median value of fish measured by DOV, revised DOV+ estimates of community biomass (778 kg/Ha) were similar to those from UVC. However, even when unmeasured fish were included in DOV calculations, biomass of some families (serranids) were still higher when using UVC. Conversely, DOV adjusted estimates of pomacentrid biomass were higher than those from UVC, due to DOV measuring fewer small bodied fish (<3 cm), thus having a larger median size for the high number of unmeasured pomacentrids compared to UVC.	comparable once weights of unmeasured fish are incorporated into DOV estimates. This may increase the spatial and temporal scales at which fish biomass can be monitored, although compatibility of data will depend on the composition and size distribution of the fish assemblages.		Visual versus video methods for estimating reef fish biomass. Ecological Indicators, 85, 146–152. https://doi.org/10.1016/j.ecolind.2017.10.038
Potential standing stock	Overview of the methodology for modelling and mapping the fishing pressure and fish standing	Table. 5 in the full report provides variable used in this study	Descriptive	The fishing pressure model explained 36% of the variability in the data set, and the correlation between observed and predicted values was 0.602. By summing the absolute predicted gain in biomass, we suggest that the standing stock of	Detail considerations for modelling potential standing stock is available in section 3.8 in the full report	Micronesia	The Nature Conservancy's Mapping Ocean Wealth Project: Modelling and Mapping Fishing Pressure and the Current and Potential Standing Stock of

	stocks are available in Fig. 5 in the full report.			these 19 species alone would increase by ~12,200 metric tons following the cessation of fishing. Detail value is available in the section 4 in the full report.			Coral-Reef Fishes in Five Jurisdictions of Micronesia. Harbonne, A. University of Queensland. (2016).
Economic value of reef-related fisheries	Willingness to pay (WTP)	Fisheries yield (Kg) Coral reefs area (Km^2) Benefits (US$)	Kg, Km^2 US$	The annual willingness-to-pay assessed in three popular diving destinations are significant. An estimated US$ 300,000 could be collected annually as entrance fees or donations in Mabini, Batangas alone. It is estimated that the 27,000 km^2 of reef in their degraded condition still contribute at least US$ 1.35 billion annually to the economy. The contribution of reef fish to the total fisheries of the Philippines ranges from 8% to 20% (or about 143,200–358,000 t). The contribution of a reef fishery to some small island fisheries in the Philippines can go as much as 70% of the total fish harvest. The average of documented reef fish yields for the Philippines is 15.6 t/km^2 as shown in Table 1. The numerous food and other uses for coral reef organisms in the Philippines are noted in Table 2.	Healthy coral reefs can produce, on a sustainable basis, 20 t or more of fish and other edible products per square kilometre per year; once destroyed by use of dynamite or cyanide for fishing, production is reduced to less than 4 $t/km^2/yr$. The sustainable catch from a good reef over 10 years is about 200 t while a destroyed but recovering reef catch over the same period is only 72 t – the loss being 128 t of fish with an estimated value of US$ 192 000 (US$ 19 200 yearly) at current (year 2000) market prices for reef fish.	Philippines	White, A. T., Vogt, H. P., & Arin, T. (2000). Philippine Coral Reefs Under Threat: The Economic Losses Caused by Reef Destruction. In Marine Pollution Bulletin (Vol. 40, Issue 7, pp. 598–605). Elsevier BV. https://doi.org/10.1016/s0025-326x(00)00022-9

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				Coral reefs in the Philippines can supply up to 35 t/km^2/yr (the highest reported fish yield from Sumilon Island in 1983) of edible and economically valuable fish and invertebrates assuming that ecologically sound fishing methods are used (Alcala, 1988). Detail information about fish yields from coral reef areas is provided in Table 1 in the full paper.			
Cultivated resources extracted	*Further studies are needed*						
Raw materials extracted	Detail procedure to collect data on taxonomy (including sample collection sites and biological material sampling); chemistry (including biological material, conditioning	Natural product	Number of species	After species identification, biological and/or pharmaceutical analyses are performed on marine organisms to assess their bioactivities. A total of 3582 genera, 1107 families and 9372 species have been surveyed and more than 350 novel molecular structures have been identified. Along with their bioactivities that hold promise for therapeutic applications, most of these molecules are also potentially useful for cosmetics and food biotechnology.	Here, we provide an updated review of 40 years of exploration of the marine micro-/macrophyte and invertebrate chemo diversity of this species-rich zone of the Southwest Pacific, with its pharmacological potential and its ecological significance. After a description of the basic operational aspects of discovering	New Caledonia archipelago, central province of the Great Barrier Reef, 1500 km away from the Australian	Motuhi, S.-E., Mehiri, M., Payri, C. E., La Barre, S., & Bach, S. (2016). Marine natural products from New Caledonia—A review. Marine Drugs, 14(3), 58. https://doi.org/10.3390/md14030058

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samples for chemistry, and extraction); biological activities; and natural product by taxon			Though far from being exhaustive, this review outlines 40 years of exciting research on the chemo diversity of marine organisms, ranging from microbes and invertebrates to vertebrates, from microalgae to macroalgae and halophytes, belonging to very different biota in association with the complex coral reef systems of New Caledonia. Traditionally “interesting” lead groups such as sponges, cnidarians and ascidians have been intensely investigated because they not only provide the most interesting array of original chemical structures, but they also show the most potent anticancer, anti-inflammatory, and antibiotic properties. Other groups have occasionally led to original and stimulating research: echinoderms, mollusks, etc. This review focused on novel products although several studies have been performed on New Caledonian marine species leading to the rediscovery of some secondary metabolites (e.g., Acremonium neocaledoniae, p. 41).	marine natural products, an overview of the work on each major taxon is presented, illustrated by case studies that have been the highlights of the abovementioned programs for the last 40 years, and carried out locally by experts in full compliance with existing regulations of biodiversity protection and the sustainability of valuable natural resources.	Queensland coast

Cultural							
Recreational value perceived by divers	Surveys on the relationship between marine life viewing preferences, diver experience and perceptions of environmental change are still scant and are needed, mainly in regions where diving is an important economic activity. Therefore, in this study, we investigate the issue of marine life	Divers' preferences For the purpose of this analysis, references made to a decrease in fish abundance were grouped as negative; no change was rated as zero, while improvement was graded as	Narrative in percentage For questions on the perception of fish abundance and motivation to return, we grouped diver revisits until 2003 and after 2003, because this	We ensured that questionnaires were answered individually to ensure that interviewees were not influenced by the opinions of other divers. Random sampling was done to select divers from three diving boats. Questions addressed gender, nationality, experience, marine life preferences, and their perceptions of change in fish abundance, and causes. Marine life preferences were assessed by the following question: 'What are your favourite animals to watch on a dive?' Respondents could select three main attributes from the eight listed: 'shark and rays', 'big fishes', 'colourful fishes', 'whales and dolphins', 'turtles', 'corals', 'cryptic fishes', and 'small invertebrates' on a scale from 1 (less preferred) to 3 (most preferred). In the last two categories, we described characteristics of the fauna, citing examples of seahorses, gobies for cryptic fishes: and nudibranchs and cleaner shrimps for small invertebrates.	This experience-related theory was named "recreation specialization", which refers to a continuum of behaviour from the general (broad interests and minimal resource dependence), to specific (skilled interests and high resource dependence). Recreation specialization is a multidirectional approach, influenced by experience, skill and activity setting preferences (Bryan, 1977). People approach their preferences differently, according with their level of experience in the activity. One indicator of experience level often used in studies of recreational scuba is number of dives performed in a	Abrolhos National Marine Park – ANMP, a no take MPA in eastern Brazil	Giglio, V. J., Luiz, O. J., & Schiavetti, A. (2015). Marine life preferences and perceptions among recreational divers in Brazilian coral reefs. Tourism Management, 51, 49–57. https://doi.org/10.1016/j.tourman.2015.04.006

preferences and perceptions of recreational scuba divers in ANMP. We examined what marine life attributes were important to divers according to gender and levels of experience (addressed here as number of dives performed). We also verify post-trip perceptions of change in fish abundance over consecutive visits, its causes and

positive. Statistical analysis was performed using R 3.0.1 (R Core Development Team 2013). Tests were done at a significance level of $p < 0.05$.

was the year when fish feeding was banned.

A total of 190 divers were interviewed between January to March 2012 (62%) and February 2013 (38%). Male gender represented 60% and female 40% of total divers interviewed. The age class between 31 and 40 years old represents 39% of respondents, followed by 21–30 (30%) and 41–50-year-olds (22%). Only two divers were foreigners from Germany. Beginner's representing 25%, somewhat experienced 20%, moderately experienced, 20%, and experienced 35%.

Sharks and rays obtained the highest mean score for beginners and somewhat experienced divers (mean score: 1.71 and 1.57, respectively; Fig. 3). Moderately experienced divers preferred sharks, rays, corals and cryptic fishes. Experienced divers preferred cryptic and small creatures, like cryptic fishes and small invertebrates.

Detail about diver’s perceptions of change in fish abundances and its causes is available in the full paper. Individual perceptions of decline in fish abundance were

lifetime (Camp and Fraser, 2012, Lucrezi et al., 2013, Thapa et al., 2006). This indicator is generally correlated with divers' certification (Miller, 2005), knowledge, skill and responsible behavior (Fitzsimmons, 2009, Musa et al., 2011, Thapa et al., 2006). However, other indices of recreational specialization have been used to empirically examine scuba divers. For instance, Miller (2005) used a Multidimensional Recreational Specialization Index based on diver's level of participation (experience), training and associated skills, and coral reef setting history to examine divers' recreational specialization.

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	how affects divers' perceptions of quality.			influenced by longer time interval between visits. Visitors elicited the end of fish feeding, and illegal fishing, as the main causes of decline.			
Tourism/recreation	Literature review Statistical meta-analysis, we use a multi-level modelling (MLM) approach to estimate the meta regression Contingent Valuation Method, using respondent’s willingness to pay (WTP) or willingness to accept (WTA) for (hypothetical) changes in	Total values, per unit of area, per visitor, different time periods (exp. per day, per visit, per year, Net present value over a given time horizon etc.), and in different currencies and years of value	N/A	The average value of coral reef recreation is 184 US$ per visit. The median value, however, is 17 US$ per visit. We therefore standardized these values to a common metric, which is US$ per visit in 2,000 prices. Values from different years were converted to 2,000 prices using GDP (Gross Domestic Product) deflators from the World Bank World Development Indicators. Purchasing Power Parity (PPP) conversions were made to correct for differences in price levels between countries. The results of our analysis on the accuracy of using estimated meta-regression functions for site-specific value transfer suggest that this is not (yet) a sufficiently accurate approach. Although meta-analysis-based value transfer may be acceptable in some contexts, there is evidently	Regarding recreational activities, we identify seven categories of activity that have been valued in the literature. These categories consist of four individuals’ activities (diving, snorkelling, viewing, and fishing) and three combinations of these activities. Value observations for the combination of diving, snorkelling, and viewing activities have the highest mean value, followed by diving by itself, and then all recreational activities valued together. Snorkelling receives the lowest mean value per visit	Data set study from Australia, Southeast Asia, East Africa, USA, and Caribbean	Brander, L. M., Van Beukering, P., & Cesar, H. S. J. (2007). The recreational value of coral reefs: A meta-analysis. In Ecological Economics (Vol. 63, Issue 1, pp. 209–218). Elsevier BV. https://doi.org/10.1016/j.ecolecon.2006.11.002

	environmental quality or quantity			still a need for high quality primary valuation studies of coral reefs.			
Aesthetic indicators	Qualitative study with key informant interview study. Quantitative study with image selection and online survey. Detail method approach is available in the full paper.	Key aspects of the coral reef aesthetic: (i) coral cover, (ii) coral pattern, (iii) coral topography, (iv) fish abundance, and (v) visibility	%, meters, image, 1-10 scale, photographs	The interviews with 30 key informants identified over 180 potential elements or themes contributing to reef aesthetics, indicating the richness of meaning behind the concept of aesthetics, while also highlighting the challenge of distilling a complex characteristic into a set of robust and practicable indicators for monitoring purposes. The full list of qualitative indicators, and the relative frequency with which they were mentioned by individuals is represented in Fig 1 (The size of words reflects their relative frequency). Qualitative indicators were then coded by the author team into themes, as presented in the S2 File, where the verbatim list of indicators of aesthetic values, how they have been thematically coded, and categorized into the final list of 12 indicators, are presented. The final list of themes was naturalness, composition, clear	Most of this work originates within terrestrial landscapes and extrapolate into underwater landscapes. Given that films, photos, paintings and media have all helped to connect a wider audience with underwater places [41, 42], it may be that people are transposing aesthetic cues from terrestrial environments towards underwater environments [6]. In identifying potential indicators to use within the GBR region, we look towards knowledge developed in terrestrial environments. Importantly, most demographic variables (including age, education, and	Great Barrier Reef, Australia	Marshall N, Marshall P, Curnock M, PertP, Smith A, Visperas B (2019) Identifying indicators of aesthetics in the Great Barrier Reef for the purposes of management. PLoS ONE 14(2): e0210196. https://doi.org/10.1371/journal.pone.0210196

				water, colour, charisma, coral, experience, tiny things, healthy, aerial, recreation, and fish. The mean aesthetic rating for all 181 photos was 6.86, with means for individual images ranging between 4.35 and 8.34 (on a 1–10 scale) (see S1 File). The highest and lowest rated photographs are presented in Fig 2. Results from the ANOVA suggested that coral topography, fish abundance and visibility were significantly correlated with survey participants' overall ratings of the images' aesthetic quality (Table 3). People who self-identified as having a high level of interest in coral reefs, and to some extent females, were also somewhat more likely to rate photographs higher than others (Table 4).	previous visitation to the Great Barrier Reef) did not significantly influence aesthetic judgement. This can be interpreted where people are more likely to reinforce their own identity of being interested by finding the images of their interest particularly appealing.		
Aesthetic value	Image selection and clustering, and elicitation of reef aesthetics through key informant	Eight aesthetic and five demographic attributes were used as	Descriptive	Overall, the participants found most images aesthetically pleasing (table 2). At the group level, the Experienced Divers were most likely to answer 'yes', while the Citizens had the highest proportion of 'no' responses. Experienced Divers were never 'unsure' about their answers,	Immersion via virtual reality (VR) is the process of replacing real sensory input with inputs from a computer system, such that the person is unaware of their outside reality. VR can produce better	Great Barrier Reef, Australia	Vercelloni J et al. 2018 Using virtual reality to estimate aesthetic values of coral reefs. R. Soc. open sci. 5: 172226. http://dx.doi.org/10.1098/rsos.172226

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interviews; Bayesian hierarchical logistic regression model. Bayesian modelling was performed using the JAGS software called by the rjags package	explanatory variables		whereas the Marine Scientists were unsure the most often (table 2). In total, 60% of participants found the training image visually pleasant, and 65% indicated that they were sure about their answer. For the reef environments that were unanimously perceived as pleasant or unpleasant, we examined how the three groups of participants scored aesthetic attributes between the three reef clusters (figure 3). The highest aesthetic value was 0.95 for a 360° image from the pristine cluster, while the lowest was 0.18 for an image from the degraded reef cluster. We also examined aesthetic values estimated by the model by reef cluster for images that were unanimously perceived as pleasant (i.e. positive perception) and unpleasant (i.e. negative perception) by observers (figure 4). In both cases, aesthetic values from the degraded reef cluster were the lowest, with an average of 0.54 and 0.23 for the positively and negatively perceived images, respectively.	qualitative information compared with traditional surveys of expert knowledge. However, to our knowledge, VR has never been used to elicit information about ecosystem-level aesthetic attributes. Our results showed that high structural complexity of coral reefs strongly increased their aesthetic value. Coral-colour diversity was also positively associated with high reef-aesthetic value, which confirms assumptions made in previous reef-aesthetic studies that humans prefer colourful reefs. We found no evidence supporting our initial hypothesis that a person's past experiences influence	

				The combined use of VR and modern statistical modelling can be easily applied to elicit information in other domains for conservation purposes including social benefits and educational and environmental outreach opportunities for coral reefs, in addition to other similar remote ecosystems that are difficult or expensive to physically access.	their perception of beauty.		
Life satisfaction related to cultural services	People's perceptions were gathered using surveys. Econometric Using coefficients from the model to generate a monetary estimate of the value of cultural ecosystem services	Life satisfacti on model	Descri ptive	Our estimate of value indicates that the (non-use) CS provided by the GBR to residents of the catchment are likely to be worth about $8.7 billion per annum; however, this result should be regarded with some caution as our estimate is based on imperfect data, as described in method section. Table 4 presents our estimates of the additional income that would be required to compensate residents should current (median) levels of satisfaction with CS values drop to zero (equivalent to a situation where residents are neither satisfied nor dissatisfied). These range from almost $30 k per capita per annum for Cairns to $17 k–$23 k per annum per capita	LS research assumes that each individual i's life satisfaction (LSi) is affected by numerous factors (Xi). Our hypothesis is that these numerous factors include values associated with the CS provided by the GBR (CSVi), resulting in a conceptual model (see full paper). There are numerous different ways of measuring LS – all of which involve asking respondents to indicate how 'satisfied' they are, either with life overall, or with various aspects	Great Barrier Reef	Jarvis, D., Stoeckl, N., & Liu, H.-B. (2017). New methods for valuing, and for identifying spatial variations, in cultural services: A case study of the Great Barrier Reef. Ecosystem Services, 24, 58–67. https://doi.org/10.1016/j.ecoser.2017.02.012

	The estimated regression model			in the other regions. Multiplying this amount by the number of employed persons in the GBR region, being 394,878 in total (Australian Bureau of Statistics, 2011), suggests that aggregate 'regional' compensation, representing the CS value of the GBR, would be about $8.7 billion per annum. It should be noted that although the coefficient on income is significant overall, and significant within the Mackay and Fitzroy regions, it was not significant in the Cairns or Townsville regions. This result could be interpreted to mean that there is no amount of income that could adequately recompense the residents of these regions should the CS cease to satisfy them; that is the CS is 'priceless' to the residents of those regions.	of life (e.g., the Cantril Ladder (Cantril, 1965)). We chose to use a single question, asking respondents to consider their own life and personal circumstances, and to then indicate, on a 5-point Likert scale, how satisfied they were with life overall.		
Tourism	Image and text analysis, including online data search extracted from national data. Detail	Social media image and texts; national data	Images, text, and percentage	Reef-adjacent expenditure is estimated at $5.7 billion annually and drives some 7.4 million visitors. Total values for all reef-associated tourism (on-reef and reef-adjacent) are now estimated at over $7.9 billion of expenditure	Scores from the social media images and texts and national data standardized, spread across a range of 0-40% to represent the actual importance of reef-adjacent values	Caribbean	Estimating reef-adjacent tourism values in the Caribbean. Spalding, M., Longley-Wood, K., Acosta-Morel, M., Cole, A., Wood, S., Haberland, C.,

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methodological approaches is available in the full report			and over 11 million visitors, with average values of 660 visitors and $473,000 per square kilometres of reef per year. Puerto Rico and the Dominican Republic benefit from visitor expenditure of over a billion dollars per year directly linked to coral reefs. The Bahamas, Cayman Islands and Puerto Rico receive the equivalent of over a million visitor trips per year directly linked to coral reefs. The very highest value reefs (top 10%) generate values of over $5.7 million per km2 and over 7,000 visitors per km2 each year. These are scattered in almost every jurisdiction other than Haiti. Barbados, Puerto Rico and the US Virgin Islands have a very high proportion of high value reefs, each with an average expenditure value of over $3 million per km^2 per year.	per jurisdiction, and then averaged to obtain a single score. These data show a spread of averaged reef-adjacent values from 4% on Haiti to 36% for St Kitts and Nevis. Correlation between the three approaches was relatively poor; however, this does not diminish the value of the study. While further work might lead to improvements, this is already a valuable finding, pointing to the risk in having an over-reliance on single metrics, and providing an important lens for interpreting studies which rely on one method only. It also indicates promise in using what are now emerging methods for harvesting social media data to examine these trends.		Ferdana, Z. Published by The Nature Conservancy (2019).

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Education/research	*Further studies are needed*
Religious/spiritual/indigenous	

Table 7. Coastal ecosystems services compilation table: seagrass

Services	Method	Indicator	Unit factor	Value	Assumption	Location	Sources
Regulating							
Carbon sequestration	Measuring the Net Primary Production (NPP), mainly for *Enhalus acoroides* and *Thalassia hemprichii*, using the leaf marking method; The relationships between each of the carbon	Carbon stocks; The estimation of seagrass carbon stock and sequestration capacity requires three basic items of information:	Coverage (%), density (shoot/ha), biomass (ton/ha), and area (ha); Above-ground carbon stock (AGC; gC/m^2), below-	Above-ground carbon, below-ground carbon, standing carbon, and carbon sequestration of the seagrass meadows in Indonesian waters were not significantly different among all scenarios ($p > 0.05$), ca. 27.40 1–35.84 gC/m^2, 66.93–79.42 gC/m^2, 94.33–114.71 gC/m^2, and 5.62–8.40 tC/ha/year, respectively; Considering the total area of seagrass meadows in Indonesian waters (i.e., 293,464–875,967 ha; Sjafrie et al. 2018), the above-ground carbon, below-ground carbon, standing stock carbon, and carbon sequestration values of seagrass meadows in Indonesian waters were ca. 80–314 ktC, 196–696 ktC, 276–1,005 ktC, and 1.6–7.4 MtC/year,	The carbon-related variables are naturally dependent on the seagrass-related variables. The number and type of data vary among locations depending upon the technical and temporal conditions during the study. Coverage data of all 28 locations are available, but only half of those locations have a completed dataset. This discrepancy is because not all the data were collected during the blue carbon related project. Almost half of the locations are	Data were collected from 28 location in Indonesia, during 2010–2018.	Wahyudi, A.J., Rahmawati, S., Irawan, A. et al. Assessing Carbon Stock and Sequestration of the Tropical Seagrass Meadows in Indonesia. Ocean Sci. J. 55, 85–97 (2020). https://doi.org/10.1007/s12601-020-0003-0

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	related variables and all seagrass related variables were analysed using the Robust Linear Mixed Models (rLMMs)	(1) the amount of biomass (i.e., standing stock), (2) the carbon sequestration capacity, and (3) the extent of the seagrass meadow.	ground carbon stock (BGC; gC/m^2) and carbon sequestered (tC/ha/year).	respectively. Using the decline rate of 2-5% per year (Duarte et al. 2008), it is inferred that the current areas of Indonesia's seagrass in 2018 would be within the range of 875,967–1,847,341 ha. However, based on ground-truthing validation, only ca. 293,464 ha have been verified up until now, which is only a slight increase from the previous verification study (i.e., 150,693 ha)	COREMAP-CTI sites that only have seagrass-related data. The analyses of carbon stock & sequestration capacity were conducted under four scenarios based on data availability. For detail explanation, please see the full paper.		
Carbon stock	For organic content and carbonate content: each sub-sample was weighed before and after drying at 50°C for 48 hours to determine bulk density and porosity. For organic	Carbon organic stock	Mt	The mean organic matter content of the sediments in the Australian seagrass habitats sampled ranged from 0.67 to 9.09% Dead Weight (DW), with a mean of 3.74 ± 3.13%. The bulk % Carbon organic ranged from 0.1 to 2.14% DW, with a mean of 0.64 ± 0.68%. The range across all 17 sub-habitats was 1.09 ± 0.32 mg Carbon organic cm^{-3}, in a shallow temperate *Posidonia sinuosa* habitat to 20.15 ± 10.95 mg	When averaging over all the sub-habitats in which a species was sampled, the mean Carbon organic stocks in the top 25 cm of the different seagrass habitats differed significantly. Several species of seagrass were sampled in more than one sub-habitat and generally showed	17 Australian seagrass habitats, for detail location please see Table 1 in the full paper	Lavery, P. S., Mateo, M.-Á., Serrano, O., & Rozaimi, M. (2013). Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. In J. F. Valentine (Ed.), PLoS ONE (Vol. 8, Issue 9, p. e73748). Public Library of Science (PLoS).

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	carbon content: the residual samples were redried and then capsulated for %C and d13C analyses using an ANCA-NT 20–20 Stable Isotope Analyzer connected to an ANCA-NT Solid/Liquid Preparation Module (PDZ Europa instruments). Detail formulation, please see the full paper.			Carbon organic cm^{-3} in a temperate, estuarine *P. australis* habitat. The estimated Carbon organic stock of the top 25 cm of sediment in Australian seagrass habitats that considered inter-habitat variability was in the order of 155 Mt. Most of this stock (54%) was in the temperate seagrass habitats, dominated by the larger, meadow-forming species of *Posidonia* and *Amphibolis*. The remaining 46% was in tropical seagrass habitats of northern Australia, which are dominated by a variety of smaller-sized seagrasses that typically have a lower sedimentary Carbon organic stock than the larger temperate species but a larger reported areal coverage. The estimates of annual Carbon organic accumulation for Australia ranged from 0.093 Mt when applying a sedimentation rate of 0.15 mm/y to 6.157 Mt at 9.9 mm/y. At a sedimentation rate of 1.5 mm/y, which, on limited dating evidence, we believe is more representative of accumulation rates in seagrass ecosystems, the	significant variability in Carbon organic stocks among sub-habitats. There is considerable spatial variability in the Carbon organic stock of seagrass sediments. This variability may be related to both the species of seagrass and the habitat setting in which they occur, particularly water depth. The data set presented here is limited and the errors associated with the estimates are likely to be significant, though no more so than the global estimates of seagrass C capture extrapolated from a much more limited set from the Mediterranean Sea, acknowledging that at the time those were the best available data. However, our data serve to emphasize the need for robust data sets on the		https://doi.org/10.1371/journal.pone.0073748

				annual organic carbon accumulation rate was 0.932 Mt.	carbon storage and accumulation rates in different seagrass ecosystems.		
Carbon storage	The measurement of total carbon (TC_{soil}) content and carbon organic (C_{org}) content of the soil samples, including the inorganic carbon content of the ash (IC_{ash}), please see the full paper.	Bulk density (DBD), loss on ignition (LOI), and organic carbon content (C_{org})	Dry weight (g), temperature (°C), length (cm)	The soils underlying the seagrass beds of the Arabian Gulf in Abu Dhabi were mainly silty sands with DBD that ranged from a minimum of 0.49 to 1.82 g cm^{-3}, with a mean of 1.37 ± 0.04 g cm^{-3}, based on 471 subsamples collected from the 18 seagrass sampling sites. Values of DBD were normally distributed, with a median value of 1.39 (Fig. 2). In general, DBD increased with depth in the top 15 cm of the cores. Below that depth, DBD showed no overall pattern down-core. The inorganic fraction of the soils was predominantly composed of calcium carbonates. IC ranged from 6.95 to 11.57 % of dry weight, with a mean of 10.15 ± 0.04 %. Assuming that all of this IC was in the form of CaCO3, which has an IC content of 12 %, the soils ranged from 57.9 to 96.4 % calcium carbonate, with a mean of 84.6 ± 0.5 %. These values largely reflect the calcareous composition of the	The subsamples were 5.0 cm^3 transverse sub-cores collected with a corer fashioned from a cut-off 20-cm^3 syringe, taken through sampling ports drilled into the larger piston core tubes. During the field surveys, 40 soil cores were collected from 18 distinct seagrass meadows. Total C_{org} stored in the soils of Abu Dhabi seagrasses ranged from a minimum of 1.9 Mg C ha^{-1} at Al Dabiya 1 to a maximum of 109.0 Mg C ha^{-1} at Umm al Hatam (Table 3, Fig. 5). Mean C stores across the 18 sites sampled was 49.1 ± 7.0 Mg C ha^{-1}. There was no significant relationship between the	United Arab Emirates: 18 sites, distributed along the coastline of Abu Dhabi on the southern shore of the Arabian Gulf, from Ras Muhayjij in the east to Ghurab NE in the west.	Campbell, J. E., Lacey, E. A., Decker, R. A., Crooks, S., & Fourqurean, J. W. (2014). Carbon Storage in Seagrass Beds of Abu Dhabi, United Arab Emirates. In Estuaries and Coasts (Vol. 38, Issue 1, pp. 242–251). Springer Science and Business Media LLC. https://doi.org/10.1007/s12237-014-9802-9

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				sediment matrix within this region (Kenig et al. 1990). Organic content (C_{org}) of the soil samples ranged from below detection (less than 0.05 %) to a maximum of 2.44 % (n = 469). The mean C_{org} was 0.64 ± 0.39 %, but values were not normally distributed. The data distribution was truncated at zero and had relatively few high values; the median C_{org} was 0.58 %. Down-core profiles in C_{org} displayed variable trends. To facilitate comparisons, we classify cores into relatively shallow (<40 cm) and relatively deep (>40 cm) cores based upon documented differences in soil characteristics (shifts in C_{org} decay rates) at this depth (Serrano et al. 2012).	abundance of seagrasses, assessed either as percent cover or living plant biomass, and soil carbon stores. Deeper cores (>40 cm) revealed general declines in C_{org} with increasing core depth (Fig. 4), however note exceptions at the Umm Al Hatam, Bu Tinah SE, and Marawah sites. Meanwhile, shallower cores (<40 cm) displayed increasingly variable trends, with some sites showing declines in C_{org} with depth (Al Dabiya 2, Ghurab NN), while others show no overall trend.		
Carbon storage	Our analysis covers the EU-27 countries. The methodology adopted for the aggregation	Carbon stock and flows	tC ha−1 yr−1 US$	The estimated accounting value of the stock of carbon storage service in currently existing saltmarshes in Europe at EUA price is US$11,203,843 and in currently existing seagrass beds is US$168,749,727. The estimated extent of *P. oceanica* in the Mediterranean Sea is larger	In this study, we use the carbon burial rate estimated by Gacia et al. (2002) for *P. oceanica* (1.82 tC ha−1 yr−1), and the rate reported for a Spanish seagrass meadow (Cebrián et al., 1997)	EU countries	Luisetti, T., Jackson, E. L., & Turner, R. K. (2013). Valuing the European 'coastal blue carbon' storage benefit. In Marine Pollution Bulletin (Vol. 71, Issues 1–2, pp. 101–106). Elsevier

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of carbon storage values in saltmarshes across Europe relies on maps of the European Environment Agency – CORINE land cover maps 2000 and 2006.

Given the estimated extent and C sequestration potential of coastal 'blue' carbon in Europe, we turn to assess its aggregated economic value. Detail estimation please see the full paper.

than the area of the saltmarshes in the whole European coastline.

We estimate that saltmarsh and seagrass carbon storage in Europe represents about 1.5–4% of existing global 'blue' carbon from coastal vegetated habitats. There are four species of seagrass found within European seas: Neptune grass (*Posidonia oceanica*), seahorse grass (*Cymodocea nodosa*), eelgrass (*Zostera marina*) and dwarf eelgrass (*Zostera noltii*).

Adams et al. (2012) estimated net C sequestration in natural (0.94 tC ha−1 yr−1) and mature managed realignment saltmarsh (1.15 tC ha−1 yr−1) located in the East of England given a 5.4 mm assumed sedimentation rate.

For the south of Europe, although it is reported in the literature that C storage decreases with increasing average annual temperature, it was also found that average annual temperature explains only 5% of the variability in rates of carbon sequestration, and that there is no significant

(0.52 tC ha−1 yr−1) for *Z. marina*. It should be noted that carbon burial rates are likely to vary significantly both temporally and spatially (Duarte et al., 2011), and future data on this variance would allow a more accurate estimation of the contribution of these habitats to carbon sequestration.

The analysis developed based on a series of assumptions, as data on carbon storage for coastal wetlands are not widely available and have mostly been collected for the North of Europe. Overlaying the CORINE maps to analyse saltmarsh rate of change produces contradictory results, with increases in saltmarsh area for all but the Mediterranean. Rather than showing the positive results of

BV. https://doi.org/10.1016/j.marpolbul.2013.03.029

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				difference between average rates of C sequestration in mangroves and saltmarsh (Chmura et al., 2003). Therefore, we use the same estimate also for the rest of Europe. We express EUA carbon price and DECC carbon prices in US$ too (conversion rates: €1 = US$1.23; £1 = US$1.50). However, since EUA price and DECC prices are defined per ton of CO2, the net C sequestration value of saltmarshes was converted in net CO2 value (3.44 tCO2 ha−1 yr−1). We also converted the *P. oceanica* and *Z. marina* C sequestration estimate to CO2 equivalent (6.67 tCO2 ha−1 yr−1; 1.91 tCO2 ha−1 yr−1). The present value of the flows of carbon storage benefits over 50-year time horizon are discounted at a 3.5% constant discount rate.	coastal realignment schemes in European coastal wetlands, this may be an artefact of better mapping techniques in use by 2006. Our analysis is limited to the differences between 2000 and 2006 because the areas covered by the 1990 dataset are significantly different (i.e., less countries were mapped).		
Blue carbon (carbon sink)	Method to analyse data followed the published sources obtained using literature values and augmented	C_{org} content of living biomass and C_{org} content and dry bulk density (DBD) of	Mg C ha^{-1}	All seagrass meadows sampled in Indonesia were composed of sandy soils, or in some cases, were growing on coral rubble (Table 1), and were dominated by *Enhalus acoroides, Thalassia hemprichii, Halodule uninervis, Cymodocea rotundata,* or *Cymodocea serrulata*. The data from all sites (Fig. 3) showed	Different data sources invariably use different methods, but we treated all data equally and standardized all nomenclature across the data The total soil C_{org} pool was standardized to a	Indonesi a	Alongi, D.M., Murdiyarso, D., Fourqurean, J.W. et al. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecol

by unpublished data, when available.	soils above-ground biomass, below-ground biomass, and the soil pool.		asymmetric distribution with very few values greater than 0.6 Mg C ha^{-1} for above-ground carbon biomass (AGCB) and 3 Mg C ha^{-1} for below-ground carbon biomass (BGCB). AGCB ranged from 0.01 to 1.15 Mg C ha^{-1} with a median of 0.29 and a mean (±1 SE) of 0.32 ± 0.03 Mg C ha^{-1} (Table 1). BGCB was greater than ABCG at all locations and ranged from 0.02 to 4.84 Mg C ha^{-1} with a median of 1.13 and a mean (±1 SE) of 1.23 ± 0.11 Mg C ha^{-1} (Table 1). The largest carbon pool was the soil, ranging from 31.3 to 293.3 Mg C ha^{-1} with a median of 118.1 and a mean (±1 SE) of 129.9 ± 9.6 Mg C ha^{-1} (Table 1). Seagrass AGCB and BGCB correlated positively (Pearson's r = 0.501; P < 0.00000167) but biomass did not correlate with soil carbon. The sum of these three pools is the median carbon storage for an Indonesian seagrass meadow, which is 119.5 Mg C ha^{-1}. Extrapolating this value to the total area of seagrasses (30,000 km^2) gives a total seagrass carbon storage value in Indonesia of 368.5 ± 19.5 Tg C or 0.3685 ± 0.002 Pg C.	soil depth of 1 m. Soil surface values were extrapolated to 1 m using the formulae derived by Fourqurean et al. (2012) from all known seagrass soil C$_{org}$ data: for C$_{org}$, −0.005 ± 0.003log10 (C$_{org}$ + 1) cm−1; for DBD, 8.6 ± 4.0 (mg (dry weight) ml^{-1}) cm^{-1}, except in one study (Alongi et al. 2008a) where the known maximum depth of core penetration was less (Fig. 2). Seagrass biomass (DW) was converted to C$_{org}$ using the C$_{org}$ content measured for the dominant species in each reference listed in Table 1. For detail, see the full paper. Indonesian seagrasses may or may not store more carbon in soils as we only report on the top 50 cm; data currently in hand would		Manage 24, 3–13 (2016). https://doi.org/10.1007/s11273-015-9446-y

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				The 'average' mangrove forest in Indonesia stores roughly as much Corg (mean = 950.5 Mg C ha_{-1}) as they do globally (mean = 956 Mg C ha_{-1}), but slightly more proportionally below-ground (83 vs 75 %) in soil and roots (Alongi 2014). But these differences with the global averages may be more representative of the small sample size in Indonesia compared with the global dataset rather than of true differences in the distribution of carbon.	suggest that Indonesian seagrasses may store less C_{org} in above- (mean = 0.32 Mg C ha_{-1}) and below-ground biomass (mean = 1.23 Mg C ha_{-1}) than the global averages of 0.76 and 1.76 Mg ha_{-1} recorded by Fourqurean et al. (2012).		
Coastal protection	Literature review The interest in understanding how seagrass vegetation interacts with the hydrodynamycs and contributes to coastal protection has led to a	Ecological functions of seagrasses	Depth (m), leaf width (mm), leaf length (cm), above-ground biomass (mg DW^{-1}), shoot elongation rate (cm	The main conclusion achieved is that seagrass meadows cannot protect shorelines in every location and/or scenario. The efficiency of the protection depends largely on the incident energy flux, density, standing biomass and plant stiffness. The optimal conditions for enhancing the defence provided might be achieved at shallow waters and low wave energy environments, with high interaction surface, in the vertical and horizontal dimension, between water flow and seagrasses, but less so when	There are three mechanisms that contribute directly to the protection of the coast by decreasing the intensity of incoming energy: (1) energy dissipation due to wave breaking; (2) energy dissipation due to friction; (3) energy reflection in the offshore direction (Duarte et al., 2013, Koch et al., 2006). These mechanisms can be triggered by seagrasses as well as	Gobal scale, no specific location	Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J., & van Belzen, J. (2014). The role of seagrasses in coastal protection in a changing climate. In Coastal Engineering (Vol. 87, pp. 158–168). Elsevier BV. https://doi.org/10.1016/j.coastaleng.2013.11.005

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growing number of experimental, field and numerical studies.		day^{-1}), shoot life span (days) rhizomes thickness (mm)	hydrodynamic conditions are more severe. Seagrass can be related to a wide range of valuable ecosystem services, including several services related with the mitigation of climate change effects such as the coastal protection, erosion control and carbon sequestration (Barbier et al., 2011, Orth et al., 2006). Among all of them, coastal protection has gained strong interest over the last decade because of the need for measures that minimize anthropogenic impacts of coastal protection structures on coastal ecosystems (Borsje et al., 2011). Coastal defense provided by seagrasses depends on its capacity to attenuate the processes of flooding and coastal erosion, which have been identified as the main natural threats for coasts (Borsje et al., 2011, Duarte et al., 2013; Granek et al., 2009). A range of dynamics are central to both processes (e.g., mean sea level, tide, storm	by other natural or artificial obstacles. The efficiency of seagrasses reducing currents and waves and stabilizing the sediment is related to the water dynamic properties and the ecosystem and biological features of plants (Orth et al., 2006). Regarding the ecosystem features, factors such as the relative water depth (water depth/canopy height), the relationship between the meadow width and the wavelength of incident dynamics or the sediment composition are also essential elements regulating the effectiveness of coastal protection (Duarte et al., 2013). Seagrasses are more successful	

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			surges, waves and currents) and will most probably be affected by climate change. Sediment stabilization by seagrasses makes up an indirect mechanism for coastal protection (Christianen et al., 2013). Both reduction in currents and wave attenuation by seagrasses not only increase sedimentation rates within meadows, but also decrease the potential for resuspension (Bouma et al., 2005, Hemminga and Duarte, 2000, Madsen et al., 2001). Besides, the rhizoidal system of seagrasses contributes to the sediment stabilization and the control of the coastal erosion (Barbier et al., 2011). The trends of seawater warming, increasing storms and sea level rise, together with the increasing population and anthropogenic threats in the coastal area may lead to rates of change too fast to allow seagrasses to adapt and maintain their coastal defence service (Orth et al., 2006).	reducing waves and currents in shallow areas, when they occupy a higher proportion of the water column. Stiffness, biomass, density, leaf length and morphology are major biological plant properties influencing the coastal protection value of seagrasses. The stiffness of leaves determines the drag forces exerted over the plants and the flow penetration in the meadow by leaves bending. The attenuation of wave and currents also depends on the above-ground biomass which is highly related with the number of shoots per unit area and number and size of leaves. *P. oceanica* is the European species with the longest and widest leaves, the highest number of		

				To optimize the protection service supplied by seagrasses efforts must be focused on improving our understanding about how climatic and anthropogenic stressors translate into changes and responses in seagrasses. With that purpose, predictive mathematical models integrating climatic and ecosystem models have been developed (Philippart et al., 2011). Climatic models project where and how climate change will impact the coastal areas focusing on those factors with a direct effect on the habitat suitability (e.g. water column height or current velocity), while ecological models project the effect of climate change on seagrasses in terms of physiology and spatial distribution of species.	leaves per shoot and in addition the highest above-ground biomass.		
Erosion control	*Further studies are needed*						
Water purification	The nutrient retention service was assessed indirectly using as indicator the nitrogen and phosphorus	Water depth, capacity of the reservoir, and seagrass ecologic al	Meters, m^3 Shoot density (m^{-2}) Above-ground	The estimated nutrient retention rates ranged from 13.9 to 130.4 g N m^{-2} yr^{-1} for nitrogen and from 1.2 to 15.2 g P m^{-2} yr^{-1} for phosphorus (Table 2), yielding a daily retention in the whole reservoir of 0.8–1.8 kg N and 0.04–0.07 kg P.	The ecosystem services provided by seagrasses in the water reservoir of an aquaculture system were assessed using indicators based on physical, chemical and biological parameters	The study was conducted at the Aquaculture Research Station	de los Santos, C. B., Olivé, I., Moreira, M., Silva, A., Freitas, C., Araújo Luna, R., Quental-Ferreira, H., Martins, M., Costa, M. M., Silva, J., Cunha, M. E., Soares, F., Pousão-Ferreira, P.,

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	retained in the seagrass biomass per year. The nutrient retention rate calculation formula is provided in the full paper.	indicators	(AG, leaves) and below-ground (BG, rhizomes, and roots) biomass (g dry weight m−2, after drying at 60 °C for 48 h)	The total particle deposition rate within the C. nodosa meadows ranged from 40.4 ± 1.8 to 78.2 ± 12.6 mg dw m^{-2} d^{-1} and it was, on average, 1.8-time higher in the receiving pond and channel than at the donating pond. The rate of particle trapping on the seagrass leaves did not vary along the reservoir sections and it was on average 1.12 ± 0.17 g dw m^{-2} leaf d^{-1} (n = 18), with similar fractions of organic (47.5 ± 3.9%) and inorganic (52.5 ± 3.9%) matter.	related to the seagrass functions and water quality (Table 1). We showed that a seagrass-dominated system contributed to improve the inflowing water quality of the aquaculture system by retaining particulate matter on their leaves and sediment, and nutrients in their tissues.	from the Institute for the Sea and Atmosphere (EPPO-IPMA) located at the Natural Park of the Ria Formosa, a meso-tidal coastal lagoon, in Portugal	& Santos, R. (2020). Seagrass meadows improve inflowing water quality in aquaculture ponds. In Aquaculture (Vol. 528, p. 735502). Elsevier BV. https://doi.org/10.1016/j.aquaculture.2020.735502
Nutrient cycling	*Further studies are needed*						
Waste remediation							
Pathogen's protection	Using amplicon sequencing of the 16S ribosomal RNA gene, further detail	Bacterial abundance	Numeric	We found that when seagrass meadows are present, there was a 50% reduction in the relative abundance of potential bacterial pathogens capable of causing disease in humans and marine organisms. Moreover, field surveys of more than 8000 reef-	The islands lack basic sanitation systems, and surface soils are thin and poorly retain wastewater (10). To ensure suitable comparisons, we selected a set of paired	Spermonde Archipelago, Indonesia	Lamb, Joleah B.; van de Water, Jeroen A. J. M.; Bourne, David G.; Altier, Craig; Hein, Margaux Y.; Fiorenza, Evan A.; Abu, Nur; Jompa, Jamaluddin; Harvell, C. Drew

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	please check the full paper			building corals located adjacent to seagrass meadows showed twofold reductions in disease levels compared to corals at paired sites without adjacent seagrass meadows. These results highlight the importance of seagrass ecosystems to the health of humans and other organisms.	sites (7) where seagrass meadows were either present or absent on the intertidal flat surrounding each island.		(2017). Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science, 355(6326), 731–733. doi:10.1126/science.aal1956
Pollutant remediation	Information about sampling method, samples preparation, trace metal analyses, and statistical calculation is available in the full paper.	Co, Cr and Ni concentrations	$\mu g\ g^{-1}$ dry wt	The results showed that metal contamination from the former mine of Canari (cobalt – Co, chromium – Cr and nickel – Ni) extends at least 5 km to the north and south. The highest Co, Cr and Ni concentrations were recorded in site C2 ([Co]C2 = 14.4 ± 1.4 µg g− 1 dry wt.; [Cr]C2 = 1.2 ± 0.1 µg g− 1 dry wt.; [Ni]C2 = 128.3 ± 13.9 µg g− 1 dry wt.; Fig. 2). The highest Hg concentration was recorded in the site L1 ([Hg]L1 = 0.21 ± 0.00 µg g− 1 dry wt.; Fig. 3) and decreased with increasing distance from this site ([Hg]L1 > [Hg]L2 > [Hg]L3). A significant difference was observed between the sites L1 and L3 (P = 0.051; Fig. 3). The highest Pb concentration was recorded in the	The usefulness of the seagrass P. oceanica as a tool for the evaluation of the spatial extent of metal contaminations from point sources and could, therefore, contribute to on-going efforts to manage coastal environments.	Canari, Livorno, Sardinia (Italy)	Lafabrie, C., Pergent, G., & Pergent-Martini, C. (2009). Utilization of the seagrass Posidonia oceanica to evaluate the spatial dispersion of metal contamination. The Science of the Total Environment, 407(7), 2440–2446. https://doi.org/10.1016/j.scitotenv.2008.11.001

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				site P2 ([Pb]P2 = 2.7 ± 0.3 µg g−1 dry wt.; Fig. 4). At any rate, mercury concentration decreased strongly with distance from the plant. Lead (Pb) contamination at the Porto-Torres harbour was very low and disappeared with distance from the harbour.			
Provisioning							
Maintenance of fisheries	Systematic long-term fisheries dataset in Port Phillip Bay to examine variability in nursery habitat value for an important commercial and recreational species, King George Whiting (*Sillaginodes punctatus*). Please see the full paper	Biomass, fish sampling	Biomass enhancement (kg ha^{-1}) Biomass production (kg ha^{-1}y^{-1})	Throughout the study period, fish abundances and biomass on seagrass beds varied notably among sampling locations. The highest median values originated from Rosebud (4,050 individuals = 432 kg^{-1} ha^{-1} y^{-1}) and lowest in Ricketts Point (450 individuals ha^{-1} y^{-1} = 51 kg^{-1} ha^{-1} y^{-1}). These data show 80.6% (5,370 ha) of the total seagrass area (6662 ha) within Port Phillip Bay on average supports 1,000 – 10,000 fish per hectare per year (ha^{-1} y^{-1}), but with some areas supporting over 30,000 fish ha^{-1} y^{-1}. Seagrass meadows as nursery grounds result in an additional biomass of 110 – 1,080 kg^{-1} ha^{-1} y^{-1}, or over 3,300 kg^{-1} ha^{-1} y^{-1} in the high-density	The associations between environmental variables and King George Whiting abundance at 8 locations in Port Phillip Bay were explored using Boosted Regression Trees (BRT), which combine machine learning with statistical modelling approaches. In this study, BRT modelling was applied to assess the importance of environmental variables (Table 1) for explaining differences in fish abundance from 2003 to 2014 across the eight sampling	Port Phillip Bay, Melbourne, Australia	Jänes, H., Carnell, P., Young, M., Ierodiaconou, D., Jenkins, G. P., Hamer, P., Zu Ermgassen, P. S. E., Gair, J. R., & Macreadie, P. I. (2021). Seagrass valuation from fish abundance, biomass and recreational catch. In Ecological Indicators (Vol. 130, p. 108097). Elsevier BV. https://doi.org/10.1016/j.ecolind.2021.108097

	for formulation. Data cleaning and merging of databases for the fish abundance and economic value analysis were carried out with tidy verse package in R (Wickham, 2017), whereas fish biomass was modelled in C++.			locations. At least 7.2% of the total seagrass area in the Bay can produce more than 3,300 kg^{-1} ha^{-1} y^{-1}. On average, hectare of seagrass supports 69 – 865 fishing trips per year, resulting in a recreational value of seagrass of AUD 887 – 6,750 ha^{-1} y^{-1} (Fig. 6). Based on biomass production and recreational fisheries data, the 6662 ha of seagrass have an estimated recreational fishing value of AUD 36.782 million annually.	locations. A random 70% of the data were assigned for training the model, 15% for testing and 15% for validating the model. BRT modelling was done in R using the gbm package (Elith et al., 2008). BRT modelling was done with the gbm package in R (Greenwell et al., 2020). All R and C++ code used to carry out the analysis is available on request.		
Fish enhancement	Literature review with search terms “fish”, “seagrass” and “Australia”.	Fish abundance	Fish per ha per m^2	Seagrass enhanced the twelve remaining fish species by a total of 980 g m−2 y−1, such that each ha of seagrass restored in southern Australia may enhance commercial fish species by a total of 9.8 tonnes yr−1 (Table 3). Grey mullet (Mugil cephalus Linnaeus, 1758) was the single most significantly enhanced species,	Data were standardized to represent the mean number of individuals per m^2. Enhancement estimates methodology applies growth and mortality to a known age class of fish to	Australia	Blandon, A., zu Ermgassen, P.S.E. (2014). Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia. Estuarine, Coastal and Shelf Science

Enhancement estimates; species selection; production calculations; life history parameters; economic valuation. Detail method, please refer to full paper.			with an additional 9260 individuals ha−1 recruiting a year, resulting in an enhancement of 3500 kg ha−1 y−1 across all age classes. This was closely followed by the six-lined trumpeter (Pelates sexlineatus [Quoy and Gaimard, 1825]), for which recruitment was enhanced by an additional 8020 individuals ha−1 y−1 across all age classes. A full overview of recruitment enhancement by species can be found in Table 3. Our estimate of the economic enhancement of fish in southern Australia by seagrass includes only the biomass of fish from the age at which they enter the fishery (r). The economic value of the enhancement is estimated at $A230,000 ha−1 yr−1 once all fish are fully recruited to the habitat (>26 yrs after restoration). The species-specific economic enhancement and biomass resulting from recruitment enhancement in seagrass habitats are given in Table 3, and can be used to make alternative site specific estimates where species presence or absence is known. Tarwhine (Rhabdosargus sarba [Forsskål 1775]) accounts	derive an estimate of total biomass attributable to enhanced juvenile recruitment. The sampling methods included in the meta-analysis primarily target young of year fish, with the efficiency declining steeply for stronger swimming individuals (Bloomfield and Gillanders, 2005), and we therefore assume that all individuals caught are juveniles. Peterson et al. (2003) made the assumption that all yr 0 fish sampled would survive to their first birthday, however, a more robust and conservative logic is to assume that the yr 0 fish sampled throughout the year, were likely to be 6 months of age on average. We adopt this reasoning in our methodology.		Volume 141, 20 March 2014, Pages 1-8. https://doi.org/10.1016/j.ecss.2014.01.009

				for the vast majority of the total value, with more than $A206,000 ha−1 yr−1 attributed to this one species, whereas the Southern Sea garfish (Hyporhamphus melanochir) only contributes $A6.00 × 10−2 ha−1 (Table 3). Most other species are economically enhanced by values between $A800-7000 ha−1 (Table 3).	Our results can be adapted by excluding species do not present at a site, to provide a more accurate site-specific estimate of potential fisheries benefits. As such our results have a broad application in assisting decision makers, practitioners, and managers in determining the potential cost effectiveness of proposed restoration efforts.		
Cultivated resources extracted	*Further studies are needed*						
Raw materials extracted (Pharmaceutics)	Detail laboratory work can be found in the full paper. The methods are: 1) Extraction of crude sulphated polysacchari	Yield of extractio n	µg/g, %	This is the first report that indicates the presence of fucoidan-like H. pinifolia crude sulphated polysaccharide (HPCSP) that are commonly found in brown algae being present in marine angiosperms. Fucoidan-like structures such as β-mannuronic acid residues and sulphate groups were confirmed by Fourier transform infrared	Researchers have focussed on the extraction and investigation of biological properties of polysaccharides from seaweeds; so far only two reports are available on the polysaccharides from seagrasses and have	Chinnapa llam, Gulf of Mannar Biospher e Reserve, Tamil Nadu, India	Kannan, R. R. R., Arumugam, R., & Anantharaman, P. (2013). Pharmaceutical potential of a fucoidan-like sulphated polysaccharide isolated from Halodule pinifolia.

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de (HPCSP); 2) Chemical analysis; 3) Fourier transform infrared spectroscopy ; 4) Human blood plasma preparation; 5) In vitro anticoagulant activity; 6) In vitro antioxidant activity			(FTIR) spectral analysis. There was a high content of uronic acid. The isolated HPCSP consisted mainly of total sugar (54.17%), protein (11.06%), carbon (18.25%), nitrogen (1.77%), hydrogen (3.62%), C/N ratio (2.04%) and uronic acid (2.61%). This isolated HPCSP was further investigated to determine anticoagulant and antioxidant activity. The HPCSP had high activity in the total antioxidant assay (125.86 mg ascorbic acid equivalents/g), DPPH radical scavenging rate (IC50 value 2.024 ± 0.12 µg/mL), deoxyribose radical scavenging rate (51.82% at 1000 µg/mL) and H_2O_2 radical scavenging rate (IC50 value 6.904 ± 0.34 µg/mL). In the anticoagulant assay, prolonged clotting time was observed with application of HPCSP with increasing concentrations. Further purification and characterization process is underway to confirm the structures of HPCSP. From the observed results, this fucoidan-like HPCSP could be developed as a new natural source of potential antioxidants in the functional food industry.	shown their potent biological properties [15], [16]. In continuation of the screening programme of seagrasses for the development of new safe functional food ingredients, we report on the chemical composition, anticoagulant and antioxidant properties of a fucoidan-like sulphated polysaccharide isolated from the seagrass H. pinifolia.		International Journal of Biological Macromolecules, 62, 30–34. https://doi.org/10.1016/j.ijbiomac.2013.08.005

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Cultural							
Recreational fisheries expenditure	To differentiate habitat use we calculated SRI (Scott et al. 2000) values for the relative amount of time a species spends in seagrass during different life stages relative to other habitats. If juvenile (highest mortality rate) survival is low, the species' contribution to fished stock will be low. Therefore,	Expenditure value and seagrass residency index	Benefit value in million €	The total annual landings value of commercial species that were, at some stage in their life history, associated with seagrass was approximately €681.2 million/year (35% of the total landings value of commercial fisheries in the Mediterranean [Table 2]). When the SRI scores were applied to determine the proportion of landings value directly attributable to the presence of seagrass, approximately €77.7 million (€58.3 million to €91.4 million; approximately 4% of the Mediterranean CFV) was directly associated with seagrass presence (Table 2). No Mediterranean fisheries' species was identified as being totally dependent on seagrass. Even the most strongly associated species, the axillary seabream (*Pagellus acarne*), showed some association with other habitats. From an ecological perspective, the commercial species that would be most affected by the loss of seagrass (highest SRI scores) are axillary seabream (*Pagellus acarne*), scorpionfishes and rockfishes (*Scorpaenidae and*	A systematic literature review was performed on habitat use (presence or absence) of commercially and recreationally important Mediterranean species. Where information was available, dominant, or key habitats were noted, both for the species overall and for each life cycle stage. We used peer-reviewed literature, online databases, and factsheets (Fishbase, SeaLifebase, Larvalbase, Marine Species Information Portal, MarLIN, BIOTIC, Arkive, FAO factsheets, and FAO Adrimed). Key habitats were primarily derived from these widely acknowledged sources, unless specific mention was made of reliance on a particular habitat in the literature. Habitat association at each life	Mediterranean	Jackson, E. L., Rees, § Siân E., Wilding, C., & Attrill, M. J. (2015). Use of a seagrass residency index to apportion commercial fishery landing values and recreation fisheries expenditure to seagrass habitat service. In Conservation Biology (Vol. 29, Issue 3, pp. 899–909). Wiley. https://doi.org/10.1111/cobi.12436

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the amount of time spent

in seagrass as a juvenile was also weighted relative to the adult stage. See the full paper for the final SRI formula.

To determine Mediterranean commercial fisheries landings value (CFV), data were extracted from the Commercial Harvest Database (Hutniczac & Roth 2012); this database evaluates European fishing in monetary terms.

Scorpaena), common pandora (*Pagellus erythrinus*), poor cod (*Trisopterus minutus*), caramote shrimp (*Melicertus kerathurus*), and great Atlantic scallop (*Pecten maximus*) (Table 1). From an economic perspective, the largest losses in landings if seagrass were to decline would be in commercial fisheries that target cuttlefish (*Sepiidae, Sepiolidae*), scorpionfishes (*Scorpaenidae*), octopuses (*Octopodidae*), European anchovy (*Engraulis encrasicolus*), and European pilchard (Sardina pilchardus).

The total annual expenditure of recreational fishers pursuing catches of species that, at some stage in their life history, depend on the presence of seagrass was estimated at €723.3 million (approximately 28% of all Mediterranean recreational fishing activity; Table 2).

stage for each species was ranked as 0 (no record found), 1 (rarely recorded or unusual), or 2 (consistently present in some abundance or many instances in the literature). This ranking was to illustrate confidence and was not used in the weighting calculations.

When the SRI scores were applied to determine the proportion of that expenditure that could be directly attributed to the presence of seagrass, €112.6 million of that expenditure (approximately 6% of RFV Mediterranean) could be attributed the presence of seagrass (Table 2).

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Social ecological service	We gathered data and information related to this research by using a semi structured interview and survey. Individuals and/or households using the seagrass ecosystem as a recreational fishing ground were interviewed.	Data based on the interactions among SES components and indicators. The full list of indicator and unit is available on the full paper.	Hectare, Kg, IDR, person, ind m-2	There are 7 species of seagrass, i.e. *Enhalus acoroides (Ea), Cymodocea rotundata (Cr), Cymodocea serrulata (Cs), Thalassia hemprichii (Th), Halodule uninervis (Hu), Halodule pinifolia (Hp), and Halodule ovalis (Ho)* (Damayanti, 2011). The total area of seagrass bed in study area was 699 ha, which were 210 ha in coastal area of Berakit Village, 261 ha in the coastal area of Malang Rapat Village and 228 ha in the coastal area Teluk Bakau Village (Adrianto et al., 2013). Adrianto et al. (2014) stated that the coverage area of seagrass of each village were 43% (Berakit), 56% (Malang Rapat) and 32% (Teluk Bakau), meanwhile the average density of seagrass were 40 ind m^{-2} (Berakit), 128 ind m^{-2} (Malang Rapat) and 72 ind m^{-2} (Berakit). The result of our analysis shows that the social ecological value of this activity is IDR 471,778.00 $person^{-1}$ $visit^{-1}$ on average. This value consists of a direct economic impact of around IDR 143,320.00 $person^{-1}$ $visit^{-1}$, indirect economic impact of around IDR 202,314.00 $person^{-1}$	The formulation to calculate index of SES indicator and total economic impact is available on the full paper. Comparing the value of the seagrass ecosystem with other values from several references shows that this economic impact (from recreational fishing) is lower than some others. Adrianto et al. (2013) estimated the economic value of seagrass by using the consumer surplus approach as its provisioning services (fish production) IDR 246.02339.55 million ha^{-1} $year^{-1}$ and for other biotas IDR 17.18–29.42 million ha^{-1} $year^{-1}$. Wahyudin et al. (2016a) estimated the economic habitat loss using McArthur and Boland (2006) at IDR 4.36 million ha^{-1} $year^{-1}$. Table 5 shows details	Three villages: Berakit, Malang Rapat, and Teluk Bakau, in East Bintan, Indonesia	Wahyudin, Y., Kusumastanto, T., Adrianto, L., & Wardiatno, Y. (2018). A Social Ecological System of Recreational Fishing in the Seagrass Meadow Conservation Area on the East Coast of Bintan Island, Indonesia. In Ecological Economics (Vol. 148, pp. 22–35). Elsevier BV. https://doi.org/10.1016/j.ecolecon.2018.01.013

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visit $^{-1}$ and induced demand around IDR 143,320.00 person $^{-1}$ visit $^{-1}$. Fig. 12 shows that Teluk Bakau receives a more significant economic impact from each visitor (IDR 503,368.75 person $^{-1}$ visit $^{-1}$) than other villages (Berakit and Malang Rapat), meanwhile Berakit shows the lowest economic impact (IDR 431,440.00 person $^{-1}$ visit $^{-1}$). Thus, it may be concluded that Berakit is still lacking when it comes to promoting its potential services to attract tourists for recreational fishing. As a cultural service of seagrass habitat, recreational fishing was found to have a significant impact on local and regional economics. Shown in Table 4, the total economic impact of this activity is around IDR 245,32 million year^{-1} on average. Hence the economic value of seagrass as well as its function for recreational fishing is estimated at around IDR 351,179.56 ha^{-1} year^{-1} on average. Seagrass in Malang Rapat has the estimated highest economic value of IDR 466,168.09 ha^{-1} year^{-1}; Teluk Bakau has an estimated value of on the economic value of seagrass from several references (see full paper).

The magnitude of the economic benefits linked with the presence of seagrass ecosystems and recreational fishing has been estimated at IDR 351,179.56 ha^{-1} year^{-1} on average. We believe the evidence of the benefit and value of these services should be the basis of management input to sustain the benefits of seagrass presence into the future.

This SES mapping is intended to support considerations to protect the seagrass ecosystem and local economic development related to the recreational fishing in the seagrass conservation area.

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				IDR 344,830.95 ha $^{-1}$ year $^{-1}$; and Berakit has the lowest estimated value of IDR 213,569.52 ha^{-1} year^{-1}. The economic value of seagrass as well as its function for recreational fishing is estimated at around IDR 351,179.56 ha $^{-1}$ year^{-1} on average.			
Education/research	The main objective of this study is to map seagrass distribution and the total areas on the three most populated islands in the Spermonde Archipelago using two different spatial resolution imageries, Sentinel-2 and Landsat 8. Several variables, including	Geometrically corrected S2 images of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while images from Landsat	In the laboratory, samples were cut into two parts, the biomass above the sediment or aboveground biomass (AGB) which	The result of this study showed that there is a strong correlation between in situ seagrass percent cover and NDVI values derived from the two satellite images. However, the correlation between in situ seagrass total biomass and the NDVI values showed a relatively weak correlation. Image classification showed that seagrass was distributed mostly on the west side of the islands, and there were six seagrass species identified on the sites, i.e., E. acoroides, T. hemprichii, C. rotundata, H. uninervis, H. ovalis and S. isoetifolium. In this study, we also discovered that there was a disparity of seagrass total cover area between Sentinel-2 and Landsat 8, due to spatial resolution diferrences. Sentinel-2 images were able to classify	Information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data to efficiently manage and monitor the seagrass ecosystems for conservation purposes. Remote sensing techniques have proven to be efficient and effective tools for seagrass monitoring. Since launched by the European Space Agency (ESA) in 2015, Sentinel-2 (S2) images with higher spatial resolution that are suitable for seagrass mapping, have been	Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of the Spermonde Archipelago, which is located west off the coast of	Nurdin, N., Amri, K., Mashoreng, S. et al. Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia. Ocean Sci. J. (2022). https://doi.org/10.1007/s12601-022-00054-2

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seagrass density and biomass, were measured directly in the field to find a correlation between in situ values and NDVI values derived from Landsat 8 and Sentinel-2 image analysis. For detail correction and analysis of satellite image, it is available in the full paper. In situ measurements of SPC and seagrass density were carried out using a 50 cm × 50 cm	8 were downloaded from USGS Glovis. Regression analysis could be found in the full paper	consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al. 2018).	seagrass distribution up to the seagrass density category, however, they cannot be applied to differentiate seagrass density based on species. Nevertheless, both Sentinel-2 and Landsat 8 are useful for seagrass condition monitoring purposes. The seagrass maps were generated using a pixel-based classification method (unsupervised classification). 3 highly populated islands in the Spermonde Archipelago were analyzed in this study. Based on the results, SPC in KL was mainly in the range between 30 and 59.9% (medium), which accounts for 60.38% of the total seagrass area on this island. Similarly, SPC on BC and BL islands were also mainly characterized by the medium SPC category, which accounts for 62.71% and 63.74%, respectively, of the total seagrass areas that were identified on each island. Overall, medium SPC category accounts for 62.02% of the total seagrass area identified on these three islands (Fig. 3; Table 1). Spermonde Archipelago has 683.70 ha of seagrass, so it can be said that these three	available and can be acquired at no cost. The use of S2 imagery for seagrass meadows ecosystem study was recently demonstrated with regard to seagrass beds on the Atlantic coasts of France and Spain (Zoffoli et al. 2020). Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland coastline between 10 and 20 km (Fig. 1). Field data were taken at BL, BC, and KL islands from 3 to 14 June 2020. Data derived from satellite images used for this study were acquired from S2 on July 29th 2019 and from Landsat 8 (L8) on January 6th 2019.	Makassar City, capital of South Sulawesi Province, Indonesia

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plot (McKenzie et al. 2001).			islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago. There were differences in total seagrass areas calculated with L8 and S2 image processing. Calculation with S2 resulted in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island compared with L8. Seagrass maps of KL and BC islands show that each island has several dominant and sparse seagrass distribution spots (Table 1). The seagrass-dominant areas at KL and BC islands were mostly on the west, southwest, to the south of the island, while on the north to the east side of the islands, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicate that lack of seagrasses on the east sides of the islands was due to water depth and human activities mostly centered on the east side of the island (the side that faces the mainland). This side was the main channel for local passenger ships (Fig. 5: A1,	The correlation between the total biomass and the NDVI values of the three islands was analyzed. R2 values acquired from regression analysis were 0.40 for Landsat 8, and 0.43 for Sentinel-2. These R2-values indicate a low correlation between the total biomass value and the NDVI value. Overall, NDVI and carbon biomass of seagrass showed a linear relation (Fig. 11). The higher the total biomass value, the closer the NDVI value will be to 0 (solid seagrass cover condition), while the lower the total biomass value, the closer the NDVI value will be to -1 (low seagrass cover condition). Moreover, on BL Island, the biomass value has more variation in the high	

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B1, C1) and the port area of each island.

The accuracy test of the S2 image classification results was obtained using field data. Field data used was a sample of seagrass cover photos that have coordinates. Based on the image analysis results, the overall accuracy of the kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

The result from in situ measurement shows that seagrass density and SPC have a synched pattern, from low to high density, and low, medium, and high categories, respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category than in the medium or low category. The consistent pattern of seagrass density in all three islands is more likely due to the relatively similar composition of seagrass species in the three percent cover categories.

The relationship between SPC from field measurements and NDVI values was analyzed using algorithmic modeling with linear seagrass cover category than in the low and medium categories (Table 4). This is due to the various species composition. Some plots were T. hemprichii dominant, while other plots were more E acoroides dominant. Morphologically, the two seagrasses have different sizes, therefore, at the same cover percentage, they have very different biomass values. In the low and medium seagrass cover categories, T. hemprichii was consistently the dominant species.

Furthermore, in the high seagrass cover category, there was quite a lot of overlap between leaves, especially with the T. hemprichii species. In some plots (Fig. 10), a regression. The regression equation was obtained from the relationship between the NDVI value of S2 images and the value of in situ SPC. The algorithm obtained was $y = 0.0053x - 0.785$. Regression analysis shows a linear correlation between NDVI and in situ data with R2 value of 0.8255. The R value indicates a strong relationship between the in situ SPC and the NDVI values of satellite images (Fig. 9).

Results from laboratory analysis showed seagrass BGB in all islands and in each seagrass cover category were higher than AGB. Seagrass BGB value on BL island on average was four times higher than AGB. Meanwhile, the ratio was smaller on the other two islands, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one of the forms of seagrass adaptation. Seagrass grows in shallow waters, which makes it very vulnerable to the influence of waves. Without specific adaptation, seagrass can be easily uprooted by the waves. Seagrass adapts by storing more photosynthetic products under the large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the high and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi, et al (2020), the high slope value of T. hemprichii seagrass regression equation at high percent cover was because of the overlapping leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

E. acoroides and C. rotundata significantly contributed to the medium to sparse percent cover category

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				ground than above, therefore, it can stay still under the impact of waves. Seagrass BGB was generally weighted higher than ABG in the seagrass categories on the three islands. High categories dominated seagrasses on the three different islands. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL Island, 3.83 ton dry weight/ha on KL Island, and 10.99 ton dry weight/ha on BC Island (Fig. 10).	on KL and BC islands. This causes the biomass values of those two categories to vary largely. The contribution of the two seagrasses was about half of the dominant species T. hemprichii, while on BL Island, it can reach a quarter in the same category.		
Religious/spiritual/indigenous	The study reported here was based on semi structured interviews, in-depth interviews, questionnaires, documentation of landings at the local fish market and participant observation	Demographic data	qualitative	People in Chwaka believe in the power of seagrasses to solve different human problems. Traditional doctors report seagrass as an important ingredient for different kinds of magic potions. Seagrasses are used both in positive (conflict resolution, love problems, work problems) and negative (to harm someone or make an unwanted person leave) ways. They are also important in the rituals and cures against ghosts and devils. Amulets and small packages containing seagrasses are placed in boats ("to have always the wind with you") and as necklaces for	All respondents were from Chwaka village. Fishermen and seaweed farmers were the focus of the study, since they are the most important stakeholders in the area. Interviews and questionnaires were planned so as to provide basic socio-economic data, as well as information on management, organization and institutions related to natural resource use, property rights,	Chwaka Bay in the East coast of Zanziba, Tanzania	de la Torre-Castro, M., & Rönnbäck, P. (2004). Links between humans and seagrasses—an example from tropical East Africa. Ocean & Coastal Management, 47(7–8), 361–387. https://doi.org/10.1016/j.ocecoaman.2004.07.005

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			babies (against nightmares “kumbasi”). “Kirambe” is the belief that adults can harm children through “treated” food and seagrasses are considered a good remedy. Ramadhan is the most important religious period for Muslims. During this holy month, the population follows strict fast rules; no eating and drinking is allowed during daylight. As a consequence, most net and harpoon fishermen have not the strength to dive and therefore shift their fishing practices to “dema” traps. As mentioned previously, “dema” fishery is directly linked to seagrasses, thus seagrass and religious practices mutually constitute and “dema” fishery permits fishermen to maintain their source of income. Examples of different value judgments given for seagrasses: “God has sent seagrasses as decoration of the sea” and “Seagrasses are the garden of life”.	conflicts and historical perspective, LEK and uses of seagrasses, threats, protein consumption issues and health, and finally exploration of aesthetical values.		

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Table 8. Overall services in multiple coastal ecosystems

Reference	Context/assumption	Indicator (unit)	Method	Location	Type of service	Value
Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193. https://doi.org/10.1890/10-1510.1	We indicate estimates of the key economic values arising from these services and discuss how the natural variability of ECEs impacts their benefits, the synergistic relationships of ECEs across seascapes, and management implications. Although reliable valuation estimates are beginning to emerge for the key services of some ECEs, such as coral reefs, salt marshes, and mangroves, many of the important benefits of seagrass beds and sand dunes and beaches have not been assessed properly. Even for coral reefs, marshes, and mangroves, important ecological services have yet to be valued reliably, such as cross-ecosystem nutrient transfer (coral reefs), erosion control (marshes), and pollution control (mangroves). An important issue for valuing certain ECE services, such as coastal protection and habitat–fishery linkages, is that	Descriptive	Qualitative	Global	Multiple, including direct and indirect use of service. See Table 1, 2 and 4 in the full paper for the summary of services provided by these three ecosystems	An important ecosystem service provided by coral reefs is coastal protection or the buffering of shorelines from severe weather, thus protecting coastal human populations, property, and economic activities. A summary of coral reefs services, please see Table 1 in the full paper. As indicated in Table 2 (see the full paper), seagrass beds provide a wide range of ecosystem services, including raw materials and food, coastal protection, erosion control, water purification, maintenance of fisheries, carbon sequestration, and tourism, recreation, education, and research, yet reliable estimates of the economic values of most of these services are lacking. Of the ecosystem services listed, three have received most attention in terms of determining their value to coastal populations. These include (1) their use by local coastal communities for a variety of products, such as fuel wood, timber, raw materials, honey and resins, and crabs and shellfish; (2) their role as nursery and breeding habitats for offshore fisheries; and (3) their propensity to serve as natural ''coastal storm barriers'' to periodic wind and wave or storm surge events, such as tropical

	the ecological functions underlying these services vary spatially and temporally. Allowing for the connectivity between ECE habitats also may have important implications for assessing the ecological functions underlying key ecosystems services, such coastal protection, control of erosion, and habitat–fishery linkages.					storms, coastal floods, typhoons, and tsunamis. A summary of services provided by mangrove ecosystem is available in the Table 4.
WAVES project, Pilot Ecosystem Account for Southern Palawan-Technical Report 2016. www.wavespartnership.org	This report reflects the work of the Southern Palawan (SP) Technical Working Group, which consists of members of the Department of Environment and Natural Resources (DENR) and the Palawan Council for Sustainable Development (PCSD). The development of the ecosystem account was supported by the World Bank-led Wealth Accounting and Valuation of Ecosystem Services (WAVES) project in the Philippines, which provided technical and financial assistance. Although experimental in nature, the account is replicable across time and geographical scales (e.g.,	Table on page vi: Mangrove area (ha), carbon storage (million-ton C), carbon sequestration (ton CO_2/year), coral reef condition (%live coral cover in sample points),	The Southern Palawan Pilot Ecosystem Account follows an adopted standardized system called the System of Environmental Economic Accounting-Experimental Ecosystem Accounting (SEEA-EEA) framework, which ensures comparability, both nationally and	Southern Palawan, Philippines	Overall	The overall volume of mangroves in the municipality of Sofronio Española dropped considerably from 337,053 m^3 in 2001 to 189,652 m^3 in 2010, representing a decline of over 43.73% in just nine years. Several factors may have contributed to this disturbing pattern, including land conversion to fishponds, and localized cutting and clearing. Coral reefs in the study area were equally under high pressure because of overfishing, destructive fishing, and pollution. Coral condition declined in the past 10 years with 12 out of 15 sites registering a reduction in live coral cover. Moreover, live coral cover rapidly declined in all sites, and there were no survey sites remaining under very good and excellent coral cover condition in 2010. Other coastal accounts were certainly no bright spots either as the condition account also recorded a decline in seagrass density and percentage cover in half of the sites, while species composition was largely unchanged. Seagrasses are more resilient

national). It is also useful in policy making.	seagrass condition (%cover in sample sites), mangrove condition (volume of trees in 100 m^3), fish production (ton/year or million pesos/year).	internationally, and consistency with regularly produced economic statistics. Therefore, ecosystem accounts can be used to monitor trends in natural capital as well as the enforcement of resource management policies.		

than coral reefs to pressures from sedimentation and runoff, but they are affected by changes in water clarity, which in turn affects photosynthesis.

The 28,813 ha of municipal waters of Sofronio Española is a rich fishing ground. Calculations based on a survey for the Phil WAVES project showed that total catch by all fishermen amounts to 1,665,853 kg/year. The gross sales value of this catch is 41,144,818 pesos (US$883,884)/year (42 pesos/kg * 1,665,853 kg/year). Preliminary estimate of the value of fishery production ecosystem service generated by the coastal marine ecosystems in Sofronio Española, measured in terms of resource rent, is calculated at 42 pesos (US$0.90)/kg or a total of 70 million pesos (US$1.5 million)/year (42 pesos/kg * 1,665,853 kg/year) for the municipality.

Understanding these and other ecosystem conditions in Southern Palawan highlights the extreme importance of mainstreaming the ecosystem accounting framework into decision making. The ecosystem accounts can serve as a benchmark to identify key policy needs and impacts as well as areas where specific policy interventions should be carried out as a matter of priority. They can also be used to monitor changes in the ecosystem. An important dimension of the value of these accounts lies in showing trends in ecosystem condition, asset, and service flows over time, requiring regular updating of the accounts. Given the capacities built and the lessons learned in the process of

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						developing these accounts for Southern Palawan, the cost of updating them in the future should be much lower compared to establishing them. Potentially, given the rate of ecosystem changes in Palawan, updates should take place at least once every two or three years. This should mark an important step forward as the Philippines pursues natural capital accounting in earnest.
WAVES project, Pilot Ecosystem Account for Southern Palawan-Technical Report 2016. www.wavespartnership.org	In the pilot ecosystem account, carbon sequestration is included only in the carbon account. This shows that carbon sequestration and carbon stocks are equally important to inform decision making. Thus, in the case of Southern Palawan, they are presented side by side. The carbon account for Southern Palawan was developed by the Forest Management Bureau of the DENR as a template for further carbon analyses within the agency. In the future, the ecosystem services supply and use account may be expanded to include carbon sequestration. Note that carbon storage and carbon sequestration in plantations are not captured. However, the inclusion of these important atmosphere and the chemical element that	Carbon storage (million-ton C), carbon sequestration (ton CO_2/year)	The carbon account specifies, in terms of tons of carbon, the opening carbon stock, carbon removals, carbon emission, net carbon emission, and closing carbon stock. Carbon stocks are calculated for the years 2003, 2010, and 2014. Biomass and carbon accounting	Southern Palawan, Philippines	Carbon account	The net carbon uptake or emission is dependent on two main biophysical processes. One concern changes in forest/woody carbon stocks owing to the net annual biomass growth of existing forest and non-forest stands, and possible biomass regrowth in abandoned lands. The other revolves around land use, forest conversion, and timber logging practices, which can lead to carbon releases through biomass burning, decay, and soil carbon release. The biomass and carbon account presents the carbon stock in 2003, 2010, and 2014. Table 4.3 presents only the biomass and carbon data on forest cover, particularly for closed, open and mangrove forests. The forest biomass takes into account the stem, aboveground, belowground, and total tree biomass (excluding soil carbon for lack of data). Biomass in closed forests in Palawan is relatively low compared to other forests in a more humid climate. This may also reflect the existence of logging in these forests in the past. The carbo stock in Southern Palawan forests stood at 16-

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contributes to climate change. Once absorbed by vegetation, carbon is stored in plants in the form of a series of organic molecules (but not as CO_2). Hence, carbon storage is commonly expressed in terms of tons of carbon (C) while carbon sequestration is usually expressed in terms of tons of CO_2. The conversion factor to get tC from tCO_2 is: 1tC = 3.67t CO_2.

data are derived from the established volume account of ***timber***. They are divided into five parameters: stem biomass, above ground biomass (AGB)-using biomass expansion factor (BEF), belowground biomass (BGB), tree biomass, and tree carbon content. The assessment methodology is as follows: 1) Computation of Tree biomass; 2) Computation of Tree Carbon

million-ton C in 2003, 9.2 million tons C in 2010, and 9.4 million tons C in 2014 (see Table 4.3).

The decrease in the first period can be attributed to the decline in the area and volume of closed forests and the wide-range conversion of closed forest to other land cover. The rise of carbon stock in the period 2010-2014 was due as well to the increase of area and timber volume in open and closed forests.

Table 4.4 presents calculations of carbon storage in Southern Palawan. Among the three forest types, mangroves have the lowest total carbon sequestration due to their relatively lower areal coverage for the period 2003-2014 compared to the other two forest types. In general, the year 2003 had the lowest carbon sequestration, while sequestration gradually increased again between 2010 and 2014.

The monetary value of carbon sequestration in Southern Palawan (in pesos per year) can be calculated using the marginal costs of 1 unit of CO_2 captured by forest vegetation. As discussed, it is tentatively assumed that this amount can be approximated using SCC, where future damages of climate change have been discounted at either 3% or at 5%. Based on the results shown in Table 4.5, it is assumed that the SCC is pegged at 1,344 pesos (US$28.87) per ton of CO_2 at a discount rate of 3%, or 462 pesos (US$9.92) per ton of CO_2 at a discount rate 5% (based on the US Environmental Protection Agency, 2013, as explained above).

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			Content; 3) Computation of Carbon Dioxide Content; Detail formula, see the report.			To facilitate comparison of carbon stocks and carbon sequestration, the summary account in the beginning of this report expresses carbon sequestration in terms of tons of C/year. This is obtained by dividing the amount of sequestered CO2 by 3.67 (relative molecular weight, as explained in the methodology discussed earlier). In view of the high uncertainties surrounding monetary valuation, monetary values are not provided in the summary account for policy makers.
WAVES project, Pilot Ecosystem Account for Southern Palawan-Technical Report 2016. www.wavespartnership.org	It is important to link the ecosystem condition account with other accounts following the ridge-to-reef framework, an ecosystem-based approach to biodiversity conservation. The paucity of data for specific indicators remains a challenge in developing the accounts, particularly considering the data link between the development of Fishery Food Provisioning Service, and the development of accounts for lowlands and uplands. There is a need to establish the Fishery Stocks and monitor key water quality indicators and link these with other ecosystem accounts.	Pollution loading indicator: nickel, copper, lead, and total suspended solids (TSS) (See Annex 6 for the location of the sampling points.) The ecosystem condition	Heavy metal concentrations were examined using atomic absorption spectophotometry; TSS through gravimetric analyses was conducted by CRL Environmental Corporation, a private full-service laboratory in the Philippines.	Southern Palawan, Philippines	Ecosystem extent	**Mangroves.** Studies show that the Philippines has a long history of mangrove degradation. The country originally had an estimated area of mangrove forests of 500,000 ha in 1918 (Brown and Fisher, 1920). A recent estimate for the year 2000 put the figures at 256,185 ha (Long and Giri, 2011). The same study reported that in 2000, Palawan had the highest mangrove forest cover in the country, representing 22% of the total mangrove ecosystems in the Philippines. **Coral reefs**. The Philippines has an estimated 27,000 km^2 of coral reefs, with over 70% in poor or fair quality and quantity. Of the remaining cover, only 5% is in excellent condition (Gomez et al., 1994). Coral reefs contribute between 8% and 70% to the total fisheries production for some island reefs (Alino et al., 2004). Meanwhile, approximately 1 million small-scale fishers representing 62% of the population living along coastal areas are directly dependent on reefs for their livelihood (Barut et al., 2004). Coral

Three indicators have been selected to show the seagrass ecosystem conditions. These include the following: 1) Biodiversity, measured in terms of Shannon-Weiner Biodiversity Index and number of species; 2) Abundance, measured in terms of percent vegetative cover; 3) Density, measured in terms of shoots per m^2 the above is frequently used indicators for assessing ecosystems, and have been identified as potentially suitable indicators for ecosystem accounting in the recent World Conservation Monitoring Centre report on biodiversity accounting (World Conservation Monitoring Centre, 2015).

The coastal ecosystem condition account shows a general decline of three ecosystems based on select key indicators. These include mangrove condition indicators in terms of area (ha), density (trees/ha), total volume (m3), seedlings/sapling (individuals/ha); seagrass condition indicators in terms of density (shoots/square meter); and seagrass cover as a

of the mangrove forest of Sofronio Española was characterized using six indicators (Table 5.4), namely, area (ha), species diversity (H'), number of species, density (trees/ha), total volume (m^3), and seedlings/saplings (individuals/ha).

reefs in Palawan are under high pressure and are declining rapidly as a result of overfishing, destructive fishing, and rising pollution. The most recent monitoring report (2004) for the province covering 305 sites in 19 municipalities shows that only 1.1% of the coral reefs of the province are in excellent condition (75-100% live coral cover), 19% in good condition (50-74.9% live coral cover), 34% in fair condition (25-49.9% live coral cover), and 45% in poor condition (less than 25% live coral cover) (State of the Environment 2004, PCSD).

Seagrass fields. Seagrasses are submerged flowering marine plants adapted to live in saline waters. A seagrass bed is one of the most productive components of the marine ecosystem, being ecologically significant and as important as corals and mangroves by serving as nursery, feeding, and breeding grounds for a variety of marine organisms. Seagrasses are associated with mangrove forests and coral reefs and are considered as an ecotone (or transitional zone) between the two ecosystems. In the Philippines, 18 species of seagrass have been recorded (Fortes, 2010), of which 14 species have been found in Palawan (2004).

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	measure of species abundance, and cover categories for coral reefs.					
Langle-Flores, A., & Quijas, S. (2020). A systematic review of ecosystem services of Islas Marietas National Park, Mexico, an insular marine protected area. Ecosystem Services, 46(101214), 101214. https://doi.org/10.1016/j.ecoser.2020.101214	Regardless of their area, the islands and their resources provide multiple services: i) supporting ecosystem services, such as primary production, larval and gamete supply, nutrient cycling, water cycling, formation of species habitat, building of physical barriers, and preserving seascape; ii) provisioning services such as wild food (fish), fertilizer, biofuels, ornaments, marine fish and plants to aquaria, medicines and biotechnology; iii) regulating services such as biological control, natural hazard regulation, waste breakdown, detoxification, carbon sequestration, promoting healthy climate, preventing coastal erosion, and waste removal; iv) cultural services such as tourism, nature watching, spiritual and cultural wellbeing, aesthetic benefits, education, research, physical and mental health benefits.	Fully understanding the ecosystem services cascade, required the identification of four components: supply, demand, social value and economic value	Literature review. For this systematic review, we considered four types of ecosystem services in accordance with The Economics of Ecosystems and Biodiversity classification (TEEB). Detail PRISMA protocol or step by step of systematic literature review, see the full paper. When a study comprised more than one component or type of ecosystem	MPA Islas Marietas National Park, Mexico	A total of 16 ecosystem services were considered in the systematic review (Supplementary data, Table S1 details the definition for each ecosystem service).	List of ecosystem services (ES) with definitions is available in Table S1 Appendix A in supplementary data document. Most of the publications about the IMNP have focused on the marine environment, but this was not always the case (Fig. 6). Before 2007, the largest number of publications on biodiversity and ecosystem services focused on the terrestrial environment, particularly in grasslands (Supplementary data, Table S4). After 2009, publications increased exponentially in the marine environment (Supplementary data, Fig. S4), particularly related to coral reefs and deep-sea areas (Supplementary data, Table S4). Migratory and habitat for species, gene pool protection and recreation and tourism were the most quantified ecosystem services. For most publications, the main component quantified is the potential “supply” for eight ecosystem services; strongly associated with this component are migratory and nursery habitat and gene pool protection. The term “social value” showed a weak association with recreation and tourism, and information for cognitive development. The component “demand” showed a weak association with recreation, tourism and food provision. In contrast, the lowest component considered is the “economic value” with weak associations to recreation, tourism, and climate regulation. Information brokers show a

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	Islas Marietas is an important tourist destination; at least 286,000 visitors traveled to the Park between October 2016 and October 2017. This number represents nearly 10.3% of the total recorded visitors to all protected areas in Mexico (SEMARNAT-CONANP, 2018). Recreational activities such as snorkeling, scuba diving, swimming, and use of beaches generate important revenue for the local population. In fact, at least 726 tour guides are certified by the National Park, and 192 boats are licensed to carry six to 200 visitors, which in total represent 3,897 seats.		service, each one was recorded as a new entry in the database, allowing more than one entry per study. For visualization, we used an alluvial diagram to illustrate the ecosystem services cascade in IMNP from literature review data.			high frequency of occurrence, followed by intermediate effect on resources.
Balzan, M. V., Potschin-Young, M., & Haines-Young, R. (2018). Island ecosystem services: insights from a literature review on	Most of the selected papers focused on cultural IES, in the form of recreation, eco-tourism and gene pool protection. However, provisioning and regulating IES were also well represented in the literature. Most of the studies discussed different management strategies and pressures arising from human use of IES. A small subset investigated the links between island biodiversity and IES, and the contribution of IES	The literature search was carried out in two stages involving (a) the screening of the title, abstract and	This study reviews the literature on island ecosystems, their contribution in the delivery of five key Island Ecosystem Services (IES) and acting pressures and trade-offs	Global scale	This study carries out a literature review relating to five key island ecosystem service (IES):	Detail type of service is available in the supplementary document. The results obtained from this literature review of IES suggest that ecosystem service assessments, and the management of IES, in small islands are likely to be hampered by the relative availability of published scientific information on the mechanisms linking ecosystem structure and function, IES delivery, benefits and values. This study demonstrates a strong prevalence of studies investigating pressures on island ecosystems, and the management of these, but few studies quantify the role of

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case-study island ecosystem services and future prospects. International Journal of Biodiversity Science, Ecosystems Services & Management, 14(1), 71–90. https://doi.org/10.1080/21513732.2018.1439103	to human well-being. This review highlights knowledge gaps in the literature and identifies the need to develop approaches for IES assessments that are informed by local knowledge, and which make use of empirical and spatial data for management that maximizes the potential of island ecosystems to deliver IES whilst reducing trade-offs.	keywords and (b) a full paper analysis.	associated with IES management. From a set of 1630 potentially relevant papers, 273 were selected for analysis. Detail data collection is available in the full paper.		food and water provisioning, erosion and pollination regulation and recreation and eco-tourism.	biodiversity in delivering key IES, investigate the value to island communities or involve stakeholders to ground truth the development of management actions or evaluate the possible management actions. Given the identified gaps, and the extensive data requirements to assess multiple ecosystem services, the consultation with experts, locals and stakeholders, who through profession or experience have developed sufficient knowledge on the subject, is likely to provide an important starting point for providing a wider picture, developing integrative assessments of IES, focused monitoring and data collection, improved understanding of the synergies and trade-offs between IES and to provide indication of ecosystem management measures that would be favoured by island communities and other stakeholders. These approaches need to consider the special case of small islands, because of the common challenges this face, the interrelatedness of island ecosystems and IES, and the significant benefits island communities derive from these ecosystems.
Basa T. Rumahorbo, Baigo Hamuna, Henderina J. Keiluhu, Alianto. (2020)	This study aims to identify and quantify the economic value of CES in Jayapura City, Papua Province, Indonesia. CES information is obtained based on perceptions of indigenous Papuans living in coastal areas. The results of this study are	Monetary value (USD) per ecosystem area per time	Data collection was carried out with 2 methods, namely (1) gathering people in the village hall,	Jayapura, Papua, Indonesia	Overall services of coastal ecosystem	The CES value in Jayapura City is estimated to be around USD 5,424,116.49/year, which consists of service values of mangrove, coral reefs, and seagrasses ecosystems that are USD 4,444,707.00/year or USD 19,066.18/ha/year, USD 424,333.06/year or USD 11,303.49/ha/year, and USD 555,076.43/year or 5,008.36/ha/year, respectively. The service value of mangrove

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Identifying and Quantifying the Economic Value of Coastal Ecosystem Services According to the Perceptions of Papuan Indigenous Peoples in Jayapura City, Papua Province, Indonesia. International Journal of Environmental Science, 5, 197-206

expected to help decision-makers to predict economic efficiency from various possible uses of ecosystems in coastal areas and can assist in the determination of sustainable coastal ecosystem management.

Data Identification of CES based on the type of utilization of the current coastal ecosystems by the indigenous peoples in Enggros, Tobati, and Nafri Villages, which consists of services that are direct, indirect and services that are of no use value. The concept used to estimate the economic value of CES in Kota Jayapura is the concept of Total Economic Value (TEV). TEV is obtained by summing all identified CES values [24]. The CES value from the calculation results in IDR is then converted to USD (USD 1 = IDR 14,178 at Mei 18, 2018).

For the mangrove ecosystem, some CES values were obtained which refer to the results of the study by Rumahorbo et al. [25]. While for the CES value of coral reef and seagrasses

and (2) direct interviews with visiting community houses. The number of respondents obtained in this study was 228 respondents consisting of 150 men and 78 women, and 3 people diving tourism businesses in the city of Jayapura. After the interview, then continued with direct observation in the field regarding the utilization of coastal ecosystems.

ecosystems is higher than that of coral reefs and seagrass ecosystems, especially in the value of direct benefits (fishery products) felt by the community. The value of CES as a provider of fishery products is quite high because of the high desire of the community to exploit and utilize natural resources such as fish, crabs, shrimp, and shellfish in coastal ecosystems to improve community welfare. The results in this study, CES of mangrove, coral reefs, and seagrass ecosystem values were USD 19,066.18/ha, USD 11,303.49/ha, and USD 5,008.36/ha, respectively. So, if there is damage to coastal ecosystems of 1 ha, then there will be a loss of CES economic value of mangrove, coral reefs, and seagrass ecosystems of USD 19,066.18, USD 11,303.49, and USD 5,008.36, respectively.

Fisheries product. One of the main benefits of various coastal ecosystems are as a provider of fishery products that can be utilized directly by humans. In this study, the economic value of the type of fishery product quantified as CES is the fishery product that is dominantly utilized by respondents. The value of CES as a provider of fishery products is quite high. The high value of CES can be caused due to the high desire of the community to exploit and utilize natural resources (fish, crabs, shrimp, and shellfish) that live in mangrove ecosystems, coral reefs, and seagrasses to improve people's welfare. This can also be caused by most indigenous Papuans who

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ecosystems, data processing and analysis must still be carried out. To estimate the value of CES that is directly utilized by humans in the form of goods (fishery and firewood products), a market price approach is used [6]. The equation for obtaining the CES value (the formula can be found in the paper).

The replacement cost method is used to determine CES values that do not provide direct benefits to humans such as CES as coastal protection and prevention of seawater instruction, while the benefit transfer method is used to determine CES values such as carbon sequestration and storage, and fish habitats. The benefit transfer method can also be used to determine the value of CES as a provider of biodiversity and bequest services. The existence value of ecosystems is one of CES that does not have a market price, then the Willingness to Pay (WTP) method is used. WTP value collection techniques are carried out using the Contingent Valuation Method (CVM). CVM

are respondents that have jobs as main fishermen and parttime fishermen.

Firewood from mangrove. Only the mangrove ecosystem provides CES as the provision of firewood. Almost all respondents stated that they often use damaged mangrove wood to be used as firewood and only used for household use. According to the results of a study conducted by Rumahorbo et al. [25] that mangrove ecosystem services in Jayapura City as the supply of firewood amounted to USD 54,289.16/year.

Tourism value. Coral reef ecosystems can provide services like the provision of tourism areas. The assessment of coral reef ecosystem services as the provision of tourism areas is carried out by using the results of interviews with dive tour guides. Diving activities are usually carried out once a week (usually on Saturdays) with a number of domestic tourists around 5–10 tourists (an average of 7.5 tourists) with the cost of a diving activity are USD 35.27. Based on these data, it can be obtained that the services of coral reef ecosystems as the provision of tourism areas are USD 12,679.20/year.

Fish habitat. Coastal ecosystems such as mangroves, coral reefs, and seagrass can be used as habitats by various species of fish [29]. The value of CES as a fish habitat can be obtained using the benefits transfer method from the value of the coastal ecosystem as a nursery ground. Based on the results of several studies in Indonesia that the service value of mangrove and

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can be done by asking respondents directly how much they will pay to get better conditions [26]. After getting the WTP value from each respondent, it is calculated to estimate the average WTP using equations: EWTP = WTP total/N, where:

EWTP: Average of WTP; WTP total: The total WTP of all respondents; N: Number of respondents. The next step is to convert the results of the

EWTP into the population WTP by multiplying the EWTP value by the total number of households.

seagrass ecosystems as a nursery ground is USD 2,292.00/ha [6] and USD 1,309.00/ha [30], respectively. While the service of the coral reef ecosystem as a nursery ground refers to Snedaker and Getter [31] that the coral reef ecosystem with an area of 1 km2 has the potential to become a nursery ground of 5 tons of reef fish or 50 kg/ha. The average selling price of reef fish in Jayapura City is USD 1.78/kg (IDR 25,250.00/kg) so that the coral reef ecosystem service as a nursery can be obtained is USD 89.00/ha. So that it can be estimated the service value of mangrove ecosystems, coral reefs and seagrasses in Jayapura City as fish habitat is USD 534,311.04/year, USD 3,341.06/year, and USD 154,076/year, respectively.

Coastal protection. CES as coastal protection is its function to block waves or reduce wave energy that reaches the coastal area. CES as coastal protection is an indirect benefit of mangrove ecosystems and coral reefs where the value can be obtained by using replacement cost from the cost of making waves and erosion resistant embankments. Data on the making embankment retaining the abrasion using standards issued by the Ministry of Public Works of the Republic of Indonesia. The cost of making the embankment with the size of 50 m x 1.5 m x 2.5 m which can be strength until 5 years reached USD 20,594,87 or USD 411.90/meters [32]. Based on this cost, the services of mangrove ecosystems and coral reefs as coastal protection are USD

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1,395,925.74/year and USD 224,789.90/year, respectively.

Carbon Sequestration and Storage. CES as carbon sequestration and storage is an indirect service for mangrove and seagrass ecosystems. Coastal ecosystems that are rich in carbon stocks are mangroves [33,34]; Hong et al., 2017] and seagrass [35-37]. CES as carbon sequestration and storage can be obtained using the benefits transfer method. Based on the results of the study by Rumahorbo et al. [25], mangrove ecosystem services in Youtefa bay, Jayapura City as carbon sequestration and storage amounted to USD 192,324.00/year. The value of seagrass ecosystem services as carbon sequestration and storage can be estimated using the potential value of carbon sequestration by seagrass ecosystems in Indonesia is USD 18.77 tons/ha/year [35]. Seagrass ecosystem services as carbon sequestration and storage are obtained by multiplying the value of the potential carbon sequestration with the carbon price which refers to Diaz et al. [38] for USD 5.50/tons, so the value of seagrass ecosystem services in Jayapura City as carbon sequestration and storage is USD 11,441.54/year.

Prevention of Seawater Instruction. CES as the prevention of seawater instruction is one of the indirect benefits of mangrove ecosystems. The value of mangrove ecosystem services as the prevention of seawater instruction can be approached by using a replacement cost from the

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cost of consuming clean water. Every household in Enggros, Tobati, and Nafri Villages was consuming 1 gallon of clean water every day at a price of USD 0.35 for 1 gallon. Based on this cost, it can be obtained that in one year (365 days), the expenditure of each household is USD 127.75/year, so that the mangrove ecosystem service as the prevention of seawater instruction is obtained at USD 65,663.50/year.

Biodiversity Services. The biodiversity value of CES can be approached using the benefits transfer method, which is by assessing the estimates of the benefits of the same ecosystem biodiversity from other places. Indonesian mangrove forests have biodiversity values of USD 15.00/ha/year [39], while coral reef ecosystems have biodiversity values of USD 2,400.00 to 8,000.00/km2/year [40]. Both biodiversity values can be used in all mangrove ecosystems and coral reefs which are ecologically important and remain naturally preserved. The biodiversity value of coral reefs used is the median value which is USD 5,200.00/km2/year or USD 52.00/ha/year.

Existence Services. One of the CES values in calculating the economic value of a natural resource is the existence value. The service value of the existence of coastal ecosystems can be obtained based on the value of the Willingness to Pay (WTP) of the community for the existence of coastal ecosystems. WTP is a potential useful value generated by natural resources and

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environmental services [41]. Therefore, the WTP referred to in this study is the willingness of the community to contribute or pay to maintain the condition of sustainable coastal resources or for a rehabilitation program to preserve coastal

ecosystems. The average value of respondents' WTP for mangrove and seagrass ecosystems was USD 3.95/year [42] and USD 3.77/year [43], respectively. While the calculation results that the average WTP for coral reef ecosystems is USD 3.38/year. Based on the average WTP, CES values such as mangrove, coral reef, seagrass ecosystems were obtained at USD 2,030.30/year, USD 1,937.78/year, and USD 1,737.38/year, respectively. The high value of the WTP obtained can show that the peoples of Tobati, Enggros, and Nafri Villages give great appreciation for the existence of coastal ecosystems in Jayapura City, Papua Province, Indonesia.

Bequest Services. The inheritance value of coastal ecosystems is one of the CES that can be useful for future generations. According to Ruitenbeek [39] that the bequest value of an ecosystem is not more than 10% of the total direct benefit value. Based on the assumptions, it can be estimated that the bequest value of mangrove, coral reefs, and seagrass ecosystems is USD 204,632.3/year, USD 17,482.93/year, and USD 35,256.5/year, respectively.

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6. Summary of ecosystem factors

Table 9. Summary of ecosystem factors

Ecosystem	Type	No	Service	Indicator	Unit factor	Method
Mangrove	Regulating	1	Carbon sequestration	Above ground and Below ground Organic Carbon; Dried Weight; Soil Sample (bulk density); Total Nitrogen Stock	ton C/ha	Laboratory work
		2	Biomass	Canopy height; Diameter Breast Height (DBH); Dead and Downed Wood Debris (DDWD); Soil cores	meters; %	Quantitative
		3	Biomass	Height (H); Crown Area (CA)	meters; %	Modelling
		4	Hurricane protection	Population; GDP per meter square; Total Damage Cost	numerical	Modelling
		5	Flood protection	Area coverage; Economic value; Temporal data	numerical	Modelling
		6	Storm surge reduction	Monetary value; Area width; Vegetation characteristic; Topography; Bathymetry; Size; Speed of wind	numerical	Modelling
		7	Water purification	Nutrient stock (phosporus and nitrogen); Nutrient stock; Estimated loads in sewages; Time	Kg; year	Modelling
	Provisioning	8	Fisheries contribution	Catch Per Unit Effort (CPUE)	Kg/ha	Quantitative
		9	Raw material	Area and weight of product; Operational cost; Net income	Ha; year; US$/year	Quantitative
	Cultural	10	Cultural usage	Social media photos	descriptive	Geotagging
		11	Tourism	Stakeholders' perception	descriptive	Qualitative
		12	Education/research	Area	Ha	Quantitative
		13	Social value	Stakeholders' perception	descriptive	Qualitative
Coral reefs	Regulating	1	Carbon sequestration	Dissolved Inorganic Carbon (DIC); Total Alkalinity (TA); Abiotic indicator (salinity; temperature; DO; inorganic nutrient)	numerical	Laboratory work
		2	Flood protection	Annual monetary value; Area; Population	US$; ha	Modelling

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		3	Water purification	Mucus; Particulate Organic Carbon (POC)	litre/m2; mmol	Laboratory work
		4	Wave attenuation	Wave energy	%	Qualitative
		5	Wind reduction	Factors affecting wave	numerical	Modelling
		6	Nutrient cycling	CO2 flux	Carbon per year	Laboratory work
		7	Calcification	Partial pressure of CO2 (pCO2); pH; salinity; temperature	numerical	Laboratory work
		8	Pollutant remediation	Water temperature; Nitrate; Nitrite; Ammonium; Phosphate; Monomeric silicate	numerical	Laboratory work
	Provisioning	9	Fisheries contribution	Fish abundance; coral area; Catch Per Unit Effort (CPUE)	Kg/ha	Quantitative
		10	Economic value	Fisheries yield; Coral area; Monetary value	Kg; Km2; US$	Quantitative
		11	Raw material	Number of species	numerical	Qualitative
	Cultural	12	Recreational value	Stakeholders' perception	descriptive	Qualitative
		13	Tourism	Social media image and texts; national data	descriptive	Qualitative
		14	Tourism	Value per visit; Gross Domestic Product (GDP); Purchasing Power Parity (PPP)	descriptive	Qualitative
		15	Aesthetic	Coral pattern; Coral topography; Fish abundance; Water visibility	numeric scale; %; meters	Mixed
Seagrass	Regulating	1	Carbon sequestration	Above ground and Below ground Organic Carbon; Dried Weight; Soil Sample (bulk density); Area	gC/m2; tC/ha/year	Laboratory work
		2	Carbon stock	Organic carbon content; Dead weight	Mt; %	Laboratory work

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	3	Carbon storage	Bulk Density; Loss On Ignition; Organic Carbon Content (Corg); Dry weight; Temperature; Length	Corg; gr; Celcius; cm	Laboratory work
	4	Coastal protection	Depth; Leaf width and length; Aboveground biomass; Shoot elongation rate; Shoot life span; Rhizomes thickness	m; mm; mg; cm/day; days	Laboratory work
	5	Water purification	Water depth; Capacity of the reservoir; Ecological indicators	m; m3; m-2; gr/m2; Celcius	Laboratory work
	6	Pathogen protection	Bacteria abundance	numerical	Laboratory work
	7	Pollutant remediation	Co; Cr and Ni content ratio	µg g-1; gr	Quantitative
Provisioning	8	Fisheries contribution	Biomass	Kg/ha; Kg/ha/year	Mixed
	9	Raw material	Yield of extraction	µg/g; %	Laboratory work
Cultural	10	Recreational value	Expenditure value and seagrass residency index	million Euros	Qualitative
	11	Education/research	Species distribution by satellite image	descriptive	Modelling
	12	Religious	Demographic data	descriptive	Qualitative

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