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Ecosystem service provision by marine habitats in Southeast Asia

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September 2022

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This report has been prepared as part of a research programme, funded by the Global Challenges Research Fund (GCRF), via the delivery partner Research and Innovation (UKRI), under grant agreement reference NE/P021107/1 to the Blue Communities research programme.

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Suggested citation:
Broszeit, S., Hattam, C., Langmead, O., Praptiwi, R.A., Creencia, L., Then, A.Y.H., Lin, V.-C., Hau, T.D., Edwards-Jones, A., Austen, M.C. et al. 2022. Ecosystem service provision by marine habitats in Southeast Asia. PML Publishing, Plymouth, UK. 121pp. doi: 10.17031/qte-y357

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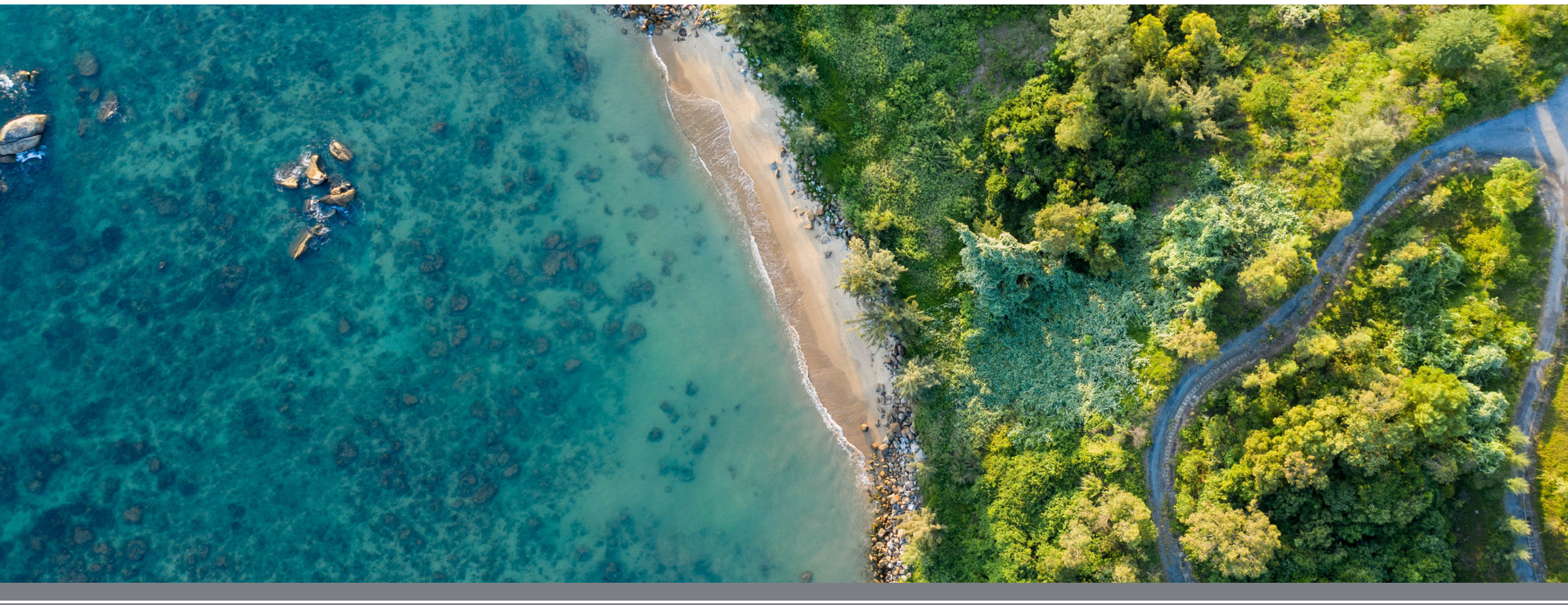


Acronyms

ASEAN	Association of Southeast Asian Nations
C	Carbon
CSP	Case study partner
Kg	Kampung, which means village in Malay language
LRFT	Live reef fish trade
MEA	Millennium Ecosystem Assessment
pers. comm.	personal communication with an expert
pers. obs.	personal observation of a co-author of the study
SE Asia	Southeast Asia
ha	Hectare
Mg	Megagram
t	Metric tonne
Tg	Teragram
yr	Year

Glossary

Charismatic species is a poorly defined term (Ducarme et al., 2013) but here we consider it as all species that may attract visitors to a certain place.

Ecosystem services are the contributions ecosystems make to human well-being while still being connected to the underlying ecosystem functions, processes and structures (Haines-Young* & Potschin 2013).

Ethnic groups referred to in the study area:

Kagayan	Live in the Philippines and Sabah, Malaysia
Suluk	Live in the Philippines, Malaysia and in Kalimantan, Indonesia, (but not in the Indonesian study region).
Ubian	Live in the Philippines, and Sabah, Malaysia.
Bajau Pelauh	Nomadic, seafaring people living in the Philippines, Malaysia and Indonesia.

Foreword by Aimee Gonzales, Executive Director of Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)

The importance of marine and coastal ecosystems to the livelihoods of millions of people in Southeast Asia is well described. The ecosystem services concept provides a holistic view of the relationships between the ecosystems and their human users.

However, the links between human well-being and ecosystems need further evidence if the ecosystem services concept is to be used to underpin policy and management.

This report is the result of a thorough assessment of the available scientific literature, as well as regional reports, on marine and coastal habitats and the services they provide in Southeast Asia. It is also informed by local and regional expert opinion from the Philippines, Viet Nam, Malaysia and Indonesia as well as expert input from the UK. The report will be useful to managers, policy makers and communities using these ecosystems.

It highlights the importance of Southeast Asia's marine and coastal habitats in providing livelihoods through local to global services such as erosion control, maintenance of nursery habitats, food provision and climate regulation. These habitats are also vital for cultural services that provide non-material benefits to people. They contribute to a sense of place, foster social cohesion, create and share knowledge and are essential for human health and well-being.

The report also draws attention to services and habitats that are less well studied and therefore deserve more scientific attention. By providing key evidence for the links between habitats and their provision of services, this report can help shape sustainable management approaches of marine and coastal ecosystems in Southeast Asia and beyond by highlighting the many services they provide. It will also help align their use and management with the PEMSEA goal of fostering and sustaining resilient oceans, coasts, communities and economies.

May 2021

Keywords

marine ecosystem services | marine habitats | ecosystem service matrix
confidence scores | evidence gaps

Executive summary

Southeast Asia is an area of rich marine biodiversity providing a host of ecosystem services that contribute to the well-being of coastal communities and beyond. Sustainable management of ecosystems and the services they provide requires a good understanding of their underlying ecological functions and processes. This understanding can be gained through the rigorous assessment of studies identifying and quantifying ecological functions and ecosystem services.

The aims of this study were to review the ecosystem services provided by marine and coastal habitats in Southeast Asia. The ecosystem service potential was scored for each habitat. The review was focused on nine key marine and coastal habitats, identified across four case study sites in Southeast Asia, contributing 18 marine relevant ecosystem services. The approach comprised a literature review supplemented with observations from experts from the case study areas. The four case study sites consist of three Man and Biosphere Reserves in Southeast Asia: Palawan in the Philippines, Cu Lao Cham- Hoi An in Viet Nam, Take-Bonerate Kepulauan Selayar in Indonesia, and a recently gazetted marine protected area, the Tun Mustapha Marine Park in Malaysia (*Figure 1*).

The nine key habitats (eight benthic and one pelagic) covered in this review, identified as highly relevant for most case study sites, were mangrove forests, coral reefs, seagrass meadows, sand, mud, rock, coarse substratum, pelagic and modified habitats. Further division of these habitats into sub-habitats on the basis of biological type and substrate type was used to capture data on differential provision of ecosystem services within the broad habitat types.

To ensure relevance in the four case study sites, firstly an ecosystem services typology was created tailored to these sites. After exploring several ecosystem service typologies, our final classification was adapted from the Common International Classification of Ecosystem services (CICES) V4.3 because it was considered to be most relevant to the objectives of this task. Provisioning, regulation and maintenance, and cultural services were assessed.

Provisioning services focused on food for consumption by humans from plants, pelagic animals, demersal fish and invertebrates; energy from harvested plants; other materials from plants and animals, such as fibres, building and housing materials, medicines, decoration, handicrafts and souvenirs; and genetic material from plants and animals (including seeds, spat, spores, whole plants or animals, individual genes), for example seed or brood-stock collection for aquaculture and mangrove replanting and new plantations.

Regulation and maintenance services assessed were treatment and assimilation of wastes or toxic substances; coastal erosion control; water flow regulation contributing to dampening the intensity of storm, floods, tsunamis, and hurricanes and the maintenance of localized water flows such as coastal current structures; maintenance of nursery, reproduction and feeding habitats; maintenance of critical habitats for charismatic species such as turtles, dugongs, cetaceans, sharks, seahorses, bats, fireflies, birds, monkeys, orchids and other epiphytes; and climate regulation through impacts on the hydrological cycle, temperature regulation, and the contribution to regulation of climate-influencing gases in the atmosphere, for example through carbon sequestration and long-term, decadal storage.

Cultural services examined included uses of habitats as places for active and passive recreation; ceremonial activities; creative activities; and knowledge-based activities, such as educational activities, and citizen science or community environmental activities.

The comprehensive literature review included peer-reviewed scientific research literature as well as grey literature such as government and other reports. To ensure a wide breadth of coverage, the research focused on studies from Southeast Asia. When no evidence was found in the literature, evidence was sought from experts, and where useful, was accompanied by observations from the authors in their respective case study sites.

The evidence gathered was used to assess the potential of each habitat to provide an ecosystem service, rather than to assess the actual provision of ecosystem services from each case study site. This important distinction allows the differentiation between services provided by the ecosystem (i.e. the potential supply of ecosystem services that a habitat could deliver) and (achieved or used) benefits (i.e. the demand for ecosystem services).

The knowledge gained from the literature, local and regional reports, together with observations from the study team and experts, was critically assessed using a robust methodology that captured different types of information together with a confidence score for the supporting evidence. The contribution of each habitat to each ecosystem service was then scored relative to other habitats. Our objective was to provide baseline information to enable better understanding of the ecosystem services arising from marine and coastal habitats in SE Asia. This provides a foundation for future assessments of natural capital and ecosystem services which may be used to inform sustainable management.

The report will serve as a useful reference to many different readers. Regulators, managers of marine sites and policy makers might use this report to inform their management choices. This should enable more sustainable use of the marine environment and maximise the ecosystem service provision of all types of services addressed in this study. Stakeholders of the marine environment such as fisherfolk or residents might use this report to help them engage in management processes, to gain deeper understanding of the marine environment or confirm their observations of the marine environment. Academics can use it as a reference source or a base for further studies, in particular for valuation studies or when considering the trade-offs between ecosystem services in marine and coastal habitats. Finally, it is hoped that this report may bring a new appreciation and understanding of the marine environment and the life support it provides to society and inspire readers to improve management of the marine environment.

This report is one of the outputs of the UK Research and Innovation's Global Challenges Research Fund (UKRI GCRF) Blue Communities Programme (GCRF Blue Communities Global Challenges Research Fund via the United Kingdom Research and Innovation (UKRI) under grant agreement reference NE/P021107/1, *www.blue-communities.org*), which aims to "build capacity for sustainable interactions with marine ecosystems for the benefit of the health, well-being, food security and livelihoods of coastal communities in SE Asia". GCRF Blue Communities is developing interdisciplinary research capability and lasting collaborations that can facilitate innovative application of integrated planning in the marine environment and respond to the UN Sustainable Development Goals of 'no poverty', 'zero hunger', 'good health and well-being' for coastal communities as well as 'conserve and sustainably use the oceans, seas and marine resources for sustainable development' through the sustainable use of marine resources.

Key messages

- The review provides information that allows exploration of the interactions between tropical marine habitats and their potential to supply ecosystem services.
- It is the first of its kind across all major tropical marine habitats and can provide a baseline for management of these tropical habitats and the services they provide.
- Mangroves, coral reefs and seagrass beds were the most studied habitats while rocky and sedimentary habitats, the pelagic and artificial habitats were less often addressed in the literature.
- Mangroves have the potential to provide the largest diversity of ecosystem services and were also often considered the most important contributing habitat to each ecosystem service assessed in this study.
- Provisioning services have been the most studied ecosystem services.
- Cultural services were strongly interlinked with each other and with other services, for example, the act of gathering provides both food and cultural benefits.
- Few modified habitats provide a high potential for any ecosystem services and usually the service they provide was linked to the reason that they were built, for example seaweed farms have high potential to provide seaweed products (both food and other materials) but for most other services the potential is low.

1. Introduction

This report provides an overview of the available evidence for the links between tropical marine habitats and the provision of ecosystem services. It forms one of the outputs of Project 3 "Impacts on Ecosystem Services and Values" of the Global Challenges Research Fund, Blue Communities Programme (grant number: NE/P021107/1). GCRF Blue Communities aims to "build capacity for sustainable interactions with marine ecosystems for the benefit of the health, well-being, food security and livelihoods of coastal communities in SE Asia". It focuses on four case study sites in SE Asia: Palawan, Philippines; Taka Bonerate Kepulauan Selayar, Indonesia; Cu Lao Cham, Viet Nam and Tun Mustapha Park in Sabah, Malaysia, the first three sites being UN Man and Biosphere Reserves, the latter being part of the largest multiple use marine park in Malaysia (Figure 1). The sites were chosen to reflect marine parks in which human use is limited by regional regulations aiming to achieve sustainable use. One site also contains some urban coastal space (Puerto Princesa City, Palawan).

GCRF Blue Communities is developing interdisciplinary research capability and lasting collaborations that can facilitate innovative application of integrated planning in the marine environment and respond to the UN Sustainable Development Goals of 'no poverty', 'zero hunger', 'good health and well-being' for coastal communities as well as 'conserve and sustainably use the oceans, seas and marine resources for sustainable development' through the sustainable use of marine resources. It aims to provide a research base that supports planning in the marine environment (marine planning) through a novel integration of ecosystem services, ecosystem valuation (monetary and non-monetary), ecological public health, and governance approaches.

Project 3 contributes to this overall aim by spatially defining what ecosystem services are delivered by each case study site, their uses and the pressures upon them. This report focuses specifically on ecosystem service delivery of marine habitats in SE Asia to ensure it can be applied to the case study sites.

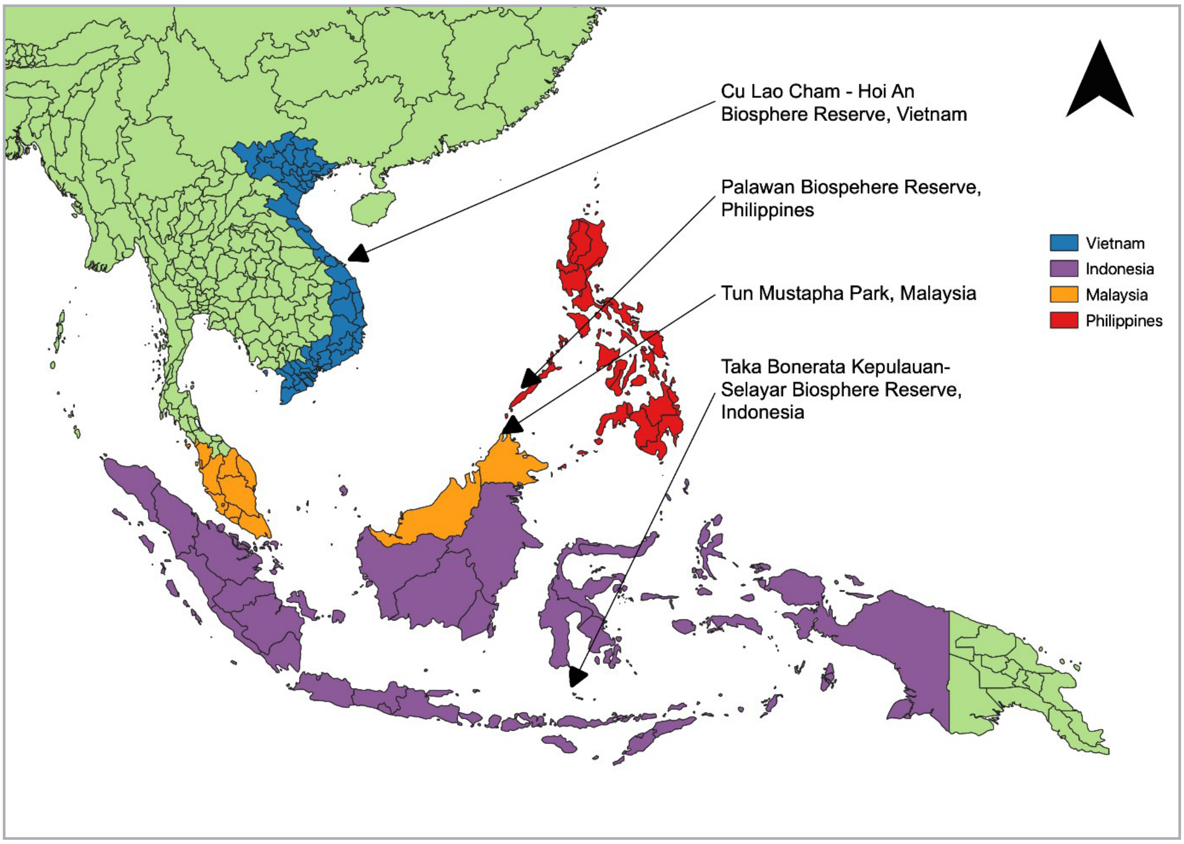


Figure 1: Case study sites in the study area. The map was created with shapefiles publically available from www.cdc.gov/epiinfo/support/downloads/shapefiles.html using QGIS (www.qgis.org).

1.1. Background

Humans depend on ecosystems, including marine ecosystems, for their sustenance, health and well-being (MEA*, 2005). In recent decades, the ecosystem service concept has been developed to capture the complexity of ecosystems and the linkages between human and biophysical systems (Inniss et al., 2017). Ecosystem services are provided through the numerous interactions of biotic and abiotic components of ecosystems (MEA*, 2005; TEEB*, 2010). By taking a holistic ecosystem service approach, the aim is to inform management choices by ensuring the recognition of all ecosystem services (including regulating and cultural services) (Broszeit et al., 2019; Cavanagh et al., 2016); overcome the shortcomings of single sector approaches (Agardy et al., 2017) and enable more sustainable natural resource and ecosystem use. In addition, the approach is a useful communication tool for stakeholders and can inform political debate (Agardy et al., 2017).

The Millennium Ecosystem Assessment (MEA*, 2005) split ecosystem services into four types: provisioning, regulating, cultural and supporting. Provisioning services include provision of food, fire wood, fibre, some natural chemicals and dyes amongst others; regulating services include for example bioremediation of waste, climate regulation or coastal protection and cultural services include aesthetic, spiritual experience and recreation (MEA*, 2005). Finally, examples of supporting services in the MEA* are primary production, or nutrient cycling (MEA*, 2005).

Since the MEA* (2005) the concept of ecosystem services has been developed through initiatives such as “The Economics of Ecosystems and Biodiversity”(TEEB*, 2010), and intergovernmental panels including the Intergovernmental Panel on Biodiversity and Ecosystem services or IPBES (Díaz et al., 2015). In an attempt to standardise ecosystem service classification, the European Union Environmental Agency has created the Common International Classification of Ecosystem Services, CICES (Haines-Young* and Potschin, 2013). International organisations such as the UN, World Bank, The Nature Conservancy, and governments such as the UK and the US now use the ecosystem service approach in their environmental assessments (Inniss et al., 2017). Ecosystem services can be considered to be a “common currency” supporting assessments and decision-making across landscapes and seascapes at different scales (Townsend et al., 2011).

There are several ways to assess the provision of ecosystem services by habitats ranging from quantitative modelling approaches to qualitative assessments based on expert judgement, each with their own limitations. Here we apply a literature review approach as they are particularly useful in data-poor situations, like many tropical marine locations. Qualitative assessments describe the linkage between particular habitats or species and the services they provide but do not aim to quantify these links. This approach is valuable because it represents the connectivity and importance of species or habitats to human well-being that stakeholders and decision makers may otherwise not have been aware of. For example, mangroves may be seen as less valuable than sandy beaches (when only considered as a tourist attraction) but provide a greater contribution of regulating services such as coastal erosion protection and climate regulation.

Numerous assessments of marine ecosystem services in temperate regions have been undertaken over the past decade with the majority being done in North America and Europe (Liquete et al., 2013). Examples include the UK’s National Environment Assessment (covering all ecosystems) (NEA*, 2011), and selected marine case studies (Hattam et al., 2015). Different approaches have been used, such as the creation of conceptual models (e.g. Broszeit et al., 2019), mapping of ecosystem services (e.g. Mongruel* et al., 2015) or matrix approaches (e.g. Geange et al., 2019; Potts et al., 2014) where ecosystem services provided by specific habitats were analysed respectively. Only a small number of qualitative reports have been prepared for tropical marine habitats such as the Maldives and Ascension Island (e.g. Agardy et al., 2017; La Bianca* et al., 2018 respectively). TEEB (The Economics of Ecosystems and Biodiversity, (*teebweb.org*)) has two initiatives currently, one for SE Asia (Brander* and Eppink, 2012) and one in the Philippines (TEEB*, 2020), both also assess terrestrial ecosystem services.

Using a matrix approach, this report contributes to the body of knowledge on tropical marine ecosystems, providing a semi-quantitative assessment of ecosystem service provision in tropical marine habitats of SE Asia. It first describes the matrix approach and how the ecosystem service assessment was undertaken (*section 1.2*). This includes a definition of each of the ecosystem services assessed, the habitat classification used, and the approach taken to allocate an ecosystem service potential score to each habitat. This is followed by a compilation of the evidence used to score the potential of each habitat to provide each ecosystem service. Natural habitats are presented first (*section 2*), followed by artificial habitats (*section 3*). For each habitat the evidence supporting how it provides each service is presented, followed by the assigned ecosystem service potential score. Where no evidence was found for a particular habitat-ecosystem service linkage, this is noted.

1.2. Methods

We used a matrix approach to provide semi-quantitative information on particular habitat- ecosystem service linkages. Evidence from the literature, observations and expert opinion were used to examine the provision of ecosystem services from different habitats. We scored potential provision reflecting the importance of each habitat to each ecosystem service in relation to the other habitats. To ensure comparability and allow the identification of the quality of information found, we gave a confidence score to each potential ecosystem service score reflecting the level of uncertainty in the evidence used to define this score. Further information on the methodology can be found in Hattam et al. (2021).

1.2.1. Ecosystem service descriptions

Ecosystem services relevant to marine tropical areas in SE Asia were defined based on CICES V4.3 (Haines-Young* and Potschin, 2013) and TEEB classifications (TEEB*, 2010). Following discussion among the project team (natural and social scientists from the Philippines, Indonesia, Malaysia, Viet Nam and the UK), these definitions were then modified where necessary to better reflect SE Asian and local case study conditions (*Table 1*). Unlike CICES, which differentiates between provisioning services derived from farmed versus natural environments, we combine these provisioning services and differentiate between the habitats from which they are provided instead (i.e. natural versus modified habitats); see *section 1.2.2*. Drawing upon Fish et al. (2016) cultural ecosystem services were updated to better reflect their relational nature (i.e. that they are co-produced outputs from human-nature interactions; (Chan et al., 2012)) and how the different habitats provide a place for cultural interactions.

Table 1: Description of relevant marine ecosystem services assessed

Section	Category	Subcategory	Description
Provisioning	Food	From plants	Food for consumption by humans from harvested plants e.g. edible products from mangroves and nipa.
	Energy	From plants	Energy source from harvested plants e.g. mangrove wood for charcoal. Fossil fuels are excluded from this definition.
	Other materials	From plants	Fibres or other biotic material from harvested plants used for other purposes, including building materials, medicine, decoration, fashion, handicrafts, souvenirs, etc. e.g. products harvested from mangroves and nipa.
	Food	From pelagic animals	Food for consumption by humans from pelagic animal species (fish, squid etc.) from wild capture fisheries and aquaculture.
	Food	From demersal fish	Food for consumption by humans from demersal fish species from wild capture fisheries and aquaculture.
	Food	From invertebrates	Food for consumption by humans from other invertebrate species (e.g. crustaceans, sea cucumbers and molluscs, but excluding squid) from wild capture fisheries, gleaning and aquaculture.
	Other materials	From animals	Fibres or other biotic material from harvested animals used for other purposes, including medicine, decoration, fashion, handicrafts, souvenirs, e.g. wild harvested and cultured pearls, sea shells.
	Genetic material	From plants and animals	Genetic material from marine plants and animals (including seeds, spat, spores, whole plants or animals, individual genes) for use in non-medicinal contexts, breeding new strains or varieties, construction of new entities (from genes), e.g. seed or brood-stock collection for aquaculture; mangrove seedlings/seeds/cuttings for plantations and mangrove replanting.

Section	Category	Subcategory	Description
Regulation & Maintenance	Treatment and assimilation of wastes or toxic substances		The removal of contaminants and organic nutrient inputs of human origin, including sewage waste and other wastes (e.g. heavy metals, agri-chemicals and other pollutants). This also includes the removal of bacteria and viruses (e.g. *E. coli*), that may impact either humans or flora and fauna that provide a service to humans.
	Erosion control		The contribution of a particular component of the marine ecosystem to coastal erosion prevention and sediment retention (also including sediment stabilisation).
	Water flow regulation		The contribution of a particular component of the marine ecosystem to the dampening of the intensity of environmental disturbances such as storm, floods, tsunamis, and hurricanes and the maintenance of localized water flows such as coastal current structures. It is recognised that tsunamis behave differently to wind and tidally formed waves and that nothing will stop some tsunamis.
	Maintaining nursery habitats		The provision by a particular component of the marine ecosystem of critical habitat for reproduction and juvenile maturation (e.g. nursery and feeding functions).
	Maintaining habitat for charismatic species		The provision by a particular component of the marine ecosystem of critical habitat for different charismatic species as a shelter, feeding habitat or a resting place during migration and that are or could be managed for the presence of these species (e.g. turtles, dugongs, cetaceans, sharks, seahorses, bats, fireflies, birds, monkeys, orchids and other epiphytes).
	Climate regulation		The contribution of a particular component of the marine ecosystem to the maintenance of a favourable climate through impacts on the hydrological cycle, temperature regulation, and the contribution to climate-influencing substances in the atmosphere (e.g. carbon sequestration and long-term, decadal storage).
Cultural	Places for recreation		Places that are used for recreational activities by visitors (tourists) and residents. The activities can be both active (such as SCUBA diving or passive such as bird watching)
	Places for ceremonial activities		Places where customs, rituals and or religious activities occur and/or are significant for local beliefs.
	Places for creative activities		Places where the collection of objects/materials or experiences important for crafts and creative processes occur.
	Places for knowledge-based activities		Places that are used for educational activities (e.g. visits by school children to learn about a site), for citizen science or community environmental activities (e.g. reef monitoring, mangrove planting and monitoring).

Some definitions of ecosystem services needed to be adjusted after discussions with colleagues, to ensure relevance.

Provision of genetic material was extended in this study to include broodstock used for aquaculture. While this is beyond the definition of CICES 4.3 it became clear that collecting broodstock, eggs or larvae to grow in aquaculture settings is an important service used extensively in SE Asia which was not covered by the nursery habitat service and that this information may have been lost if it was not captured in this way.

In regulating services, the service of pest and disease control was removed. Disease control in the marine environment is closely linked to bioremediation of waste. For example, coliform bacteria will be cleared out of the water column by filter feeders or buried in mud, similarly to waste particles. Although pest species such as invasive alien species can heavily impact coastal and marine habitats in SE Asia (Wu* et al., 2018), how habitats contribute to the reduction or management of these species was not evident in the literature. This is also evidenced in the IPBES regional assessment report which states that knowledge on invasive alien species is patchy and geographically biased (towards Australia) (Wu* et al., 2018). Also, while pollution does negatively affect the potential provision of ecosystem services of a habitat, this effect is not considered here because the effect of pressures on ecosystems and the services they provide will be assessed in a separate piece of work.

The two cultural services of ‘places for recreational activities for residents’ and ‘places for recreational activities for tourists’ were combined into one service. Firstly, a lack of disaggregated data made distinctions difficult. It does mean, though, that this output may need careful evaluation when applied to a certain habitat. For example, some habitats are used for recreation mostly by tourists and tour operators may come from outside to guide tourists. In such cases the ecosystem service of recreation for tourists is not beneficial to residents.

The term “charismatic species” is not well described. One issue is that species that may seem charismatic to tourists can be dangerous (e.g. crocodiles in mangroves) or a nuisance to residents (Ducarme et al., 2013). For this report, a list of charismatic species was created that included a selection of species known to function as tourist attractions in the case study sites but it is not considered exhaustive (*Table 2*). These species are all found in the habitats studied here whereas terrestrial species listed can be found in mangroves in SE Asia.

Table 2: List of marine and coastal charismatic species

Broad group	Examples
Plants (marine)	Seaweeds, ‘red tide’ phytoplankton, mangrove trees
Plants (terrestrial)	Orchids, other epiphytes, pitcher plants, cashew, almaciga, many endemic hardwoods, coconut
Reptiles (marine)	Sea snakes, sea kraits (*Laticauda* sp.), saltwater crocodile, turtles,
Reptiles (terrestrial)	Crocodiles, tortoises, monitor lizards, snakes
Mammals (marine)	Otter, dugongs, whales, dolphins, porpoise
Mammals (terrestrial)	Bats, monkeys, tarsiers (small primate), pangolin, Palawan bearded pig, Palawan bearcat, Palawan leopard cat, flying squirrel, common palm civet, Calamian deer, Balabac mouse-deer, porcupine
Birds	Eagles, terns, owl, cockatoo/parrot, Palawan peacock pheasant, talking myna, Palawan hornbill, Palawan scops owl, Palawan flycatcher, woodpecker, swiftlets
Fish	Sharks, especially whale sharks, manta rays, barracuda, seahorses, Napoleon or Humphead wrasse, frog fish, lionfish, marlin, groupers, tuna, mudskippers
Invertebrates (marine)	Corals, crabs, sea urchin, octopus, crown of thorn, giant clams, abalone, pearl oyster
Invertebrates (terrestrial)	Fireflies, butterflies, earth worms, honeybees

1.2.2. Habitat types

No standard and accepted habitat classification exists for tropical marine habitats. Taking an approach similar to the European Nature Information System (EUNIS (EEA*, 2019)), nine habitats (eight benthic and one pelagic) were described that are relevant to the case study sites: mangrove forests, coral reefs, seagrass meadows, sand, mud, rock, coarse substratum, pelagic and modified habitats (*Table 3*). Habitats were divided into sub-habitats (macro- and micro-habitat level where appropriate) on the basis of biological type (largely related to depth) and substrate type. This enabled the capture of differential provision of ecosystem services within the broad habitat types, e.g. provision of space for recreational use is much greater by sandy beaches than for subtidal sand. Sand, mud, rock and coarse habitats were split into intertidal and subtidal. Other habitats were also initially split as appropriate for the region, for example different types of coral reef sub-habitats were included in the assessment. However, not enough evidence was found to support information on sub-habitats and so only sand and mud were split into intertidal and subtidal sub-habitats. All habitats and sub-habitats are described below (*Table 3*).

Rock is an abiotic habitat on which species can grow and for the most part the focus was on the animals and plants living on rock surfaces that provide a service. In erosion control however, we decided to compare rock to coral reefs because, although in the former case it is an abiotic service, because the rock itself is not alive like a coral reef, the ecosystem service is still delivered. On the other hand, although rock contributes to the carbon cycle and therefore could be considered as contributing to climate regulation, it was felt that this particular service is not provided at a measurable scale within a timeframe which would be useful for management decisions.

Modified habitats (e.g. fish cages, seaweed farms and artificial structures such as jetties and pontoons) were included separately within the habitat classification. Modified habitats were defined as habitats that had artificial substrata introduced (*Table 3*). Intertidal clam culture and mangrove plantations were therefore not included as modified habitats, as no artificial structures are introduced in either case. While areas are seeded or planted, there are no new habitat types introduced through artificial structures, and functionally they are similar to their unmanaged 'wild' habitats. Clam culture and mangrove plantations are thus included within intertidal mud and mangrove forests respectively. Shrimp ponds which are a dominant feature in SE Asia are found in estuarine mangroves rather than coastal and were therefore omitted. To ensure this work is applicable to the case study sites and to use expert knowledge of the study teams, focus was on those modified habitats that occur in the case study regions. This report focuses on ecosystem services rather than pressures, including those caused by modified habitats; pressures are assessed in a follow-on study which is currently in preparation. *Tables 3a* and *3b* detail the habitat types included in the study.

Table 3a: Natural habitats

Habitat	Macro-habitat	Description	Sub-habitat	Description
Mangrove - including mangrove plantations	Fringe		Monotypic	
			Mixed	
	Basin		Monotypic	
			Mixed	
	Riverine/ estuarine		Monotypic	
			Mixed	
Coral reef	Hard corals	>1% hard coral cover (Mumby and Harborne, 1999)	Branching corals	Branching corals include *Acropora* sp. and non-*Acropora* branching corals, digitate and *Millepora* sp. (=fire) corals
			Massive corals	Massive corals are characteristically ball- or boulder-shaped and relatively slow-growing. Because they have very stable profiles, massive corals are seldom damaged by strong wave action unless they are dislodged from their holdfasts. This includes brain and mushroom corals.
			Sub-massive and mixed coral communities	Submassive corals have knobs, columns or wedges protruding from an encrusting base. This category includes table (table-like structures of fused branches), foliose (broad plate-like portions rising above the substrate), *Heliopora* sp. and encrusting corals
	Soft corals	Bare substratum dominated by soft corals, organ pipe (*Tubipora* sp), leather (*Sarcophyton*), gorgonians etc.)		
	Macroalgae	>50% macroalgal cover (and <1% coral cover). This category does not include turf or coralline algae (Mumby and Harborne, 1999)		
	Coral rubble	Mobile dead coral: reef rocks between 0.5cm and 15cm in diameter (Hodgson* et al., 2006)		
	Dead coral	Recently killed coral in growing position: appears fresh and white or overgrown by algal turf but with coralline structures still recognisable (Hodgson* et al., 2006)		
	Other organism assemblages	This category has <1% hard coral and may include sponges, zoanthids, ascidians, clams, *Actiniaria, allimorpharia*, Echinoidia etc) Corallimorpharia, Echinoidia etc)		

Habitat	Macro-habitat	Description	Sub-habitat	Description
Seagrass	Intertidal to shallow (<5m)		Dense monotypic	
			Dense mixed	
			Thin monotypic	
			Thin mixed	
			Patchy monotypic	
			Patchy mixed	
	Deep (>5m)		Dense monotypic	
			Dense mixed	
			Thin monotypic	
			Thin mixed	
			Patchy monotypic	
			Patchy mixed	
Sand	Intertidal		Steep beaches	
			Flat beaches	
	Subtidal			
Mud	Intertidal			
	Subtidal			
Rock (incl. limestone, bedrock, beach rock etc.)	Intertidal			
	Subtidal			
Coarse substratum (gravel, pebbles, dead coral banks)	Intertidal			
	Subtidal			
Pelagic	Photic zone			
	Aphotic zone			

Table 3b: Modified habitats

Habitat	Macro-habitat	Description	Sub-habitat	Description
Modified habitat	Seaweed farms	Seaweeds are grown from germlings that are attached to cultivation lines connected to buoys or poles and anchors. These structures may cover extensive shallow coastal areas, particularly in the Asia-Pacific region (Chung et al., 2017). The habitat therefore is created by both the seaweeds growing on ropes and the ropes and other structures		
Modified habitat	Fish cages	Fish cages are used for the marine culture of finfish. Small fish are grown on to a harvestable size, fed on either pellets or wild caught fish. In Viet Nam and Philippines finfish cages are often located over coral reefs as they both require good water quality and sheltered conditions (Hedberg et al., 2015; Hedberg et al., 2017)		
Modified habitat	Invertebrate aquaculture farms such as pearl, mussel farms or shrimp ponds	Invertebrate aquaculture structures can take many different forms such as ponds in or near mangroves or long lines attached to buoys in the case of pearl oyster farms		
Modified habitat	Artificial structures (e.g. jetties, pontoons, seawalls, breakwaters etc.)	Structures that have been constructed for either access or to prevent flooding and reduce erosion		
Modified habitat	Artificial beaches and beach nourishment	Areas where additional substrate has been brought to the coast and changed the geomorphology of the location.		

1.2.3. Literature search

A comprehensive literature review was carried out that included peer-reviewed scientific research literature as well as grey literature such as government and other reports (e.g. from non-governmental organisations). When no evidence was found in the literature, evidence was sought from experts working in this region, identified through their publications or other outputs, some of whom are co-authors on this report. Further information was gathered through observations made by the authors in their respective case study sites. If co-authors provided information, this is shown in the document as (name, pers. obs.) while evidence gathered from colleagues outside of the GCRF Blue Communities programme is displayed as (name, pers. comm.).

Evidence gathered focused on the potential of each habitat to provide an ecosystem service, rather than the actual provision of ecosystem services from each case study site. This distinction is important because it allows the differentiation between services provided by the ecosystem (i.e. the potential supply of ecosystem services that a habitat could deliver) and (achieved or used) benefits (i.e. the demand for ecosystem services).

Several targeted literature reviews were undertaken using the search engines Web of Science and Google Scholar. The search terms were structured in the following manner: “habitat” AND “ecosystem service” where “habitat” stands for each of the habitats addressed in this study (including the subcategories of habitats) and “ecosystem service” stands for each of the 18 ecosystem services. For habitats that occur in both freshwater and marine environments, the search terms were extended to include “AND marine”. If the habitat is also found in temperate or polar regions the term “AND tropical” was added (for example sand or mud habitats).

All studies providing evidence from SE Asia were assessed, the SE Asia subregion was considered to include areas that are geographically south of China, east of the Indian subcontinent and north-west of Australia. Evidence was predominantly identified in English, although evidence was also sought from local and regional reports in Vietnamese, Malay and Indonesian. Grey literature used in this report is identified through the use of an asterisk after the first author.

1.2.4. Scoring of ecosystem service potential of each habitat

Once the literature research was complete, each case study team assessed the evidence collected and discussed which score to give to each ecosystem service-habitat relationship (*Table 4*) based on the evidence provided and their own expertise. The UK team assessed the literature evidence only, given the lack of case study specific expertise within the UK team. To ensure that scores are relevant across SE Asia our aim was to assess not the actual provision but the potential provision. The scores are related to the ecosystem services provision within the range of habitats discussed and not based on the extent of a habitat or the biomass of a particular fishery. The scores therefore represent the diversity of different contributions a habitat provides to a particular service. If a habitat provides several species to collect or observe this will lead to a higher score within the range of habitats it is compared to. In this way, after assessing all evidence from the literature, the teams decided which habitat had the highest score and which one the lowest. After these two habitats were identified the other habitats were ‘measured’ against these two habitats. The case study teams used their personal knowledge of their case study sites in discussions to come to a solution and each team collectively agreed on one score for each habitat-ecosystem services link.

Scores allocated by each team were compared during a two-day workshop (August 2019). The workshop aimed to explore similarities and differences between scores and to identify whether a standardised score across all case study sites would be possible. During the workshop, groups were formed with at least one member from each case study site. Each of these teams assessed a set of ecosystem services. In general, scores were similar across case studies. Where differences emerged, these were discussed to ensure mutual understanding of the ecosystem service and the evidence base. Where necessary, scores were then adjusted. For the majority of ecosystem services-habitats links, a common score could be agreed upon. Where disagreements persisted, this was noted, and the information is presented in the final score matrix. A confidence score was then allocated to each ecosystem potential score and the justification for each score was recorded. For ceremonial activities, no good way to score this service was found because it is highly location specific and dependent on local traditions and practices. Therefore, this service was marked as present or absent only, rather than scoring it.

Once all the scores and additional information provided during this meeting were incorporated in this document, the scores were sense-checked by the UK team to ensure each potential score and confidence score reflected the evidence. The full report was then sent out for peer review to provide an additional sense check for the scores given and to ensure the accurate representation of the evidence gathered. The peer review was carried out by Dr Paul Somerfield (PML, UK), Dr Natasha Bhatia (NTU, Singapore), Dr Justine Saunders (ETH, Switzerland) and Dr Lydia Teh (UBC, Canada).

1.2.5. Assessment of each service

Each service was assessed and scored even where there were overlaps with other services. This was in order to give as full an assessment as possible (while not valuing individual services), although we accept that this may seem like double counting to some practitioners.

1.2.6. Definitions of ecosystem service potential score values and confidence scores

Ecosystem service scores (*Table 4*) reflect the potential of a particular habitat to provide the ecosystem service assessed in relation to the other habitats identified (Table 2). Scores ranged from 0 (no relative potential) to 3 (high relative potential). A score of 0 was rarely allocated as it was assumed that most habitats would provide some level of service, even if very small.

Table 4: The scoring scale used in this report

3	High relative potential
2	Medium relative potential
1	Low relative potential
0	No relative potential
NA	Not applicable, for example pelagic ecosystems do not provide erosion control

Each ecosystem service potential score also received a confidence score to communicate the level of uncertainty in the evidence base. To ease comparability among ecosystem service-habitat linkage scores, confidence scores definitions were standardized (*Table 5*).

Table 5: Confidence score definitions used in this study

Score	Definition	Explanation
3	Strong, consistent evidence and/or intuitive scientific support.	Most likely to be supported by extensive published material (both peer reviewed and grey literature). High level of agreement among sources and/or united scientific support. If it is intuitive and unchallenged by other scientists, united expert opinion can also carry high confidence. This may also be supported by local observations and information from other regions.
2	General scientific support, but some uncertainty.	There may be some published material, although some may be from grey literature. Some disagreement among sources. Evidence available is more limited. There may also be some observations from the study team.
1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence.	Published material may not exist or may be limited/inconsistent. Expert opinion maybe the only evidence available. There may be disagreement among sources or expert opinion is particular to an individual expert rather than widely held.
Blank	There is no evidence for a link.	

The final scores for each habitat and ecosystem service after the review and communal scoring can be found in *Table 17*, *Section 4*.

2. Natural habitats

Natural habitats assessed in this study were selected because they occur in the case study sites. They include unaltered and managed habitats as long as no artificial substrata are included (these are in *Section 3,* modified habitats). Therefore clam culture and mangrove plantations are included in this section.

2.1. Mangroves and mangrove plantations

Mangroves are distinctive tidally-influenced tropical and subtropical wetland ecosystems consisting of tidal forests made of trees, shrubs, epiphytes and ferns (Tomlinson, 2016). Mangroves are found in sheltered depositional coastal environments and estuaries where fine, often nutrient rich sediments collect. They are generally confined to tidal areas between the lowest low water and highest high water level (Aksornkoae and Kato, 2011). Plants that are confined to the mangrove are called true mangroves, while those that can also live elsewhere are known as mangrove associates (Tomlinson, 2016). There are approximately 70 mangrove species belonging to 19 families and 28 genera (Duke et al., 1998). The distribution of mangroves is predominantly governed by climate, soil structure, salinity and tidal amplitude.

Mangrove plantations are artificially created and managed mangrove forests that have been planted either as part of a restoration effort or through managed silvicultural activities. They are often mono-specific stands of *Rhizophora* species, as is the case in Viet Nam (Phan et al., 2019). Mangrove plantations can also contribute to ecosystem services, although it has been recognized that they may be less biologically diverse (e.g. Chow, 2015) and therefore their capacity to produce ecosystem services may be less than that of natural mangrove stands, especially during their early growth stages. That said, Honda et al. (2013) found no significant differences in fish abundance nor fish species richness between mangrove plantations and natural mangrove stands.

The nipa palm (*Nypa fruticans*; also nypa and nipa) is an important and distinct component of mangrove ecosystems in SE Asia. Its current distribution ranges from Sri Lanka through Asia to Northern Australia and the Western Pacific islands (Hossain and Islam, 2015).

2.1.1. Provisioning services

Mangrove ecosystems are particularly important to coastal communities, providing a multitude of products (*Table 6)*.

Table 6: Products of mangrove ecosystems modified from Saenger* et al. (1983)

Sector	Products
Fuel	Charcoal
	Alcohol
	Firewood (cooking, heating)
Construction	Timber
	Scaffolds
	Heavy construction (e.g. bridges)
	Railroad ties
	Mining pit props
	Boat building
	Dock pilings
	Beams and poles for buildings
	Flooring, panelling
	Thatch or matting
	Fence posts, water pipes, chipboards, glues
Fishing	Poles for fish traps
	Fishing floats
	Wood for smoking fish
	Fish poison
	Tannins for net and line preservation
	Fish attracting shelters (Fish aggregating devices)
Textiles, leather	Synthetic fibres (e.g. rayon)
	Dye for cloth
	Tannins for leather preservation
Food, drugs, beverages	Sugar
	Alcohol
	Cooking oil
	Vinegar
	Tea substitute
	Fermented drinks
	Dessert topping
	Condiments from bark
	Sweetmeats from propagules
	Vegetables from propagules, fruits or leaves
	Cigar substitute
Household items	Furniture
	Glue
	Hairdressing oil
	Tool handles
	Rice mortar
	Toys
	Matchsticks
	Incense
Agriculture	Fodder
	Green manure
Other products	Packing boxes
	Rope
	Wood for smoking sheet rubber
	Wood for brining bricks
	Medicines from bark, leaves and fruits
	Wood for brining bricks
	Medicines from bark, leaves and fruits
Animal-derived products	Fish
	Crustaceans
	Shellfish
	Honey
	Wax
	Birds
	Mammals
	Reptiles and reptile skins
	Other fauna (amphibians, insects)

Food, energy or other materials from plants

Food and drink

Mangroves provide numerous raw materials for food and drink production, with evidence that this occurs in most of the case study sites (*Table 6* and *Table 7*).

Table 7: Food and drink produced from plants collected in mangrove habitats and countries where evidence was found (though they may also be consumed elsewhere)

Group/species	Use	Countries	References
Rhizophora mucronata fruit	Food and anti-diabetic properties	Indonesia	Hardoko et al., 2015
Sonneratia sp. fruit	Food	Indonesia, Bangladesh	Hossain et al., 2013; Widjanarko et al., 2014
Nipa palm	Sweet sap extracted to produce molasses, wine, edible seeds, tea from leaf and sugar, alcohol (tuba), vinegar	Philippines, Malaysia	Chinte-Sanchez*, 2008
Nipa fruit	Concentrate, jam, boiled as sweets, also eaten while young	Philippines	Dichoso*, 2010; Israel et al., 2012); L. Creencia, pers. obs.
Ceriops tagal and *C. decandra*	Fermenting agent for vinegar, dye for soft drinks, leaves for tea	Philippines, Malaysia	Boopathy et al., 2011; Cooke, 2003; Primavera* and de la Peña, 1998; Sinfuego and Buot, 2014

Category	Score	Justification
Ecosystem service potential	3	Multiple sources of evidence attesting to the importance of mangrove plant species for food
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Energy

Mangrove habitats are an important source of energy for many residents in SE Asia. Mangrove wood is used as firewood or turned into charcoal, and nipa extract can be used to produce bioethanol (*Table 6* and *Table 8*).

Table 8: Materials used for energy creation provided by mangroves and countries where evidence was found (though they may be consumed elsewhere)

Group/species	Use	Countries	Reference
Rhizophora sp.	Firewood, charcoal	Southeast Asia	Cashion*, 2013; Ewel et al., 1998; Garcia et al., 2014; Junaenah and Hair, 2010; Kridiborworn et al., 2012; Mojiol et al., 2017
Mangrove general (no species name given)	Baking and cooking	Philippines	Garcia et al., 2014; See et al., 2011; Walters, 2004
Nipa	Extract can be processed into bioethanol	Philippines	Andres*, 2017

Category	Score	Justification
Ecosystem service potential	3	Multiple sources of evidence attesting to the importance of mangrove plant species for energy
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Other materials

Mangrove habitats provide materials that can be used for many different purposes (*Table 6* and *Table 9*). Mangrove trees are used for the production of timber for construction, furniture and fishing poles and other materials. Evidence from the Philippines suggests that harvesting for construction wood is both size- and species-specific from both natural and plantation forests (Walters, 2005).

Table 9: Non-food materials collected in mangroves and countries where evidence was found (though they may be consumed elsewhere)

Type of use	Species used	Use	Countries	References
Construction materials	Several species, e.g.. *Rhizophora* sp., *Ceriops tagal*	Piling	Malaysia, Indonesia, Viet Nam	Carandang et al., 2013; Cooke, 2003; Lee et al., 2009; Ngoc, 2018; Walters, 2004; Walters, 2005; R. Praptiwi, pers. obs.
	Rhizophora mucronata	Bridges	Malaysia	Cooke, 2003
	Sonneratia alba	Boat frames	Malaysia	Cooke, 2003
	Heritiera sp. and *Xylocarpus* sp.	Furniture	SE Asia, not further specified	Ewel et al., 1998
	Nipa leaves	Roof material	Philippines, Malaysia, Viet Nam, Indonesia	Carandang et al., 2009; Min* et al., 2017; Ngoc, 2018; Nguyen et al., 2015
Fishing material	Several species, e.g. *Rhizophora* sp.	Bunsod (fish weir posts)	Malaysia	Carandang et al., 2013; Walters, 2004; Walters, 2005
Ornaments and other materials	*Pandanus* sp.	Mats	Malaysia	Min* et al., 2017
	Midribs of nipa leaves	Brooms	Philippines	Carandang et al., 2009
	Not specified	Ornaments and handicrafts	Not specified	Datta et al., 2011; Malik et al., 2015
Chemical	*Ceriops tagal*	Dye for fish nets	Malaysia	Cooke, 2003
	Not stated	Tannins to coat and preserve wood, nets and fishing gear; colours to dye clothes	Philippines, Malaysia	Anomynous*, 2016; Philippines News Agency*, 2016
Medicinal	*Ceriops tagal*	Wound dressing	Malaysia	Cooke, 2003; Min* et al., 2017
	Ceriops decandra	Potential anti-cancer effect	Indonesia	Boopathy et al., 2011
	Not specified	Anti-oxidant, anti-diabetic and antibacterial compounds	Not specified	Nyapraphatsara et al., 2003; Govindasamy and Kannan, 2012

Category	Score	Justification
Ecosystem service potential	3	Multiple sources of evidence attesting to importance of mangrove plant species for other materials e.g. construction, ornamental, chemical and medicinal materials.
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Image. Left: mangrove structure built with mangrove wood, Philippines. Right: Pigpen built from mangrove wood into the mangrove, Philippines. © Blue Communities Philippines.

Food and other materials from animals

Food

Harvesting of crabs, shrimp, molluscs and fish occurs in association with mangroves across SE Asia for both subsistence and commercial purposes (Carrasquilla-Henao and Juanes, 2017; Hutchison* et al., 2014; Malik et al., 2015; Primavera*, 2005). Most evidence does not distinguish between pelagic, demersal and invertebrate resources or commercial and subsistence fisheries. Although dated, in 1994 in the ASEAN (Association of Southeast Asian Nations) region, mangrove-associated fish, crustaceans and molluscs were reported to contribute 21% (1.4 million t) annually to the inshore capture fisheries (Singh* et al., 1994). In 2000, for the same countries, mangrove-associated fish (not distinguished between demersal and pelagic) contributed approximately 30% (1.09 million t) of annual finfish resources excluding trash fish (Primavera*, 2005). Elsewhere, mangroves are reported to be important to subsistence fisheries (Rönnbäck, 1999). For example, mangroves were estimated to contribute 10-20% of total fish catch in Sarawak (Bennett and Reynolds, 1993), and 90% in Korea (Naylor and Drew, 1998). Other studies suggest that mangroves support 75-90% of both fishing industries (Rajpar* and Zakaria, 2014 and references therein). The Philippine mangroves host one of the highest numbers of fish species in the world at 128 species (Chong et al., 1990) and Primavera (2000b) stated that half of the towns in the country were dependent upon mangroves for food. Elsewhere, in India, 23% of marine fish catch can be attributed to mangroves (includes pelagic, demersal, crustacean and mollusc species) (Anneboina and Kavi Kumar, 2017).

Reviews suggest higher abundance of fish and shellfish species in mangroves than in adjacent habitats (see e.g. Rönnbäck, 1999 and references therein). Sasekumar et al. (1992) found 37 species of fish and 11 prawn species on mudflats during ebbing tide, compared to 119 fish and 9 prawn species in mangrove creeks and inlets in Selangor, Malaysia. Similarly, Chong et al. (1990) found 70 species of fish and 16 prawn species on mudflats compared to 119 fish and 9 prawn species in the mangroves. There is no indication as to whether these are species important to commercial and subsistence fisheries. In Sabah, Malaysia, however, many of the commercially important species (e.g. fish species such as *Lutjanus* spp., crustaceans such as *Scylla serrata*, *Penaeus* spp., and sea cucumber *Holothuria scabra*) have been recorded living in or near mangrove swamps, estuaries and fringes (Chin*, 1998).

Blaber (2007), however, argues that most evidence for associations between mangroves and fish populations is circumstantial. He suggests that more quantitative and experimental studies are needed, as different mangroves may have different relationships with fish (Blaber, 2013). For example, in Malaysia, Affendy and Chong (2007) showed that shrimps and small fish prefer inland shallower areas of mangroves, possibly to avoid predation.

Pelagic species

The majority of pelagic species are not mangrove dependent but some pelagic fish species have been documented in SE Asian mangrove waters. These are not, however, important species in terms of proportion of pelagic species landed in India (CMFRI*, 2015). For example in India, species of clupeids, anchovies and carangids have been caught in reforested mangrove areas (Singh et al., 2012).

In the Philippines, the mangrove ecosystem contributed 10,100 t of small pelagic and 178 t of large pelagic species to the fisheries production in 2006 (Padilla*, 2008). In the Mantalip reef system, Philippines, the most common juvenile fish (57.04 %) in the mangroves (biomass and abundance) were silversides (Atherinidae). In the same mangrove system sharks have been observed and caught periodically (Ramos et al., 2015). Hemiramphidae (halfbeaks) and Sphyraenidae (barracudas) have also been found in mangroves (Ramos et al., 2015).

Category	Score	Justification
Ecosystem service potential	2	Fish enter the mangroves only during high tide.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal species

Demersal fish are caught in mangroves but due to their size and the complex structure of the ecosystem due to stilt roots and pneumatophores, little fishing activity takes place in mangroves. Also, many fish living within mangroves are juveniles and not of marketable size. That said, the mangrove ecosystem contributed 12,991 t of demersal fish to the Philippines fisheries production in 2006, although it is not clear from this report whether the fish were caught within the mangrove ecosystem itself (Padilla*, 2008).

Category	Score	Justification
Ecosystem service potential	2	Mangrove provides habitat for many small demersal fish
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

Invertebrates are important contributors to food provision in SE Asia and are either collected for direct and personal consumption or for commercial purposes (*Table 6* and *Table 10*). For example, in-depth interviews revealed that 97% of the surveyed households in Kg. Sungai Eloi, Tun Mustapha Marine Park (TMP), Malaysia catch crabs, shellfish and clams in mangroves for their own consumption (Min* et al., 2017). In the Philippines, 6,833 t of invertebrates were caught in mangroves in 2006 (Padilla*, 2008).

Table 10: Contribution of invertebrates from mangrove habitats

Group/species	Use	Countries	References
Crab, shellfish and clams	Direct consumption	Malaysia, Philippines	Carandang et al., 2013; Min* et al., 2017
Bivalves *Geloina* sp.	Direct consumption	Malaysia	Ransangan and Tan, 2018; S. Johari, pers. obs.
Ten species of mollusc species in Puerto Princesa	Commercially important	Philippines	Picardal and Dolorosa, 2014
Shipworm *Teredo navalis*	Commercially important delicacy	Philippines	Ortiz*, 2007
Mangrove clam *Anodontia* sp.	Direct consumption	Philippines	L. Creencia, pers. obs.
Rock oyster *Saccostrea cucullata*	Direct consumption	Philippines	Racuyal et al., 2016
Mud crabs (*Scylla* sp.)	Commercially important	Southeast Asia	Motoh, 1980; Overton et al., 1997; Shelley*, 2008
Prawns	Commercially important	Southeast Asia	Hutchison* et al., 2014)

Category	Score	Justification
Ecosystem service potential	3	High biomass, large populations, but lower diversity than corals, lots of nutrients and high productivity, lots of layers of mud (although some rock and hard substrate)
Confidence	3	Strong, consistent evidence and/or intuitive scientific support.

Other materials from animals

Mangroves are known to be habitats for crustaceans that have been explored to produce medical compounds. For example, the mud lobster (*Thalassina anomala*) occurring in Malaysia has potential to be exploited as a natural source for antibacterial compounds (Zohir et al., 2018). In addition, waste shells from mud crabs are used in the production of biofuel from palm oil, where the shells are used as a source of calcium oxide to transesterify palm olein into methyl esters (biodiesel) (Boey et al., 2009).

Some mangrove species are habitat for bees, which are managed as a source of honey and beeswax. Mangrove honey is harvested in Indonesia, Viet Nam and many other countries in SE Asia (e.g. Bangladesh, India) (Adalina and Heryati, 2019; Baba* et al., 2013; Bandaranayake, 1998).

The carapaces of crustaceans, as well as bivalve and gastropod shells, are made into ornaments, handicrafts, jewellery and accessories (E. Jose, pers. obs.)

Category	Score	Justification
Ecosystem service potential	2	Mangroves provide materials that can be used in several ways
Confidence	2	General scientific support, but some uncertainty

Genetic material from animals and plants

The mangrove ecosystem is used for broodstock collection of oyster, tilapia, mud crabs, mangrove red snapper, grouper, Asian seabass and mangrove jack (Baliao* and Tookwinas, 2002; Emata et al., 1994; Paixão et al., 2013; Sudaryanto and Mous, 2004). Juveniles of some fish species, such as spinefoot (*Siganus* sp., also known as rabbit fish) and snapper, mangrove red snapper (*Lutjanus argentimaculatus*) and John's snapper (*Lutjanus johnii*), may be collected from mangrove ecosystems in Viet Nam (TH Nguyen, pers. obs.).

Sea cucumber spat are collected from muddy and sandy shores located close to mangroves in Sabah, Malaysia (Lim et al., 2021). Juvenile penaeid prawns are sometimes caught in mangroves to stock adjacent aquaculture ponds. Although hatcheries are being increasingly used, wild juveniles are often preferred because they are considered to be of better quality and have higher survival rates than those from hatcheries (Hutchison* et al., 2014). The larva, juvenile, adolescent and sub-adult stages of tiger prawns (*Penaeus monodon*) are found in coastal estuaries, lagoons and mangroves and the brood stock are commonly caught from the wild as local hatchery supplies can be insufficient, but hatcheries are common for the supply of seeds (FAO*, 2005).

Mangrove plantations can provide mangrove seedlings and cuttings for replantation purposes (Komiyama et al., 1998; Primavera and Esteban, 2008) and evidence suggests that genomic information could be used to support mangrove adaptation to climate change and replanting efforts (Wee et al., 2018).

Category	Score	Justification
Ecosystem service potential	3	Provide brood stock of several commercially important species and seedlings for mangrove plantations and reforestation
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.1.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Mangroves can support the remediation of waste waters and trace metals through sedimentation and bioaccumulation (Lewis et al., 2011). For example, evidence from the Philippines shows that mangroves can potentially support the retention of copper from the water and reduce transport elsewhere (Paz-Alberto et al., 2015). Evidence from New Caledonia also demonstrates how mangroves act as a buffer by trapping contaminants long-term in the sediments and within the mangrove trees themselves (Marchand et al., 2011; Marchand et al., 2012). Heavy metals were found to be less mobile beneath *Rhizophora* sp. stands in the mangrove fringe than *Avicennia* sp. stands further from the shore (Marchand et al., 2011).

In addition, mangrove ecosystems can also ameliorate hydrocarbon pollution in the form of polyaromatic hydrocarbons (PAH), with degradation by microbes in the sediment accomplished at around four weeks (Yu et al. 2005, Tam et al. 2008). However, they are particularly sensitive to oil spills (more so than seagrasses) and herbicides (Lewis et al., 2011). In the northeast part of Australia, the occurrence of a mass die-off of mangrove plants due to the application of herbicides, particularly diuron, has been observed (Bell and Duke, 2005; Duke et al., 2005). Mangroves are also susceptible to solid waste pollution as it can prevent seedling development and affect natural nutrient recycling in the sediment (Singare, 2012).

Research carried out by Ewel et al. (1998 and references therein) indicate that basin mangroves may be particularly important for transforming organic nutrients and immobilising microbes and chemicals such as pesticides. Depending on their age, mangrove plantations may perform a similar function in terms of waste assimilation to natural mangrove stands.

Category	Score	Justification
Ecosystem service potential	3	Evidence supports the contribution of mangroves to this service through several mechanisms
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Erosion control

Mangroves can reduce tidal velocities and thereby prevent erosion, but the extent of this performance depends on local hydrodynamics (Struve and Falconer, 2001). Evidence from Thailand indicates that coasts with mangrove stands are known to erode less than those without (Thampanya et al., 2006) and this was also found in Malaysia for both plantations and natural forests (Hashim et al., 2010; Othman, 1994). As a result, several schemes promoting erosion protection of coastal areas by mangrove restoration have been introduced with success and show that restoration increases the elevation of the site through the retention of sediments (Hashim et al., 2010).

Ewel et al. (1998) suggest that the fringe and riverine mangroves are particularly important for erosion control due to their role in binding surface soils. Branches and stems of fringe mangroves are capable of reducing water flow and stifling wave action, while their roots stabilise and bind sediments (Nicholls and Ellis, 2002). Total inundation is the main driver of sedimentation rate (Adame et al., 2010) with trees further from the sea experiencing less soil accretion (Cahoon et al., 2006).

Category	Score	Justification
Ecosystem service potential	3	Mangroves have been shown to be very important in protecting coasts from erosion through several mechanisms
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Water flow regulation

Mangroves are known to directly and indirectly attenuate waves and surges (Granek and Ruttenberg, 2007; Mazda et al., 2006), but typically they develop along low-energy or protected coasts. They are only likely to be important for coastal protection if they are located where storms/ tsunamis occur periodically (Ewel et al., 1998).

Tsunamis and storm surges behave differently to tidal and wind waves (Mazda et al., 2006) and therefore the effectiveness of mangroves in water flow regulation differs, depending on, among other factors, the type of natural disaster affecting water flow. In general, for more routine storms mangroves provide significant protection (Spalding et al., 2014). Mangrove forests serve as barriers and reduce storm wave height as well as affording protection to the area behind (Prasetya*, 2006). Mangroves have also been observed to provide protection from less energetic but more frequent events, such as tropical storms (Granek and Ruttenberg, 2007). Storm surges can be slowed down by wide mangrove tracts, reducing surge height by 4-48 cm per km mangrove belt width that the storm surge goes through. Furthermore, they reduce water level and slow surface waves (McIvor et al., 2012). Wave heights can be reduced by between 13 and 66% over 100 m of mangroves (Spalding et al., 2014). Ewel et al. (1998) suggest that basin mangroves provide flood storage capacity and act to reduce water velocity.

For tsunamis the role is less well understood, however, there is growing consensus that mangroves attenuate waves and reduce debris movement. Healthy mangrove forests afforded substantial protection in the 2004 tsunami in Thailand (Chang et al., 2006). In a review of the coastal protection role of mangroves from cyclones and tsunamis, Marois and Mitsch (2015) report that observational studies are inconclusive about the role of mangroves for coastal protection against extreme natural disasters, although model outputs suggest mitigation capabilities against storm surges and small tsunamis.

A study from Viet Nam suggests that a minimum forest belt width, forest height, canopy closure and forest density are the main components necessary in water flow regulation (Bao, 2011). Duncan et al. (2016) measured coastal protection potential in six areas on Panay Island, Philippines to assess the contribution of mangroves planted around and in former fish ponds to coastal protection. Their results indicate that such areas can be useful for rehabilitation to increase this ecosystem service.

Category	Score	Justification
Ecosystem service potential	3	Evidence that mangroves contribute strongly to this service in several different ways
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Maintaining nursery habitats

Mangroves are considered an important nursery habitat for many different species. The complex structure of the habitat reduces predator encounters and the habitat offers a rich food supply (Laegdsgaard and Johnson, 2001). Some species are permanent residents of mangroves, while others spend only some of their life stage in mangroves (Rönnbäck, 1999; Whitfield, 2017). For example, the density of fish species in coral reefs is a function of the presence of mangrove habitats and seagrass beds in the nearby coastal bay (Nagelkerken et al., 2002). Many finfish caught offshore are associated with mangroves in their juvenile stage. Notable species include barramundi (*Lates calcarifer*), various species of snapper (Lutjanidae), mullet (Mugilidae) and sea catfish (Ariidae) (Hutchison* et al., 2014). In Malaysia, 50% of annual offshore fishery landings are thought to be sustained by mangroves (Chong, 2007). High densities of juvenile fish have also been found in mangroves in Luzon, Philippines (Saenger* et al., 2013). In New Caledonia, 85% of the coral reef fish *Lutjanus fulviflamma* inhabit mangroves for their entire juvenile life (about 1 year) (Paillon et al., 2014). In Viet Nam, the mangroves in the Thu Bon estuary play an important role as nursery areas for several commercial importance namely finfish species such as *Lutjanus argentimaculatus*, *Scatophagus argus*, *Siganus guttatus*, *Epinephelus coioides*, *E. malabaricus*, mud crab *Scylla serrata*; and bivalves (*Corbicula* sp.) (Van Long and Dat, 2018).

There is a particularly close association between prawns in the Penaeidae family and mangroves. Juveniles will spend a few months inshore, especially around mangroves before migrating offshore for the rest of their lives (Hutchison* et al., 2014).

Pereira et al. (2017) suggests, however, that seagrasses are more important than mangroves as potential fish nursery areas. While mangroves provide juvenile species with shelter from predation, densities of the juvenile species are lower than in seagrass, coral reefs, non-vegetated habitat and marsh (Sheridan and Hays, 2003).

Comparing fish communities in mangroves and a jetty in Indonesia, Weis and Weis (2005) found more juveniles in the mangroves than around the jetty. Lutjanidae juveniles are well established in mangroves (Pereira et al. 2017 and references therein).

Category	Score	Justification
Ecosystem service potential	3	Well documented that many species use mangroves as nursery areas, although at lower densities than in seagrass and coral reefs.
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Maintaining habitats for charismatic species

Mangrove habitats in SE Asia are home to charismatic species such as barracuda, seahorses, and humphead wrasse (Choo and Liew, 2005; Dorenbosch et al., 2006; Faunce and Serafy, 2008). Mangroves also provide a habitat for a variety of other flora and fauna from macrofauna (e.g. invertebrates such as mud crabs) to insects (e.g. fireflies), birds and mammals (e.g. otters) (Nagelkerken et al., 2008), some of which can be considered charismatic. Sievers et al. (2019) list several groups of megafauna using mangroves for stages of the life cycle such as breeding and nursery habitats, these include sharks and rays, crocodiles and alligators and sea turtles. Similar species are commonly sighted in the mangroves of Kudat, Banggi Island and Marudu Bay, Sabah including Proboscis monkeys, White bellied sea eagles and crocodiles (Mojiol et al., 2017; Zakaria and Rajpar, 2015).

The Philippine cockatoo, a critically endangered and charismatic species in the Philippines, is known to occur in mangrove habitats in Puerto Princesa and other parts of Palawan (Dangan-Galon et al., 2015). Besides the Philippine cockatoo, Dangan-Galon et al. (2015) also recorded a total of 91 mangrove-associated vertebrate species including 15 Palawan endemics. Picardal and Dolorosa (2014) also recorded 108 molluscan fauna in two bays of Puerto Princesa, including two rare mitres (intertidal gastropods), seven newly described species and first record of the gastropod *Tricolia imbricata*.

Category	Score	Justification
Ecosystem service potential	3	Evidence indicates that many species considered charismatic can be found living in or associated with mangroves.
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Climate regulation

Mangroves ecosystems are considered one of the most carbon-rich tropical forests (Donato et al., 2011) and are recognized as important long-term carbon sinks (Alongi, 2014). Mangroves equate to approximately 0.5% of the global coastal ocean area but account for 10-15% of total carbon sequestration (Alongi, 2014). The mean whole-system carbon stock is estimated to be 956 $t\,C\,ha^{-1}$ for mangroves compared to 593 $t\,C\,ha^{-1}$ for tropical salt marshes and 142.2 $t\,C\,ha^{-1}$ for tropical seagrasses (Alongi, 2014). Most of the carbon stored in mangrove forests is sequestered as below-ground carbon rather than above-ground carbon, with most of it in the forms of soil and dead roots (Alongi, 2012). Where mangroves are within the forest and which species occur has implications for sequestration. Higher organic content has been found in *Rhizophora* stands in the fringe than in *Avicennia* trees behind (found at higher elevation and lower salinity) (Marchand et al., 2011).

For mangroves, the global mean for carbon sequestration is currently 174 $g\,C\,m^{-2}\,yr^{-1}$ with global mean burial rate for soil carbon being 24 $Tg\,C\,yr^{-1}$. For global sequestration of atmospheric carbon in the top metre of sediment, it is estimated that mangroves contain 407 $Mg\,C\,ha^{-1}$ (Himes-Cornell et al., 2018).

Faridah-Hanum et al. (2012) estimated the carbon sequestered by the mangroves within a one-hectare plot along the rivers at Marudu Bay, Sabah (Malaysia) to be approximately 49 $t\,C\,ha^{-1}$, and consequently concluded that the small mangrove patches in the one-hectare plot were capable of long-term carbon sequestration. Similarly, a study for the Tun Mustapha Park concluded that the 11,505 hectares of mangroves in the park were capable of fixing 15,992 $t\,C\,yr^{-1}$ (13.85 $t\,C\,yr^{-1}ha^{-1}$) compared to the 103,000 hectares of estuaries in the park, which could fix 51,500 $t\,C\,yr^{-1}$ (0.5 $t\,C\,yr^{-1}ha^{-1}$) (Research*, 2011).

Mangrove plantations are also capable of storing carbon, although their ability to do so varies with age of the plantation and level of establishment. Banacon Island, the Philippines, has many replanted mangrove stands. These plantations are reported to be in a vigorous condition. The 40 year old plantation has a carbon density of 370.7 $t\,ha^{-1}$, but this drops to 208.5 $t\,ha^{-1}$ in the stands that are 15 year old, 149.5 $t\,ha^{-1}$ in the 20 year old and 145.6 $t\,ha^{-1}$ in the natural stand (Garcia et al., 2014).

Category	Score	Justification
Ecosystem service potential	3	Carbon is stored in the soil as long as it is not disturbed. The capacity of mangroves to store carbon is reported to be higher than that of other coastal ecosystems
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.1.3. Cultural services

Places for recreation (visitors and residents)

Mangroves can be important recreational areas for local communities and tourists. Tourists are said to be attracted by bird watching, charcoal kilns, archaeological sites, fishing villages and untouched mangrove forest. Recreational fishing is also reported in mangroves around the world (Hutchison* et al., 2014).

River cruise activity takes place in the riverine mangroves close to the communities of Tampakan, Simpang Mengayau, Kimihang and Pitas, in Sabah, Malaysia. These are mostly operated by outside tour operators for tourists (S. Johari and E. Vivian, pers. obs). The riverine mangroves and estuaries in Marudu Bay, Sabah, are also reported to have potential for eco-tourism, such as river cruises and birdwatching, due to their high diversity of fauna (Ghani 2015; Zakaria & Rajpar 2015). This is also true in Palawan, Philippines where regular mangrove tours operate on the Puerto Princesa underground river, San Carlos river in Bacungan and Iwahig river where firefly watching tours take place (E. Jose, pers. obs.). Mangrove forests in the coastal region of East Java, Indonesia are also used for nature-based tourism (Hakim et al., 2017).

Category	Score	Justification
Ecosystem service potential	2	While mangroves provide opportunities for recreational activities, they tend to be less exploited than corals suggesting a lower potential to provide this service
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for ceremonial activities

Ceremonial activities can take place in mangroves, also they can give inspiration for ceremonies. For example, in the Philippines, many towns are named after mangroves. This includes Manila which owes its name to the species *Scyphiphora hydrophyllacea*, locally known as nilad and which grew abundantly in pre-Hispanic times (Primavera, 2000a and references therein). The so-called “Love Affair with Nature” festival of the city government of Puerto Princesa includes mangrove sapling planting as the main event, while a free wedding ceremony is also offered to young couples and initiated by the city mayor during this event.

The mangroves in Pitas, Sabah, Malaysia (near a small river known as Lowotung Radap with big rocks in the vicinity) are a sacred site for the Tombonuo ethnic group. They perform rituals there to ask that unpleasant incidents might be avoided, to reduce the impact of incidents that have already happened to an individual and/or family and to ask for wellness and rain during times of drought (Min* et al., 2017).

Category	Score	Justification
Ecosystem service potential	Present	Sacred, ancestral and modern ceremonies occur in mangroves (e.g. replanting, weddings), but this may be specific to particular peoples or locations
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for creative activities

In various places in Southeast Asia and India, mangrove forests are utilized by humans as a source of creative inspiration, for instance for photography, batik making, painting and small scale handicrafts (Akagawa and Smith, 2018; Datta et al., 2011; Ismail et al., 2015; Kovacs, 1999; Sukardjo, 1991).

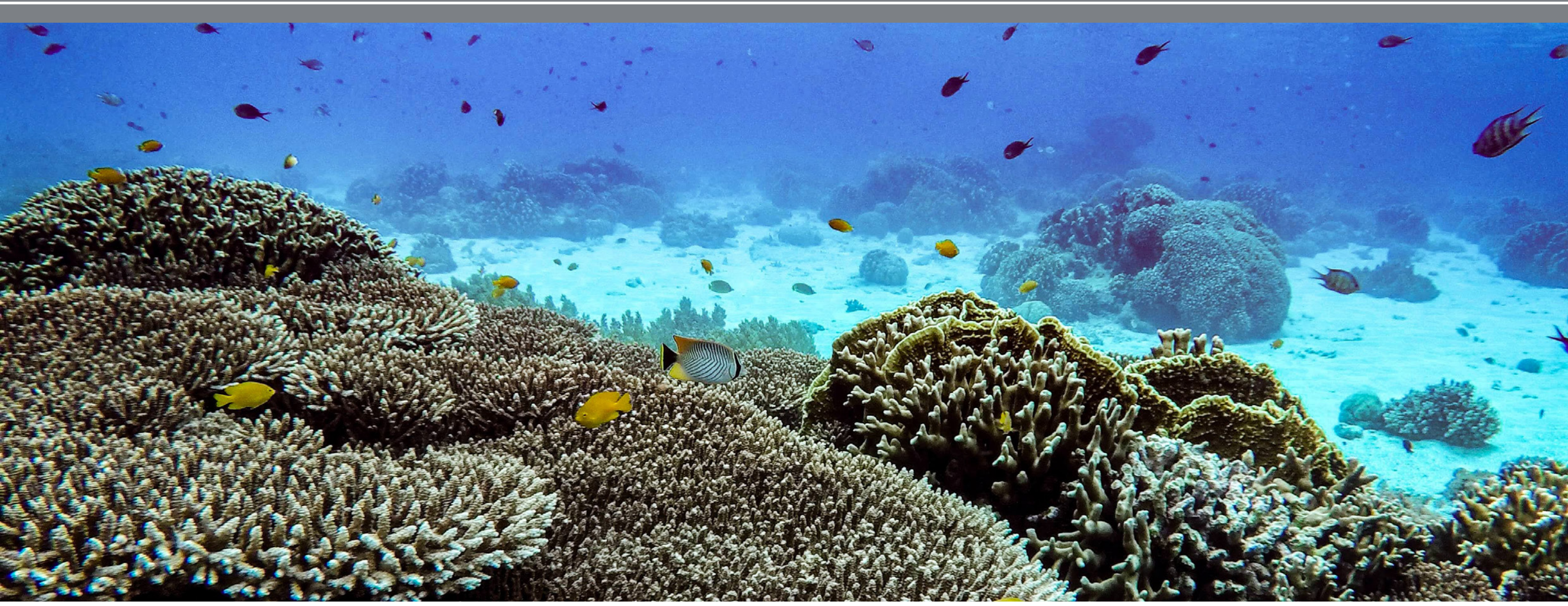
Category	Score	Justification
Ecosystem service potential	3	Mangroves used in many different ways, for creative activities and as a source of inspiration. Indonesia gives this a potential of 2.
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for knowledge-based activities

In some parts of Indonesia, Malaysia, Thailand and Singapore, conservation of mangrove has been incorporated into the local school curriculum with mangroves used as a site for citizen science or community environmental activities (Abdullah et al., 2014; Kigpiboon, 2013; Kwan and Stimpson, 2003; Tolangara, 2014). In Bavang Jamal, Sabah, the communities have initiated mangrove planting as part of a community-based educational programme (Lim et al., 2021). Educational messages are also commonly given during mangrove tours. For example, firefly watching tour guides on the Iwahig River, Puerto Princesa (Palawan, Philippines) often highlight the importance of mangroves for fireflies to customers and the mangrove boat tour guides working in Puerto Princesa's Underground River introduce songs to their guests that are associated with the indigenous knowledge about the "Tamilok" (shipworm) - an edible worm-like bivalve commonly harvested in decaying mangrove trunks (E. Jose, pers. obs.). Collecting plastic litter in mangroves is also used as an education and outreach activity and can involve residents and tourists.

A considerable academic literature exists on mangroves, their functioning and their relationship with communities, indicating their importance for knowledge-based activities.

Category	Score	Justification
Ecosystem service potential	3	Nature watching and listening, citizen science, mangrove planting and teaching to fish/crabs and collect food
Confidence	3	Strong, consistent evidence and/or intuitive scientific support



2.2. Coral reefs

Coral reef ecosystems are among the most productive and biodiverse ecosystems on Earth (Knowlton, 2001; Moberg and Folke, 1999). Coral reefs provide habitats for millions of species that live primarily or exclusively within them (Knowlton, 2001). Stony corals are the basic building blocks of the coral reef; massive and branching corals provide significant three-dimensional habitat for fish and other reef-dwelling animals (Principe* et al., 2012). Coastal fringing reefs run parallel to the shoreline and are divided into the reef crest, which is the seaward edge of the reef, where incoming waves break. Moving towards land, the reef crest is followed by the reef flat where water circulation is reduced, sediments are accumulated and which can be exposed during low tides (Ferrario et al., 2014). A thin subtidal line of corals on a coast is called a fringing reef (Levinton*, 2001). Degraded and dead coral reefs are included in this assessment.

2.2.1. Provisioning services

The Coral Triangle which includes the seas around Indonesia, Malaysia, Papua New Guinea, the Philippines, Solomon Islands and Timor Leste supports the highest coral and reef fish species diversity in the world. This diversity supports the food security of 100 million people (Albert et al., 2015). Alcala and Russ (2002) calculated that a mean sustainable annual yield of goods from coral reefs in the Philippines would be about 350,000 t, thus coral reefs are considered a major food source.

Food, energy or other materials from plants

Healthy reefs do not support high abundances of seaweeds or other marine plants, because healthy corals will successfully compete for space with seaweeds. Therefore, seaweeds on coral reefs are an indication of reef degradation, for example due to eutrophication or loss of grazers.

Food

The green seaweeds *Caulerpa racemosa* var. *clavifera f. macrophysa*, *C. racemosa* var. *laetevirens*, and *C. lentillifera* are considered as delicacies and eaten raw as salad by people in Sabah, Malaysia (Nagappan and Vairappan, 2014).

Category	Score	Justification
Ecosystem service potential	1	*Caulerpa* sp. collected from coral reefs for food
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Energy

No evidence was found.

Other materials

Macroalgae harvested from coral reef habitats are sought after for their medicinal or pharmaceutical properties (Putri* et al., 2018). For example, *C. racemosa* has potential antioxidant properties (Matanjun et al., 2008).

Category	Score	Justification
Ecosystem service potential	1	Negligible use of plant material from coral reefs, but potential exists
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Food or other materials from animals

Food

Healthy reefs can produce up to 35 t of fish km^{-2} yr^{-1} and the catch from coral reef fisheries may contribute 10% of the world fisheries catch (Moberg and Rönnbäck, 2003). For example, in Vanuatu, 80% of the subsistence fishery is based on coral reef fish, while the other 20% is from crab, octopus and other shellfish (Pascal* et al., 2015). It has been estimated that 1 ha of coral reef in Cu Lao Cham supports 20% of the total amount of fisheries production in that area (Nguyễn* Thị Minh et al., 2010). At Sumilon and Apo reefs in the Philippines, of the approximately 200 finfish species observed, about 125 were used for food (Alcala and Russ, 2002).

Cabral and Geronimo (2018) found that coral reef fisheries contribute substantially to food and livelihood security of coastal communities in the Philippines but this is unaccounted for in national statistics.

Pelagic

Coral reefs are not considered a pelagic habitat but there is evidence that some pelagic fish species visit coral reefs, especially where there is sufficient water depth to allow pelagic species to appear. Some fishing gears used over corals, such as drift nets, are also used to target pelagic species. Indian mackerel (*Rastrelliger kanagurta*) has been recorded near reefs in Sabah, Malaysia (Chin*, 1998). In 2006, Philippine coral reefs contributed 83,272 t in small pelagic and 1,355 t large pelagic fish species to fisheries production, substantially more than are contributed by mangroves (Padilla*, 2008). Sharks and rays are caught in reefs of the central Philippine seas and Sulu seas.

Category	Score	Justification
Ecosystem service potential	2	Coral reefs are visited by pelagic species and are targeted there
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

The complex structure of coral reefs offers a variety of habitats for a diversity of fish. In 2006, coral reef ecosystems contributed a total of 34,272 t of demersal fish to Philippine Fisheries (Padilla*, 2008). In an assessment of finfish species in Puerto Galera and Laguindingan, the Philippines, Honda et al. (2013) recorded 12,305 individuals comprising 234 species in 37 families, many of which are food species (e.g. Serranidae, Lutjanidae, Labridae amongst others). Alcala and Russ (2002) listed 18 families of major reef and reef associated fishery species that includes Acanthuridae, Siganidae, Scaridae, Labridae, Haemulidae, Lethrinidae, Lutjanidae, Mullidae, Serranidae, Carangidae, Scombridae, Sphyraenidae, Belonidae, Caesionidae, Pomacentridae, Pomacanthidae, Chaetodontidae and Muraenidae which are caught in the Philippines to be exported.

Live reef food fish for export is an important income source in Malaysia, Indonesia and especially Palawan in the Philippines. The main fish harvested are leopard coral grouper (*Plectropomus leopardus*), Napoleon wrasse (*Cheilinus undulatus*) and humpback grouper (*Cromileptes altivelis*) (Fabinyi, 2016). Most cater for luxury seafood demand in China (Burns*, 2004; Chin*, 1998; Daw* et al., 2002; Daw* et al., 2003; Scales et al., 2007; Teh et al., 2005), but from Palawan, the majority of exports go to Hong Kong and Taiwan with a small percentage being sent to Malaysia and Singapore (Pomeroy et al., 2008).

Category	Score	Justification
Ecosystem service potential	3	Evidence for demersal fish caught from coral reefs including for live reef fish trade. Structural complexity of the reefs is high offering opportunity for fish habitat
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Invertebrates

Coral reef habitats are known to provide various edible echinoderms, crustaceans and molluscs, such as sea cucumber, sea urchin, shore crab, squid and octopus (Chouvelon et al., 2009; Muthiga, 2005; Oikawa et al., 2002). Over 75,850 t of invertebrates were harvested in Philippine coral reefs in 2006 (Padilla*, 2008). In Palawan, invertebrates such as crustaceans and cephalopods are harvested from reefs for local consumption (Alcala and Russ, 2002). In Viet Nam a variety of species is collected for food such as gastropods and bivalves. Evidence was found in several case study countries and for a number of species groups (*Table 11*).

Table 11: Edible invertebrates from coral reefs (species names provided when given by source)

Phylum	Group/species	Use	Countries	Reference
Molluscs	Rock oyster, *Saccostrea cucullata*	Subsistence fishery	Philippines	Racuyal et al., 2016
	Trochus shell	Subsistence fishery	Philippines	Akimichi, 1995
	Green snail	Subsistence fishery	Philippines	Akimichi, 1995
	Giant clams (*Tridacna* sp.)	Commercial and subsistence	Malaysia	Koh* et al., 2002; Lee* and Chou, 2003
	Tridacna elongata, T. squamosa and *T. máxima*	Commercial and subsistence	Viet Nam	UNEP/GEF*, 2006
	Abalone e.g. *Haliotis ovina*	Commercial and subsistence	Viet Nam	Dong and Trinh, 2016
	Cuttlefish (*Sepia* sp.)	Not specified	Worldwide	Reid* et al., 2005
	Sepia tigris	Not specified	Viet Nam	UNEP/GEF*, 2006
	Squid *Sepioteuthis lessoniana*	Not specified	Viet Nam	UNEP/GEF*, 2006
	Squid *Loligo* sp.	Not specified	Viet Nam	UNEP/GEF*, 2006
Echinoderms	Sea cucumbers (several species)	Commercial and subsistence	Philippines	Jontila et al., 2018
	Sea cucumbers (several species)	Subsistence fishery	Indonesia	Akimichi, 1995
Crustaceans	Spiny lobsters	Not specified	Viet Nam	Dang et al., 2014; UNEP/GEF*, 2006;
	Lobster *Panulirus ornatus*	Export	Viet Nam	UNEP/GEF*, 2006
	Lobsters (several species)	Not specified	Philippines	Alcala and Russ, 2002
	Penaeus monodon and other shrimp species	Not specified	Viet Nam	UNEP/GEF*, 2006

Category	Score	Justification
Ecosystem service potential	3	Evidence for the collection of multiple species of invertebrate from coral reefs from across the SE Asia region
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Other materials

Reefs provide other materials such as live coral and reef fish for the aquarium trade, mother-of-pearl shells and coral for jewellery, and the curio trade (Moberg and Folke, 1999). Albert et al. (2015) asked residents of the Solomon Islands to list what they removed from corals (and other habitats near coral reefs) and they included sand, rubble stone, lime, curio and aquarium goods. In Sri Lanka coral mining for building materials and ornaments is important, although illegal (Berg et al., 1998).

Since the 1970s trochus shells have been sourced for button production in Indonesia and Papua New Guinea (Akimichi, 1995). In Sabah, Malaysia, corals and shells are collected by locals (possibly in intertidal areas) and sold as curio and souvenirs in Kudat market and along the roadside in Simpang Mengayau (Burns*, 2004). Gastropods and bivalves are collected for food and for their shells in Viet Nam. Large quantities of the ornamental trumpet triton *Charonia tritonis*, triton shells *Trochus* sp. and pearl oysters *Pinctada* sp. and *Turbo* sp. are also collected in Viet Nam (UNEP/GEF*, 2006).

In South Sulawesi, Indonesia, fishermen targeting ornamental fish operate with little or no functioning management and catch a large diversity of species (Ferse et al., 2012 and references therein). The mushroom coral *Heliofungia actiniformis* is also routinely harvested in Indonesia for the aquarium trade (Knittweis and Wolff, 2010).

In the Spermonde Archipelago, Indonesia, sea cucumber trade and bamboo coral (*Isis hippuris*) trade for international markets are also common economic activities (Glaser et al., 2015), although it is unclear whether bamboo coral trade still occurs. It was potentially considered an important replacement for the red coral trade with China, which has become restricted (S. Ferse, pers. comm.).

In Viet Nam, 22% of the feed given to the caged species in aquaculture is fish caught from nearby coral reefs (Hedberg et al., 2017).

Category	Score	Justification
Ecosystem service potential	3	A variety of different species are caught for non-consumption purposes including ornamental/aquarium trade, curios and aquaculture feed
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Genetic material from animals and plants

Brood stock of corals (eggs for transplantation purposes), grouper fish, giant clam (*Tridacna derasa*), flame angelfish and various species of aquarium fish are commonly collected from coral reef habitats (Callan et al., 2012; Dufour, 2002; Macaranas et al., 1992; Nakamura et al., 2011; Williamson et al., 2009) for the purpose of establishing new populations.

Juveniles of coral reef fish are harvested from reefs and used in ranching in Viet Nam and likely other places (Hedberg et al., 2017). Grouper fry are collected in Palawan, Philippines and exported for use in aquaculture (destination unspecified) (Pomeroy et al., 2008). Clownfish for the aquarium trade can be grown in aquaculture from breeding pairs taken from the wild, as occurs in the Philippines (Pomeroy and Balboa, 2004). According to a survey in the Indo-Pacific region, corals and live rock are cultured in reefs and once tradeable size is reached, the animals are harvested (Pomeroy et al., 2006).

Post settlement and juvenile lobster *Panulirus ornatus* have been collected in Cu Lao Cham for aquaculture (UNEP/GEF*, 2006).

Category	Score	Justification
Ecosystem service potential	3	Many different animal species harvested for multiple purposes including aquaculture and the aquarium trade
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.2.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Coral reefs do not seem to be important in waste or toxic substance treatment or assimilation (Moberg and Folke, 1999). This is due to the sensitivity of cnidarians to chemicals, particularly during fertilization and early life stages (Reichelt-Brushett, 2012). No evidence was found for the ability of SE Asian coral reefs to treat and assimilate wastes or toxic substances; however, some studies for sponges and macroalgae were found from other tropical areas.

Erosion control

Coral reefs provide some degree of protection from erosion and storm surge due to their capacity to attenuate waves, capture sediments, and vertical accretion (Spalding et al., 2014). Different parts of a coral reef are likely to make different contributions to this service.

Category	Score	Justification
Ecosystem service potential	2	The physical structure of the reef and its ability to attenuate waves and capture sediments contributes to this service. Different components of a reef will make a different contribution to the service
Confidence	2	General scientific support, but some uncertainty

Water flow regulation

Coral reefs continually deposit a calcium carbonate skeleton that forms new rock structures which can protect land masses against storm and wave damage (Burns*, 2004). Villanoy et al. (2012) modelled coastal protection under different climate change scenarios using a Philippine reef and showed that the reef dissipated wave action and reduced wave run-up on land. A global meta-analysis calculated that coral reefs reduce wave energy by 97%, with reef crests contributing 86% to this service and reef flats dissipating waves by a further 65% (of the remaining wave energy) (Ferrario et al., 2014). Their influence on waves and currents is also down to their physical geometry and roughness contributing to water flow regulation (Roberts et al., 2008), for example, variability in the topography of the reef platform influences wave characteristics in the reef platform (Brander et al., 2004). On the other hand, the physical structure of fragmented reef patches and channels can serve to locally accelerate and funnel wave energy (Spalding et al. 2014) and fringing coral reefs have the potential to generate energetic waves due to their vertical structures, causing flooding during strong storm events (Roeber and Bricker, 2015).

Simulations of tsunami events revealed that coral reefs may reduce the height of tsunami waves in various regions around the world (Roberts et al., 2008). For example, coral reefs were found to have helped reduce damage on land following the Indian Ocean earthquake and tsunami (December 2004). Diver observations and damage assessment in Sri Lanka after the 2004 tsunami indicated that where coral mining and reef destruction had taken place, damage on land was much greater than where coral reefs were in a healthy state (Fernando et al., 2005). However, assessing tsunami damage in Aceh, Indonesia, Baird et al. (2005) concluded that coastal topography and wave height are more closely linked to damage on land rather than health of the coral reefs (although evidence for this is anecdotal). Chatenoux and Peduzzi (2005) also suggest that distance to tectonic fault lines and depth and length of slopes were mainly responsible for the scale of impact from the 2004 tsunami.

Despite their ability to form natural barriers, coral reefs are still susceptible to damage caused by strong winds and waves, thus their function in protecting coastlines is determined by both their resilience and vulnerability (UNEP-WCMC*, 2006).

Category	Score	Justification
Ecosystem service potential	2	Well studied service and several streams of evidence suggesting that corals can regulate water flows, but their ability is disputed in the context of tsunamis
Confidence	2	General scientific support, but some uncertainty

Maintaining nursery habitats

Coral reefs are important feeding, nursery and breeding areas (Moberg and Folke, 1999). Many fish species recruit onto live coral irrespective of adult habitat associations (Wilson et al., 2008 and references therein). Structurally complex corals are often favoured by fish as sites for recruitment of juveniles and as refuge from predators (Harding et al., 2000). For example, parrot fish use branching coral as a nursery habitat in the Solomon Islands (Hamilton et al., 2017). In Tun Mustapha Park (TMP), Malaysia, the juveniles of the popular yet increasingly rare humphead wrasse *Cheilinus undulatus*, a commercially important live reef food fish trade (LRFT) species, settle on or near coral reefs as larvae (Sadovy et al., 2003).

Spawning events also take place around coral reefs. Sixty-seven species of mainly commercial fish spawn in aggregations around coral reefs in Asia and the Western Pacific (Sadovy De Mitcheson et al., 2008). This has also been documented for grouper species in Papua New Guinea (Hamilton et al., 2011). Spawning aggregations of *Ctenochaetus binotatus* as well as *Dascyllus trimaculatus* and *Parupeneus multifasciatus* have been observed around mostly hard corals and coral rocks, near Pantai Kelambu, Sabah, Malaysia (Burns*, 2004).

Fish can exhibit preferences for specific sub-habitats for spawning and nursery habitats. Several types of juvenile coral fish prefer lagoon patch-reef and rubble in comparison to back-reef and other lagoon habitats (Adams and Ebersole, 2002). Others use coral rubble, or mixed rubble (including shells) as nursery habitats. Coral grouper (*Plectropomus areolatus*), a commercially important fish in Palau uses coral rubble almost exclusively in early juvenile stages (Tupper, 2007). Some fish create rubble mounds that other fish use as nursery habitats (Büttner, 1996). Using laboratory experiments Öhman et al. (1998) showed that some Australian damselfish prefer coral rubble over live coral as recruitment sites.

Macroalgal dominated reefs and beds surrounding the reefs are observed to have a similar role to seagrass meadows in providing essential habitats for juvenile species. Their function as such is positively determined by canopy density, height and cover (Evans et al., 2014; Wilson et al., 2017).

Category	Score	Justification
Ecosystem service potential	3	Many species spend crucial life stages in coral reefs, with different species preferring different coral sub-habitats
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Maintaining habitats for charismatic species

Coral reefs provide habitats for numerous charismatic species, including the corals themselves. Ashmore Reef Ramsar Site, located in the Indian Ocean 840 km west of Darwin, Australia is an important habitat for coral species, 42 of which have threatened status (Hale* and Butcher, 2013). In Malaysia, 273 species of hard corals (Scleractinia) around the Banggi Island and southeast of Malawali Island have been recorded (Burns*, 2004; Burns* et al., 2005; Murphy* et al., 2005; Waheed* et al., 2009). A more recent survey in TMP recorded 39 species of Fungiidae, 30 species of Agariciidae and 15 species of Euphyllidae corals in 38 reef sites (Waheed et al., 2015).

In Southeast Asia, various species of seahorse are found to inhabit coral reef ecosystems (Lourie and Vincent, 2004; Perante et al., 2002). Seahorses have been observed looking for food in coral reefs in Malaysia, as have turtles (S. Johari & E. Vivian, pers. obs.). The hawksbill turtle is an important predator in the food webs existing in coral reefs (León and Bjorndal, 2002). Sea turtles have also been found sleeping under the corals in the Philippines (E.Jose, pers. obs).

Many shark and ray species are also found associated with coral reefs, with sharks being considered the apex predators of coral reefs as well as fulfilling many other trophic roles (Roff et al., 2016). Similarly, Indonesian waters are reported to contain 109 species of shark, 96 batoids (rays) and 2 ghost sharks (Fahmi* and Dharmadi, 2012).

In terms of marine invertebrates that can be considered charismatic, abalone occur in coral reefs around Cu Lao Cham, for example species *Haliotis varia* and *Haliotis ovina* (Dong and Trinh, 2016).

Category	Score	Justification
Ecosystem service potential	3	Many charismatic species live in coral reefs including the corals themselves, seahorses and turtles, abalone as well as numerous fish species
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Climate regulation

The role of coral reefs in burying carbon, a process contributing to climate regulation, was considered historically as important, but increasing evidence in the last two decades suggests that they are more likely a source of carbon dioxide (Heckbert* et al., 2011; Hoegh-Guldberg et al., 2007; Smith* and Gattuso, 2009; Suzuki* and Kawahata, 2004). This can be explained by the precipitation of calcium carbonate and the subsequent shift of pH, leading to the release of CO_2 (Kinsey and Hopley, 1991; Ware et al., 1992). One study calculated that coral reefs contribute approximately 0.02 to 0.08 Tg C as CO_2 annually, which is estimated to be about 0.4% to 1.4% of the current anthropogenic CO_2 production by combustion of fossil fuels (Ware et al., 1992).

Category	Score	Justification
Ecosystem service potential	0	Net burial of carbon is negligible and coral reefs are now considered more likely a source of carbon dioxide
Confidence	2	General scientific support, but some uncertainty

2.2.3. Cultural services

Places for recreation (visitors and residents)

Coral reefs add significant value to coastal tourism by supporting leisure activities such as SCUBA diving, snorkelling and glass-bottom boat touring (UNEP-WCMC*, 2006). Studies covering cultural services of coral reefs focus to a large extent on diving tourism. Tamayo et al. (2018) assessed the economic benefits of dive tourism in the Philippines and found that higher cover of corals leads to higher value income from tourism activities. In Indonesia and the Philippines coastal/reef related tourism accounts for 29 and 30% of overall tourism respectively (Spalding et al., 2017). Different types of coral reef and reef species may be particularly important for tourism. For example, fringing coral reefs at Maliangin Besar Island, Malaysia are popular for diving and snorkelling (Saleh* and Jolis, 2018), and a study in Palau showed that diving with reef sharks brings considerably more income to local communities than fishing for the same sharks would (Vianna et al., 2012).

In Malaysia, a dead coral bank is currently promoted as a new attraction in Tun Mustapha Park (Floating Coral Bar in Pitas). The nearby local communities in Malubang have initiated homestay and boat tour businesses to generate additional income from this attraction, consequently shifting from fishing as their means of livelihood (Lim et al., 2021).

Category	Score	Justification
Ecosystem service potential	3	Strong agreement in literature and among experts
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for ceremonial activities

Coral reefs can provide space and opportunity for ceremonial activities and provide materials and food for ceremonies. For example, some sites in coral reefs in Palawan are considered sacred though no ceremonial activities take place there. Coral reefs are also used for scuba weddings in some places (E. Jose, pers. obs.).

Coral products are common in wedding ceremonies and for other ceremonial purposes. A community in Timor Leste uses coral bead necklaces as a gift to brides at weddings (McWilliam, 2011). It is also believed in the Philippines that hanging black corals in your doorway offers protection against bad spirits (E. Jose, pers. obs.). Shells of giant clams can also be seen as receptacles of holy water in churches (S. Broszeit, pers. obs.).

Category	Score	Justification
Ecosystem service potential	Present	Coral reefs and associated products are associated with ceremonial activities although evidence is limited and very case specific
Confidence	2	General scientific support, but some uncertainty

Places for creative activities

Coral reefs provide colourful fish, corals and other biota as well as clear water which create opportunities for underwater photography and film making, as well as inspiring artists to make sculptures (Endt-Jones, 2017). Evidence on the Internet including photographs, videos and blogs also indicate how coral reefs are used to inspire creativity. In Singapore, coral reefs have been used as the source of inspiration for contemporary dance by schoolchildren (Lai Keun and Hunt, 2006).

Category	Score	Justification
Ecosystem service potential	3	Same importance as mangroves and across the region
Confidence	2	General scientific support, but some uncertainty

Places for knowledge-based activities

Citizen science schemes have been launched to monitor coral reef biodiversity and health, and to raise awareness in local coastal communities in Australia and the Red Sea (Branchini et al., 2015; Marshall et al., 2012). There is a substantial body of academic literature focused on SE Asian coral reefs, suggesting the importance of these habitats for knowledge-based activities.

Category	Score	Justification
Ecosystem service potential	3	Hotspot of knowledge-based activities for example in Indonesia
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.3. Seagrass meadows

Seagrasses are marine flowering plants, which form extensive meadows in shallow coastal waters on all continents except Antarctica (Green and Short, 2003). Seagrass meadows (or seagrass beds) are important for their ecological functions such as their role as a primary producer in food web dynamics, seascape interactions and ecological resilience potential. The nearshore and intertidal location of seagrasses generally enables easy human access and multiple uses as well as exposing seagrass meadows to both terrestrial and marine based threats (Mizuno et al., 2017).

2.3.1. Provisioning services

Food, energy or other materials from plants

Food

Evidence suggests that some seagrass genera are consumed by humans in the tropical Indo-Pacific region e.g. *Syringodium*, *Thalassia* and *Enhalus*, but for other genera there is evidence that they are not consumed e.g. *Halophila*, *Ruppia*, *Halodule*, *Thalassodendron*, *Cymodocea* and *Zostera* (Nordlund et al., 2016). In Indonesia, the seed of *Enhalus acoroides* and the rhizomes of *Cymodocea* sp. are eaten (Hutomo and Moosa, 2005). Based on one observation in Kota Kinabalu, Sabah, some locals eat the fruits of seagrass, likely to be *Enhalus* sp. (Michael Yap, pers. comm.) and this has also been observed in Peninsular Malaysia (A. Amri, pers. comm.).

In the Philippines, the rhizome of *Enhalus acoroides* is served as delicacy in some coastal villages. The seeds are eaten by children and recently the starch from seeds has been extracted for baking cookies (and is hoped to be a viable commercial venture). Another species, *Halophila ovalis*, is used as salad vegetable (L. Creencia, pers. obs.). Seagrasses can be used as medicinal food because they are rich in protein, fibre, lipids, vitamins and antioxidants (Rengasamy et al., 2013).

Category	Score	Justification
Ecosystem service potential	1	It is eaten, but only some species. Evidence that it is eaten in Indonesia, Malaysia and the Philippines, but not in Viet Nam. No evidence found on the volume consumed nor to indicate that consumption is widespread.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Energy

No evidence was found that seagrass is used in the production of energy.

Other materials

In addition to being a source of food, evidence indicates that seagrasses have been used by humans for over 10,000 years. The handicraft and furniture industries have utilized seagrass blades as a component and to accentuate parts of selected furniture, handicrafts and other saleable household items. In addition, they have been used to fertilize fields, insulate houses, weave furniture, make carpets, thatch roofs, make bandages, and fill mattresses and even car seats. Fishing communities in Sabah, Malaysia report that they use seagrass to treat jellyfish stings (V. C. Lim, pers. obs.) Further uses are listed (*Table 12*).

Table 12: Non-food uses of seagrass in SE Asia

Group/species	Use	Countries	Reference
Posidonia sp.	Fibre	Australia	Kirkman and Kendrick, 1997
Several species including *Halophila ovalis, Zostera japonica, Syringodium isoetifolium, P. oceanica*	Potentially in medicine for antibacterial, anti-oxidant and anti-inflammatory properties	Malaysia, Viet Nam,	Hammami et al., 2013; Hua et al., 2006; Ravikumar et al., 2012; Tran et al., 2019; Yuvaraj et al., 2012
Seagrass - Not specified	To cure diarrhoea	Philippines	E. Jose, pers. obs.
Seagrass - Not specified	Remedy to treat jellyfish stings	Malaysia	VC. Lim, pers. obs.

Category	Score	Justification
Ecosystem service potential	2	Well used for fibre, but there is uncertainty about the potential for medicinal/pharmaceutical use. Does not provide as many materials as mangroves
Confidence	2	Evidence from publications and expert opinion on use for fibre, evidence less strong for medicinal uses

Food or other materials from animals

Food

Seagrass provides critical habitat for fish and invertebrate species of subsistence and commercial value. In Wakatobi National Park, Indonesia, intertidal seagrasses are exploited by men, women and children gathering a major portion of their daily nutrition (Cullen-Unsworth et al., 2014). In the same area, 40% of fishermen catch finfish in seagrass beds (Cullen-Unsworth et al., 2014). In addition, seagrass meadows constitute reliable and accessible fishing grounds when other areas are not accessible due to poor weather e.g. coral reefs.

In Sabah, Malaysia, dugong are killed opportunistically for example when caught as bycatch or killed by bomb fishing. The meat is eaten and some body parts are used for medicine and other uses (see below in the '*Other materials section*') (Rajamani et al., 2006). They are also traditionally hunted for food by Bajau Laut (Perrin* et al., 2002). The distribution of seagrasses within coastal areas dictates the kind of grazers that are associated with them. Vertebrates such as parrotfishes (Scaridae), surgeonfishes (Acanthuridae), green turtles and dugongs are the main grazers on seagrass meadows in the tropics (Fortes, 1991).

Pelagic

Different species are found in both shallow and deep seagrass beds. Several fish species, including pelagics are caught over seagrass beds in Viet Nam, for example, anchovies, and jacks (Nguyen et al., 2009).

Category	Score	Justification
Ecosystem service potential	1	During high tide, pelagic fish may be found above seagrass
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

Important species found in seagrass beds include sweetlips, snappers, cardinal fish, coral breams, rabbit fish, scads, trevallies (Nguyen et al., 2009). In 2006, seagrass ecosystems were reported to contribute a total of 3,089 t of demersal fish to Philippine fisheries production (Padilla*, 2008).

Category	Score	Justification
Ecosystem service potential	2	Many commercially important species found in seagrasses
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence. Most studies do not differentiate between the types of fish (i.e. pelagic and demersal).

Invertebrates

Several groups of edible epibenthic invertebrates are present in seagrass beds, such as shrimps, sea cucumbers, sea urchins, crabs, scallops, mussels, and snails. Therefore, seagrass beds provide important areas for invertebrate gleaning in SE Asia (*Table 13*). In Wakatobi National Park, Indonesia some types of fishing, such as invertebrate gleaning (e.g. for clams, sea cucumbers) is primarily conducted in seagrass meadows (82%), and is considered an important backup livelihood when food or money is scarce (Cullen-Unsworth et al., 2014). This is similar in Malaysia, where local communities collect shellfish and sea cucumbers in seagrasses for sale and own consumption during low tide (Gumpil* and De Silva, 2007).

Table 13: List of edible invertebrates from seagrass beds

Group/Species		Use	Countries	References
Molluscs	Tropical bivalves (not specified)	Not specified	Indo-pacific region	Yamaguchi, 1998
	Octopus varians	Commercial	China	Xu et al., 2016
	Cuttlefish *Sepia* sp.	Not specified	Not specified	Reid* et al., 2005
Echinoderms	Sea cucumbers, for example *Holothuria scabra*	Direct consumption	Philippines, Vanuatu, Sri Lanka, Malaysia	Gumpil* and De Silva, 2007; Jontila et al., 2018; Purcell* et al., 2012
	Sea urchins, for example *Tripneustes gratilla*	Direct consumption	Philippines, Indo-Pacific region	Balisco, 2015; Schoppe*, 2000; Yamaguchi, 1998
Crustaceans	Asian paddle crab (*Charybdis japonica*)	Not specified	China	Xu et al., 2016
	Portunus sp.	Commercial	SE Asia and beyond	Lai et al., 2010

Category	Score	Justification
Ecosystem service potential	2	Many commercially important species found in seagrasses
Confidence	2	General scientific support, but some uncertainty

Other materials

Sea cucumbers are used in Chinese traditional medicine (Gumpil* and De Silva, 2007), as a remedy by Kagayan ethnic group for heart diseases and by the Suluk and Ubian for wound healing (Foo et al., 2018), ethnicities found in the Philippines, but also Malaysia and Indonesia.

Dugongs are closely associated with seagrasses as they forage in seagrass meadows. Although hunting for dugongs is no longer common place due to their rarity, their body parts are used in different ways, including as an aphrodisiac, as a delicacy (especially for special occasions e.g. wedding), ornaments and amulets by Bajau, Ubian and Chinese communities in Kudat and Banggi Island. They also use the tears of dugongs (collected by medicine men after capture when exposed to air) for love potions (Rajamani et al., 2006). In Viet Nam, dugongs are hunted for their meat, but their bones, teeth and tusks are used for medicine or sold to China for medicine. Tusks are also used as gifts. This is true to a lesser extent in Cambodia (Hines et al., 2008). In Kudat, Malaysia, dugong tusks are made into pipes because the smoke is said to have medicinal properties. Other parts of the body are used for medicinal and other purposes (Rajamani et al., 2006).

Several invertebrates living in seagrass are exploited for handicrafts and medicinal purposes (Nijman, 2019; Salma et al., 2016). In Puerto Princesa, Palawan, horseshoe crab (*Tachypleus tridentatus*) exoskeletons and exuviae are sold as ornaments (L. J. Gajardo, pers. obs).

Category	Score	Justification
Ecosystem service potential	2	Evidence from different places, if only observation. Use of materials derived from dugong is unlikely to be widespread due to their rarity, but use of seashells for souvenirs is commonplace
Confidence	2	General scientific support, but some uncertainty

Genetic material from animals and plants

Seagrass meadows can be utilised as seedbanks for seagrass seedlings for replantation purposes (Kirkman, 1999).

Seagrass habitats also provide brood stock for sea cucumber aquaculture (*Holothuria scabra*), black tiger shrimp (*Penaeus monodon*), venerid clam (*Katelysia rhytiphora*) and Sydney cockle (*Anadara trapezia*) (Giraspy* and Ivy, 2005; Nell et al., 1994; Pitt, 2001). In Malaysia, local communities collect juvenile fish and spat of green mussel (*Perna viridis*) for aquaculture during low tide (S. Johari, pers. obs.) (Gumpil* and De Silva, 2007). In Sri Lanka and Malaysia, wild sea cucumber (*H. scabra*) juveniles are collected, mainly from seagrass beds, for rearing in sea pens until they are of marketable size (Gumpil* and De Silva, 2007; Kumara and Dissanayake, 2017). It is also common in SE Asia to collect juvenile mud crabs for mud crab aquaculture, which is based on the capture and growing on of juvenile crabs from the wild (Allan* and Fielder, 2003). Juvenile mud crabs strongly select for seagrass habitat, although they are also found in reed beds, areas with macrophytes, under stones and within mud and sandy sediments (Shelley* and Lovatelli, 2011).

Category	Score	Justification
Ecosystem service potential	3	Brood stock of oysters, green lip mussels, shrimps, sea cucumbers and clams
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.3.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Seagrass beds can ameliorate detrimental inputs to coastal waters via two processes: nutrient uptake and suspended particle deposition (Short* and Short, 1984). Nutrient cycling by seagrass beds is recognized as an important ecosystem service in Wakatobi National Park (Cullen-Unsworth et al., 2014) but seagrasses are sensitive to excessive nutrient loading as showcased in a long-term study in several places in the Americas (Short et al., 2006). Some seagrass species were found to accumulate low levels of heavy metals in a study of nine species occurring in the Flores Sea, Indonesia (Nienhuis, 1986). In general, seagrasses can bioaccumulate small amounts of trace metals, but tend to be sensitive to higher levels of herbicides and heavy metals, such as copper and zinc which are found to potentially inhibit photosynthesis (Macinnis-Ng and Ralph, 2002; McMahon et al., 2005). Nonetheless, seagrass beds are found to be resilient to oil pollution due to the buffering capacity of the plant community and to be capable of protecting benthic fauna from direct contact with the oil (Fortes, 1988). For other wastes, there is uncertainty about their level of sensitivity (Lewis and Devereux, 2009). Seagrass beds have also been found to be efficient in the removal of pathogenic bacteria with 50% less bacterial pathogens in nearshore waters with seagrass beds compared to waters without seagrass beds nearby. The study was carried out in Indonesia where the bacterial load of tested water was higher than recommended by the US Environmental Protection Agency (Lamb et al., 2017).

Category	Score	Justification
Ecosystem service potential	2	Smaller potential than mangroves because of their higher sensitivity to high nutrient and pollutant loads
Confidence	3	Strong, consistent evidence or intuitive scientific support

Erosion control

Seagrass meadows protect coastal areas from erosion due to their ability to trap fine sediments and their impact on dynamics and resuspension of sediment (Van Katwijk et al., 2010). The optimal utilization is in shallow waters with low wave conditions (Ondiviela et al., 2014). A study in Tun Mustapha Park, Malaysia, found that seagrasses in Karakit, Banggi Island, help reduce erosion by trapping sediments (Saleh* and Jolis, 2018). The service is linked to water flow regulation and likely to be delivered non-linearly with high temporal and spatial variability due to meadow size, seasonality (which may change canopy cover) and species interactions (Koch et al., 2009).

Category	Score	Justification
Ecosystem service potential	2	Traps and stabilizes sediment, but less so than mangroves and coral reefs but arguably much greater than bare sediment
Confidence	2	General scientific support, but some uncertainty

Water flow regulation

Seagrass beds attenuate both waves and currents and can increase the settlement, capture and storage of sediments (Spalding et al., 2014). This ability is dependent on seasonal variance affecting the density of the meadows and the specific characteristics of the species found in the meadows (Koch et al., 2009). Seagrass contributes substantially to wave dissipation, despite its status as a secondary wave barrier behind reefs and other frontline buffer features of coastal areas (Cochard et al., 2008).

Category	Score	Justification
Ecosystem service potential	2	Not as good at absorbing energy as mangroves, but better at attenuating waves and currents than bare sediments
Confidence	3	General scientific support, but some uncertainty

Maintaining nursery habitats

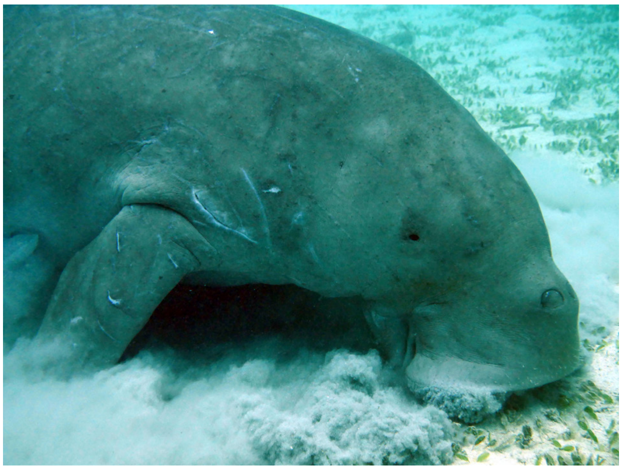
Seagrass beds are important nursery habitats for a large range of species. In Viet Nam, for example, 1,500 species are associated with seagrass beds with the nursery function being considered the most important reason for this association (Thu et al., 2011). The complexity of a seagrass bed provides refuge from predators, attenuates water movements and provides a range of microhabitats and a variety of food resources (Saenger* et al., 2013). According to a global meta-analysis, seagrass meadows are more important for juvenile invertebrates than for fish (McDevitt-Irwin et al., 2016).

In Ambon Bay, Eastern Indonesia, higher structural complexity of seagrass beds was related to the higher richness, abundance, and biomass of fish (Ambo-Rappe et al., 2013). However, the importance of lower structural complexity of seagrass patches should not be underestimated because such patches provided different habitats depending on the growth stage of fish. Smaller fish preferred dense seagrass of small-sized dominant species (*Halodule uninervis*) and they moved to the less dense beds of large-sized seagrass (*Thalassia hemprichii* and *Enhalus acoroides*) upon reaching a particular size threshold (Ambo-Rappe et al., 2013). Post-settlement individuals of Napoleon wrasse (*Cheilinus undulatus*), a popular yet increasingly rare live reef fish trade species in Tun Mustapha Park (Teh and Sumaila, 2007; Teh et al., 2007), have been found in seagrass (*Enhalus acoroides*) (Sadovy*, 2007). In Cu Lao Cham, seagrass provide habitat to several fish species of commercial importance namely Red Snapper *Lutjanus argentimaculatus*, scat *Scatophagus argus*, spine foot *Siganus guttatus*, groupers *Epinephelus coioides*, *E. malabaricus*, mud crab (*Scylla serrata*); gastropod *Chicoreus* sp., squid *Sepioteuthis* sp. and bivalve *Corbicula* sp. (Van Long and Dat, 2018). In Malaysia, seagrass beds house spat of the green mussel *Perna viridis* (Figure 4) (S. Johari, pers. obs.). Juveniles of the sea cucumber *H. scabra* are also reported to prefer to settle in *Thalassia hemprichii* and *Enhalus acoroides* (Ismail, 1993; Jumin* et al., 2010; Rajamani and Marsh, 2015).

Category	Score	Justification
Ecosystem service potential	3	Strong evidence that many species use seagrass meadows as nursery grounds
Confidence	3	Strong, consistent evidence or intuitive scientific support

Maintaining habitats for charismatic species

Based on a review paper on the role of vegetated coastal wetlands for marine megafauna conservation, sea turtles, dugongs, sharks and rays are reported to breed in seagrass beds amongst other coastal wetlands (Sievers et al., 2019). In Malaysia and Indonesia, dugongs use seagrass beds as important feeding grounds (de Longh et al., 1995; Hashim et al., 2017; Rajamani and Marsh, 2010; Rajamani, 2009).



Various species of seahorse are found to regularly inhabit seagrass ecosystems (Curtis and Vincent, 2005). The conservation value of seagrass beds has been evaluated by using such flagship taxa (Syngnathids – seahorses and pipefish) in estuaries in SE Australia (Shokri et al., 2009).

Tiger cowries and other gastropods, turtles, sea horses, pipefish, sharks, rays, octopus, cuttlefish are also regular inhabitants of seagrass beds (O. Langmead, pers. obs.).

Category	Score	Justification
Ecosystem service potential	3	Some species are tightly associated with seagrass e.g. turtles, dugongs and seahorses. Other charismatic species can also be found there such as dolphins, sharks and rays
Confidence	3	Strong, consistent evidence or intuitive scientific support

Climate regulation

Seagrass species are important for carbon sequestration and it is estimated that the global sequestration of atmospheric carbon for just the top metre of sediment is 142 Mg C ha^{-1} for seagrass beds (Himes-Cornell et al., 2018). The structural complexity of seagrass meadows including a leafy canopy and a below-sediment rhizome system, means they are highly efficient in trapping sediment and associated organic carbon originating from internal and external sources (Mcleod et al., 2011). Therefore, they represent a carbon sink (Mcleod et al., 2011) but there are differences in the effectiveness among genera and species (Duarte et al., 2013; Duarte et al., 2010; Fourqurean et al., 2012). For example, it is likely that some seagrasses, such as *Posidonia* sp., *Thalassodendron* sp. and *Enhalus acoroides* contribute more to carbon deposits than other seagrasses (Macreadie et al., 2014). A global review revealed carbon burial in seagrass meadows of between 48 and 112 Tg yr^{-1}, showing that seagrass meadows are natural hotspots for carbon sequestration (Fourqurean et al., 2012; Kennedy et al., 2010).

Category	Score	Justification
Ecosystem service potential	2	Seagrasses are less capable than mangroves but more so than other inter- and sub-tidal habitats
Confidence	3	Strong, consistent evidence or intuitive scientific support

2.3.3. Cultural services

Places for recreation (residents and visitors)

Seagrass beds are not attractive for recreation in their own regard, but they are visited for the charismatic species that can be encountered there (Shokri et al., 2009). A study in Green Island (Australia), revealed that tourists appreciate turtles but do not necessarily make the connection between the presence of turtles and healthy seagrass meadows (Cullen-Unsworth et al., 2014).

Category	Score	Justification
Ecosystem service potential	1	Small proportion of all recreational activities occurs in seagrasses. People don’t like swimming/walking through seagrasses
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for ceremonial activities

Seagrass meadows in Wakatobi National Park represent a source of spiritual fulfilment (in addition to income and food security), with lives and lifestyles intricately interlinked to the seagrass system (Cullen-Unsworth et al., 2014).

Category	Score	Justification
Ecosystem service potential	Present	Potential provision of this service through association with dugongs and some ancestral/sacred seagrass sites
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for creative activities

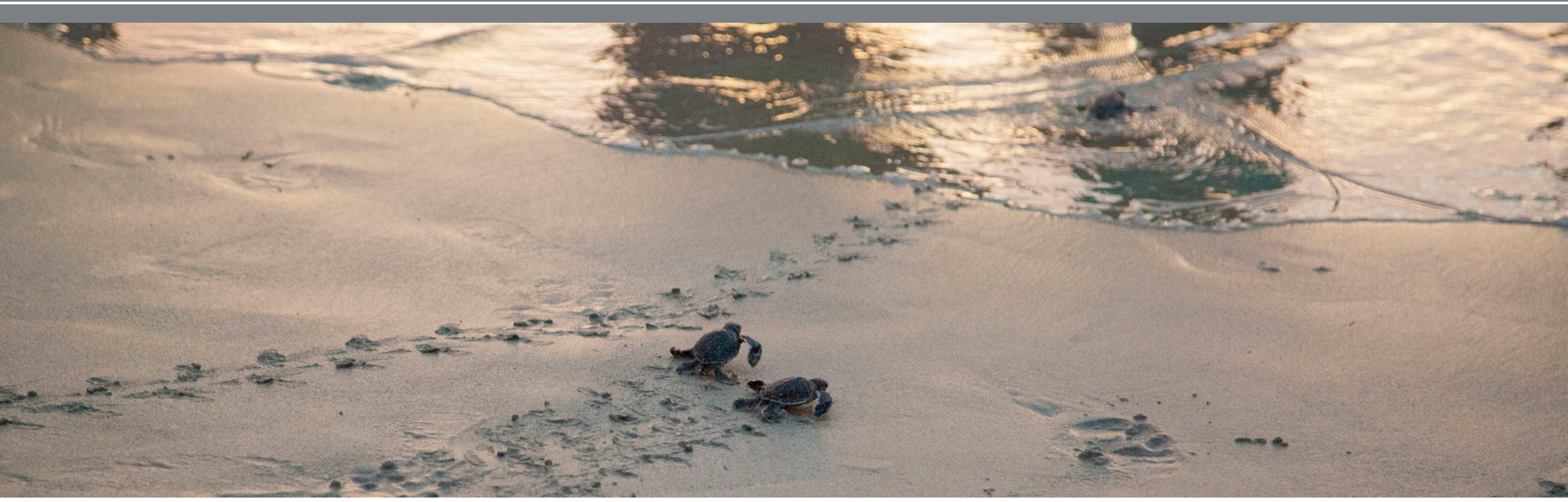
Seagrass ecosystems are known to provide inspiration for artistic works such as painting and sculpture (MacGill, 2019). In the Philippines, seagrass is used in home-based craft businesses providing additional income to rice farmers in flood-prone areas. Examples of craft products prepared in San Fernando, Philippines, include hand woven slippers, embroidered bags and embellished baskets (Hermoso*, 2019). In Victoria, Australia seagrass stems are gathered for use in craft projects by coastal communities (Wallace, 2006; Wallace*, 2006).

Category	Score	Justification
Ecosystem service potential	1	Mostly based on the extraction of fibres, but also the use of shells and other species living within the seagrasses that are then made into crafts
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for knowledge-based activities

Citizen science approaches have been used to raise awareness and highlight the importance of seagrass conservation in coastal communities around the world (Finn et al., 2010; Jones et al., 2018; Mellors et al., 2008). Seagrass areas are also used in the filming of documentaries.

Category	Score	Justification
Ecosystem service potential	2	Less important than coral and mangrove, also less interest in seagrass than in coral and mangrove, also little potential for tourists. Dugongs and turtles live in seagrasses but boats take tourists through them to corals
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence



2.4. Sandy habitats

Sandy habitats include beaches (within the intertidal zone) and subtidal sandy coastal lagoons, sandy sediments and sand banks. Beaches are highly dynamic intertidal accumulations of unconsolidated material, mainly sand but also some pebbles and shells and can be classified as a soft coast (Prasetya*, 2006). They experience short-term cycles of erosion and accretion (Prasetya*, 2006). They harbour a range of invertebrates of marine and terrestrial origin (Schlacher et al., 2015) and provide unique ecosystem services (Schlacher et al., 2007). Beaches are highly valued by society as sites of recreation (Schlacher et al., 2007), thereby supporting economies, communities and tourism (Schlacher et al., 2015).

For the purpose of this study, seagrass beds which grow in sandy habitats are excluded from this section. Seagrass beds are assessed and scored as a separate habitat within this report (*Section 2.3*) and sandy habitats addressed within this section are assumed to be unvegetated.

2.4.1. Provisioning services

Food, energy or other materials from plants

Food

At times, floating seaweed may wash up on shore or is found floating over sandy habitats. When it is not desiccated it may be collected and eaten in Malaysia. For example, *Eucheuma spinosum* and *E. cottonii*, *Caulerpa* sp., are eaten by locals as salad and sold as dried products, (S. Johari, pers. obs.). Sargassum is collected and sold to sea cucumber aquaculture sites for feed (M. A.B.S. Hussein, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Some collection of seaweed from sandy intertidal habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Energy

No evidence found. The use of coconuts for energy is excluded as they are not an intertidal plant.

Other materials

No evidence found.

Food or other materials from animals

Food

In Malaysia, locals will eat fish and squid caught at beaches (S. Johari, pers. obs.). Ashmore Reef Ramsar Site, located in the Indian Ocean near Australia has been fished for several centuries by Indonesians who collected fish, birds, sea cucumbers, clam flesh and shells for food and trade (Hale* and Butcher, 2013). This also occurs on beaches in Sabah (Lydia The, pers. comm.).

Pelagic

Anchovies are usually associated with sand amongst other habitats (S. Johari pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Pelagics move around and there will be time during their travel when they appear over the sand
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

Seine netting and angling occurs off beaches and some demersal species are caught such as flatfish and mullets. For example, *Hapodon nehereus* (local name: ikan nomei, a species of lizardfish) is normally found along flat sedimentary coastlines in Indonesia. It is caught for subsistence and sold in markets after processing in Indonesia (R. Praptiwi, pers. obs).

Category	Score	Justification
Ecosystem service potential	1	Some fishing from beaches for demersal species including flat fish and mullets
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

Several species of invertebrates are collected and harvested from beaches around the world, including SE Asia. Subsistence collection of Asiatic hard clams (*Meretrix meretrix*) and crabs occurs in both sandy and muddy habitats in Sabah, Malaysia (Lim et al., 2021). *Donax faba* (another species of edible clam), is commonly found in the beaches of India (Singh et al., 2012).

Sea cucumbers such as *Holothuria scabra* (called sandfish locally) occur on reefs, seagrass beds and in sandy areas. They are also collected commercially from sandy habitats (Conand, 2018).

The blue crab (*Portunus pelagicus*) occurs in sandy and sandy muddy areas and is harvested in Taytay, Palawan (L. Creencia, pers. obs.). In Viet Nam, shrimp occur on muddy and sandy benthic substrates and are caught in the intertidal and subtidal in lagoons or near mangroves (Son* and Thuoc, 2003). Collection of horseshoe crabs by locals for consumption, especially egg-bearing females, occurs in the intertidal area of sandy beaches (Jawahir et al., 2017; Manca et al., 2017).

Several countries in SE Asia catch jellyfish for export to China, and this activity can also take place using beach seines (Omori and Nakano, 2001).

Category	Score	Justification
Ecosystem service potential	1	Clams, blue crabs, shrimp, horseshoe crabs, clams and jellyfish mainly small scale and low potential production
Confidence	2	General scientific support, but some uncertainty

Other materials

The starfish *Archaster typicus* is collected for ornamental trade from sandy habitats in the Philippines (Bos et al., 2011). Also, windowpane oysters (*Placuna placenta*) are collected from sandy and muddy intertidal habitats and shallow subtidal areas and transferred to culture areas by fishermen and traded (Nair*, 2001). Mollusc shells and sand dollars are collected from sandy habitats in Malaysia and used to make accessories and decorations (S. Johari, pers. obs.; Lim et al., 2021). In Malaysia, hermit crabs are collected as pets by children (VC, Lim pers. obs.) and by fishermen for bait (L. Teh, pers. comm.). In certain areas of Sabah, locals reportedly hang horseshoe crab *T. tridentatus* carcasses in their homes for protection from bad spirits in addition to use for ornamental purposes (Manca et al., 2017).

Category	Score	Justification
Ecosystem service potential	2	Collection of shells and other marine species, such as starfish, for ornaments and souvenirs. Hermit crabs also collected for pets
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Genetic materials from animals and plants

Window pane oyster spat can be collected from sandy areas for cultivation for ornamental resources (Nair*, 2001). A study from the Solomon Islands suggests that young sea cucumbers migrate from seagrasses to subtidal sand when they reach ~6 mm long, from where they are collected for use in sea cucumber culture (Mercier et al., 2000). In Malaysia, sea cucumber juveniles are collected and kept at sandy shores as part of mariculture farming (Lim et al., 2021).

Category	Score	Justification
Ecosystem service potential	1	Limited spat collection from sandy habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

2.4.2. Regulating services

Treatment and assimilation of wastes or toxic substances

One study in Singapore discovered that microorganisms isolated from beach sediments may be utilized for the purpose of bioremediation of oil contamination due to their ability to break down petroleum hydrocarbons (Mathew et al., 1999). Various organisms that exist in sandy beaches worldwide, especially those belonging to the group of annelids, crustaceans, molluscs and interstitial fauna, are found to bioaccumulate heavy metals and may therefore contribute to this service (Wenner*, 1988).

Category	Score	Justification
Ecosystem service potential	1	Capability due to microbes but also bioaccumulation by other organisms living in sand. Levels of waste treatment and accumulation is unclear
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

The majority of coastal erosion is caused by a loss of protection by other habitats such as coral reefs (Prasetya*, 2006). Beaches, dunes and barrier islands built of sand provide important sediment reserves which help to maintain coastlines and (to some degree) support adaptation to sea level rise (Spalding et al., 2014 and references therein). However, sand particles are easily moved by erosive forces.

Category	Score	Justification
Ecosystem service potential	1	Low potential compared to other habitats
Confidence	2	General scientific support, but some uncertainty

Water flow regulation

Beaches, dunes and barrier islands built of sand can attenuate waves (Spalding et al., 2014). Mobile sediment can be moved, transmitting energy from water to the moving particles and potentially contributing to water flow regulation.

Category	Score	Justification
Ecosystem service potential	1	Has some capacity to absorb energy and attenuate waves. Perhaps more evidence for sand vs mud in the temperate literature
Confidence	2	General scientific support, but some uncertainty

Maintaining nursery habitats

Breeding water birds have been recorded in sandy habitats at Ashmore Reef Ramsar Site in Australia and the sandy beaches are important for nesting birds for food gathering while tending to their eggs and chicks (Hale* and Butcher, 2013). Dugongs live and potentially breed in the Ashmore Reef Ramsar Site in Australia (Hale* and Butcher, 2013), the shallow sandy areas being suitable breeding grounds. One study in northern Australia found that shallow intertidal habitats, including sandy beaches, provide critical habitats for larval and juvenile stages of fish and elasmobranchs since they often function as refuge areas with less risk of predation (Tobin et al., 2014).

The exposure of intertidal sandy habitats at low tide means that few species use this zone as a nursery ground, although some species of mollusc have juvenile stages in sand and others may move from the sand to other habitats at low tide. Subtidal sand, however, can be important for deep sea aggregations of fish and crustaceans.

Juvenile mud crabs strongly select for seagrass habitat, although they are also found in reed beds, areas with macrophytes, under stones and within mud and sandy sediments (Shelley* and Lovatelli, 2011).

Category	Score	Justification
Ecosystem service potential	2	Sandy habitats are very different habitats intertidally and subtidally in terms of the physical gradients, therefore, the justifications are split. However, both habitats are scored 2. **Intertidal:** Few species use intertidal sand as a nursery ground due to the harsh physical environment although there may be some movement into and out of sandy habitats with the tide. **Subtidal:** deep sea aggregations for fish and crustaceans may occur in sandy habitats
Confidence	2	General scientific support, but some uncertainty

Maintaining habitats for charismatic species

Turtles nest in the upper (supratidal) areas of beaches and once juveniles hatch from their eggs, they migrate to the water via beaches. In Tun Mustapha Park, not all sandy beaches are suitable hatchery sites for turtles, as they prefer quiet beaches as nesting ground (E. Vivian, pers. obs.). Breeding water birds have been recorded in sandy habitats at Ashmore Reef Ramsar Site in Australia and the sandy beaches are important for nesting birds for food gathering while tending to their eggs and chicks (Hale* and Butcher, 2013). Other charismatic species dependent upon sandy habitats include crabs, rays, sharks, gastropods, cuttlefish (O. Langmead, pers. obs.). In Thailand, five of the seven seahorse species found in the country live over sandy bottom sites (Aylesworth et al., 2017).

Category	Score	Justification
Ecosystem service potential	2	Turtles and birds are the main charismatic species associated with this habitat, but some other can be seen here such as crabs, rays and sharks
Confidence	2	General scientific support, but some uncertainty

Climate regulation

Sand has few active components that can sequester carbon. One study from Singapore suggested that sandbars can store organic carbon but that the amount is very low compared to mudflats, seagrass beds and mangrove forests (Phang et al., 2015).

Category	Score	Justification
Ecosystem service potential	1	Negligible carbon storage
Confidence	2	General scientific support, but some uncertainty

2.4.3. Cultural services

Places for recreation (visitors and residents)

Published studies on recreational values of coastal areas tend not to focus on beach environments but rather on coastal areas in general. Only evidence from other areas of the world was found for these services and include angling (Bennett, 1991), swimming, surfing and boating as active interaction as well as sunbathing and sight-seeing (James, 2000). The intertidal sandy beaches in Simpang Mengayau and Pantai Kelambu, Malaysia (Pantai means beach in Malay language) were reported to be popular tourist attractions due to their aesthetic features (Burns*, 2004; Saleh* and Jolis, 2018).

Muck diving is becoming increasingly popular, particularly in destinations like Indonesia and the Philippines. It takes place over sandy and muddy bottoms with the purpose of finding cryptic and rare species that do not occur on coral reefs (De Brauwer et al., 2017).

The activities listed above take place in the intertidal, in the water column and on the benthos and therefore the habitats were split into intertidal, and benthic subtidal and scored accordingly.

Intertidal (beaches and water column)	Score	Justification
Ecosystem service potential	3	Beaches are main location of recreational activities for the majority of tourists and residents in coastal locations. High potential capacity of deliver this service, equal to coral
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Subtidal (benthos)	Score	Justification
Ecosystem service potential	1	Less accessible and less of interest to recreational SCUBA divers and snorkellers who tend to be oriented towards corals. The exception is muck diving, but this is a niche activity.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for ceremonial activities

The Ashmore Reef Ramsar Site contains Indonesian artefacts such as ceramics and a relic cooking site as well as graves (Hale* and Butcher, 2013). In some parts of Indonesia, sandy beaches are used annually for ceremonial activities as part of traditional rituals of the Selamatan laut (Bugis, Sulawesi) and Labuhan (Parangtritis, Central Java) (R. Praptiwi pers. obs.). In the Philippines several cultural activities take place on beaches. Privately developed beaches and resorts have been used for ceremonial activities such as weddings, birthdays, and even local and international workshops and conferences (E. Jose, pers. obs.).

In the Philippines, horseshoe crabs are caught from sandy beaches and their tails are hung in doorways for good luck. Fishing ceremonies to ask for good weather and bountiful harvest as well as scattering ashes into the sea also take place at beaches (E. Jose, pers. obs.).

Intertidal	Score	Justification
Ecosystem service potential	Present	Several cultural activities take place at beaches, but they are small in scale and can be specific to particular ethnicities and locations
Confidence	2	General scientific support, but some uncertainty

Places for creative activities

Many creative activities such as photography, filming, beach art and the creation of sand sculptures take place on beaches in SE Asia. They also inspire painters. Many photos from sandy habitats can be found in online archives.

Intertidal	Score	Justification
Ecosystem service potential	3	Several activities take place on beaches such as photography and others
Confidence	2	General scientific support, but some uncertainty

Places for knowledge-based activities

Beaches have a similar potential to mangroves and coral reefs because marine awareness programmes often take place at sandy beaches that are accessible and attractive to the public. These include beach cleans and other community environmental activities. Beach cleans are used to explain problems around plastic pollution. In addition, dive schools use sandy habitats for diving lessons. Ashmore Reef Ramsar Site provides several habitats for scientific study that are little disturbed due to their remoteness including coral reefs, atolls and other habitats (Hale* and Butcher, 2013).

Category	Score	Justification
Ecosystem service potential	2	Safe and accessible locations for the transfer of knowledge and participation in environmental programmes e.g. beach cleans, sea turtle hatching information programmes and releases, dive training
Confidence	2	General scientific support, but some uncertainty

2.5. Muddy habitats

Intertidal soft sediment flats are characterized by regular tidal inundation, low slopes and muddy deposits. They include salt marshes and mudflats. These habitats are biologically very productive, provide a range of biota and ecosystem services and support large human populations (MacKinnon* et al., 2012). Subtidal muddy habitats extend to where animals can burrow and continue to live - up to 2 m into the sediment (Kaiser* et al., 2011). For the purpose of this study, salt marshes and mangroves which grow in muddy habitats are excluded from this section. Mangroves are assessed and scored as a habitat in their own right in *section 2.1*, while salt marshes do not occur in the case study areas and are not addressed in this report. Habitats addressed in this section are assumed to be unvegetated.

2.5.1. Provisioning services

Food, energy or other materials from plants

Not applicable. Due to the lack of attachment spaces few macroalgae grow in muddy areas (maybe on occasional rocks).

Food or other materials from animals

Food

Food is collected and fished in some muddy areas in SE Asia, in both, the intertidal and the subtidal zones.

Pelagic

A comparison of fish assemblages from the tropical Australian coast revealed that many edible fish occur over soft sediments, not only coral reefs, including Carangidae (jacks, trevallies), Leiognathidae (ponyfish), Terapontidae (grunters) and Mullidae (mullet) (Travers et al., 2010). Species lists from Cu Lao Cham show commercially important fish species which are associated with mud. Species composition, yield and revenue are highest (31 groups, 11.245,38 t), with fish being the most dominant in the soft sediments off the Thu Bon estuary and coral reefs in Cu Lao Cham (Van Long and Dat, 2018).

Category	Score	Justification
Ecosystem service potential	1	Pelagic species move around and there will be time during their travel when they appear over mud. Likely to be similar over all habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

In a comparison of fish and prawn communities among coastal mangroves, intertidal mudflats, near inshore and far inshore waters in Selangor, Malaysia, Chong et al. (1990) found that the mudflat community is transient, mainly being used at high tide by periodic foragers. Recent findings suggest that diversity can be high and important in supporting coastal fisheries (Lee et al., 2019; Lee et al., 2016). Garces et al. (2006), in a review of the assemblage structure of demersal fish species in South and Southeast Asia, report that fish from the Sciaenidae family (croakers or drum fish), benthic carnivorous fish, are more abundant in muddy inshore waters. Sciaenidae are of commercial interest with Indonesia and Malaysia capturing 130,434 t and 39,617 t respectively in 2017 (FAOSTAT*, 2017). In a comparison of fish and prawn communities between coastal mangroves, intertidal mudflats, near inshore and far inshore waters in Selangor, Malaysia, Chong et al. (1990) found that the mudflat community is transient, mainly being used at high tide by periodic foragers. The fish community comprised some demersal species, but species diversity was low and dominated by species of low commercial value. Garces et al. (2006), in a review of the assemblage structure of demersal fish species in South and Southeast Asia, report that fish from the Sciaenidae family (croakers or drum fish), benthic carnivorous fish, are more abundant in muddy inshore waters. Sciaenidae are of commercial interest with Indonesia and Malaysia capturing 130,434 t and 39,617 t respectively in 2017 (FAOSTAT*, 2017).

Category	Score	Justification
Ecosystem service potential	1	Evidence for transient use of intertidal mudflats by demersal species. Some commercially important species are found in muddy habitats
Confidence	2	General scientific support, but some uncertainty

Invertebrates

Muddy areas provide several invertebrate groups that can be caught in SE Asia for consumption. Subsistence collection of saltwater clams *Meretrix meretrix*, marsh clam *Polymesoda expansa* occur in muddy intertidal shores in Sabah, Malaysia (V.C. Lim, pers. obs.). At Sungai Bandau, the locals rake for clams (*Meretrix* sp. and *Lioconcha* sp.) in the mudflats during low tide (Manjaji-Matsumoto* et al., 2017) and to collect mud crabs and other shellfish (S. Johari pers. obs.). In the muddy estuary areas of southeast India, the edible bivalves, *Perna viridis* and *Modiolus metcalfei*, are commonly gathered by the local communities (Ponnusamy et al., 2014).

The blue crab (*Portunus pelagicus*) occurs in sandy and sandy muddy areas and is harvested in Taytay, Palawan using different fishery methods (Gonzales, 2017; Gonzales and Matillano, 2008). The harvesting of horseshoe crabs and their eggs in the muddy intertidal zone during low tide for local consumption has been recorded in Marudu Bay, Malaysia (Suleiman et al., 2017) and observed at Kampung Loro Kecil near Simpang Mengayau, Limau-Limauan and Pitas, Sabah, Malaysia (S. Johari, pers. obs.). The blue crab (*P. pelagicus*) occurs in sandy and sandy muddy areas and is harvested in Taytay, Palawan using different fishery methods (Gonzales, 2017; Gonzales and Matillano, 2008). The harvesting of horseshoe crabs and their eggs in the muddy intertidal zone during low tide for local consumption has been recorded in Marudu Bay, Malaysia (Suleiman et al., 2017) and observed at Kampung Loro Kecil near Simpang Mengayau, Limau-Limauan and Pitas, Sabah, Malaysia (S. Johari, pers. obs.).

The prawn and shrimp fishery is an economically important activity in SE Asia (*Table 14*) for capture fishery volumes). Many prawns and shrimp species are associated with muddy habitats, with spawning typically occurring offshore in deeper waters (Chong et al., 1990). For example, in Viet Nam, shrimp occur on muddy and sandy benthic substrates and are caught in the intertidal and subtidal in lagoons or near mangroves (Son* and Thuoc, 2003).

Table 14: Annual shrimp and prawn production in the four study countries (FAOSTAT*, 2017)

Country	Volume in t (all wild caught shrimp and prawn)
Indonesia	390,507
Malaysia	114,640
Philippines	30,073
Viet Nam	194,323

Intertidal	Score	Justification
Ecosystem service potential	3	Many layers, many burrowing organisms, mussels, and oysters and crabs collected and consumed from this habitat
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Subtidal	Score	Justification
Ecosystem service potential	3	Subtidal muddy habitats are known to be important for economically valuable penaeid prawns (e.g. tiger and white leg prawns), especially for spawning
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Other materials

Windowpane oyster (*Placuna placenta*) and pearl oyster (*Pinctada* sp.) are collected in muddy habitats (as well as sandy habitats) (L. Creencia, pers. obs.). The juveniles of horseshoe crab (*T. tridentatus*) prefer sandy-muddy substrate where they can bury themselves before the incoming high tide (Almendral and Schoppe, 2005). In Puerto Princesa, Palawan, horseshoe crab exoskeletons and exuviae are sold as ornaments (L. Gajardo, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Some use of shells and exoskeletons for ornaments and souvenirs
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Genetic materials from animals and plants

Collection of brood stock and juveniles for aquaculture and ranching is carried out in muddy habitats. Some aquaculture also takes place in muddy habitats in SE Asia (*Table 15*).

Table 15: Genetic materials from animals collected in muddy areas

Group/species		Use	Countries	References
Molluscs	Several species, e.g. green lip mussel *Perna viridis*, clam *Tegillarca granosa*, horse mussel *Modiolus* sp.	Aquaculture and rearing	SE Asia	Lee, 2012; Nair*, 2001; Shelley*, 2008
	Various species of bivalves, including ark shell (*Scapharca subcrenata)*, Manila clam (*Ruditapes philippinarum*) and angelwing clam (*Pholas orientalis*)	Aquaculture and rearing	Asia	Ng et al., 2009; Park et al., 2011; Zhang and Yan, 2006
Crustaceans	Mud crab *Scylla* sp.	Aquaculture and rearing	Numerous countries in SE Asia, Viet Nam	Allan* and Fielder, 2003; Azra and Ikhwanuddin, 2016; FAO*, 2019; Johnston* and Keenan, 1997

Category	Score	Justification
Ecosystem service potential	2	Mud has the potential to provide habitat to life stages suitable for aquaculture of several species of commercial interest
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

2.5.2. Regulating services

Treatment and assimilation of wastes or toxic substances

In mudflats, water purification is undertaken by living organisms such as clams, microalgae and bacteria (BirdLife International*, 2015). For example, Denil et al. (2017) measured the heavy metal content, particularly arsenic and manganese, of four bivalve species (*P. viridis*, *M. meretrix*, *Crassostrea gigas* and *Polymesoda expansa*) from Marudu Bay, Malaysia. All were shown to accumulate heavy metals in their body tissues. Kohata et al. (2003) have also demonstrated the efficiency of the Venus clam (*Ruditapes philippinarum*) and the Pacific oyster (*Magallana gigas*) to remove particulate organic matter from a shallow coastal lagoon.

Microorganisms found in muddy ecosystems are also important in the treatment and assimilation of wastes. They have been demonstrated to break down PAHs and absorb sewage discharge (Jiao et al., 2014). Microorganisms also contribute to the nitrogen cycle which helps reduce eutrophication, but no studies have been found that measured this process in SE Asia. Muds are low oxygen environments and therefore able to lock away many contaminants such as metals (Watson et al., 2016).

Category	Score	Justification
Ecosystem service potential	2	Several species found in and on mud contribute to this service by removing different types of wastes
Confidence	3	Strong, consistent evidence or intuitive scientific support

Erosion control

Mudflats can contribute to erosion control through sediment stabilization, given the right conditions, such as grain size distribution and mineral composition. Such conditions facilitate rapid dewatering and consolidation of sediments (Barbier et al., 2011).

Category	Score	Justification
Ecosystem service potential	1	Compared to other habitats, mud has likely a similar potential to contribute to erosion control as sand
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Water flow regulation

A meta-study, comparing the wave attenuation attribute of vegetated and unvegetated mudflats, found that wave energy is more significantly diminished in vegetated marsh rather than bare intertidal mudflat (Shepard et al., 2011).

Category	Score	Justification
Ecosystem service potential	1	Mud habitats are less exposed than other sedimentary habitats. Intertidal mud absorbs water which regulates flows, unlike sand which absorbs energy from the water; scores for both habitats are likely to be equal but for contrasting reasons
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

Mudflats harbour juvenile blood cockles (*Andara granosa*), horse mussels (*Modiolus* sp.) (Nair*, 2001; Shelley*, 2008), mud crabs (Scylla sp.) (Allan* and Fielder, 2003) and juvenile horseshoe crabs *T. tridentatus* (Kaiser and Schoppe, 2018). In terms of providing feeding and nursery opportunities for juvenile fish species, mudflats are thought to function similarly to mangrove forests (Tse et al., 2008). While juvenile mud crabs strongly select for seagrass habitat, they are also found in reed beds, areas with macrophytes, under stones and within mud and sandy sediments (Shelley* and Lovatelli, 2011).

Intertidal	Score	Justification
Ecosystem service potential	2	Shallow mud acts as a nursery area for the same reasons as sand – it is shallow and food is available with more food likely to be available in the mud. Mostly mudflats occur in estuaries and close to mangroves, which are well known nursery habitats. There may be some spillover effect from these habitats to mud. Cockles, blood cockles and horseshoe crabs are also common in these habitats
Confidence	2	General scientific support, but some uncertainty

Subtidal	Score	Justification
Ecosystem service potential	1	Shrimps and shellfish occur in deep mud, but it is not typically an accumulator of juveniles
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining habitats for charismatic species

Some mudflats are important feeding grounds during stopovers for migratory birds, for example in Malaysia and Indonesia (MacKinnon* et al., 2012). They house shorebirds and terns but also resident water birds such as the great-billed heron, milky stork and lesser adjutant (Yong* and Low, 2018).

Category	Score	Justification
Ecosystem service potential	2	Birds are the key group of charismatic species occurring in muddy habitats
Confidence	2	General scientific support / logic, but some uncertainty

Climate regulation

Storage of carbon is a global service taking place in mudflats (BirdLife International*, 2015).

Category	Score	Justification
Ecosystem service potential	1	More than sand but less than seagrass or other vegetated areas
Confidence	1	Limited evidence. Based on knowledge from temperate regions and assuming this service will occur in tropical mud in a similar fashion

2.5.3. Cultural services

Places for recreation (visitors and residents)

Muck diving is becoming increasingly popular, particularly in destinations like Indonesia and Philippines (De Brauwer et al., 2017).

Category	Score	Justification
Ecosystem service potential	1	Muck diving may take place even if at a low level.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for ceremonial activities

In Kep, Cambodia, blue crabs are culturally significant and each year they carry out a Kep Crab festival. To signify this importance a statue of a crab was erected in Kep bay (S. Widdicombe, pers. comm.).

Category	Score	Justification
Ecosystem service potential	Present	One example of a festival based on crabs caught in muddy habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for creative activities

Muddy areas may provide opportunities for some creative activities, for example the collection of shells for decorations.

Category	Score	Justification
Ecosystem service potential	1	Has potential but thought to be very low
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for knowledge-based activities

Mudflats provide places for bird and monkey watching and to teach children how to glean food.

Category	Score	Justification
Ecosystem service potential	1	Nature watching (monkeys and birds), teaching of gleaning to children
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Statue of a crab in Kep Bay, Cambodia.

2.6. Rock

Rocky shores are open ecosystems, with varied environmental gradients. The vertical and horizontal gradients that characterize rocky shores provide habitats that will attract different organisms, for example, those that prefer wave swept conditions compared to sheltered conditions. Other rocky habitat types include steep rocky cliffs, platforms, rock pools and boulder fields (Kaiser* et al., 2005). Rocky subtidal habitats are common where coasts are rocky. While rocky subtidal outcrops can be found in the tropics, they are often covered in corals (Levinton*, 2001) and therefore not much information was found on this type of habitat in SE Asia.

2.6.1. Provisioning services

Food, energy or other materials from plants

Food

In Viet Nam intertidal macroalgae are collected for human consumption, for example *Porphyra crispata* is a food species from rocky habitats (T.D. Hau, pers. obs.). *Porphyra* sp. is collected in the Philippines and is considered a high value species, *Codium intricatum* is also collected (E. Jose, pers. obs). Several species of seaweed are collected in Indonesia, for example the seagrape *Caulerpa lentillifera* (Tapotubun et al., 2020). In Malaysia, seaweed is not collected from intertidal rocky areas as it is desiccated by the sun and air (S. Johari, pers. obs.).

Malaysians eat some seaweed species found in the subtidal, for example *Eucheuma spinosum* and *E. cottonii* and *Caulerpa* sp., either as salad or purchased as dried products. However, these are considered difficult to retrieve due to the danger of damaging the boat on the rocks from which they are collected (S. Johari, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Seaweeds are collected in rocky habitats in all case study sites but it is not a very important source of plant-based food, except in Viet Nam where seaweed collection is more prevalent. Viet Nam score: 2.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Energy

No evidence found.

Other materials

Rocky shores provide other materials from plants that are used by locals in SE Asia. Some coastal communities in the Philippines use seaweeds as fertilizer (Cajipe*, 1981). Some plants are also used as remedies in traditional medicine (not further specified).

Category	Score	Justification
Ecosystem service potential	1	A few uses have been identified, some during discussions with experts
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Food or other materials from animals

Food

Little evidence is available on the contribution of rocky habitats in SE Asia to food provision by animals, most likely because rocky areas are not extensive or well-studied.

Pelagic

Pelagic species move around and there will be times during their travel when they appear over rocky habitats.

Category	Score	Justification
Ecosystem service potential	1	It is likely that pelagic and other fish species can be encountered over rocky habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

Evidence indicates that demersal fish species occur in rocky habitats in SE Asia, for example, groupers (*Epinephelus* sp. and *Plectropomus* sp.) inhabit shallow coastal waters in rocky areas in Sabah, Malaysia (Chin*, 1998).

Category	Score	Justification
Ecosystem service potential	1	Demersal fish that can be used as food occur over rocky habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

Harvesting of intertidal and subtidal invertebrates and algae for food, recreational use as fishing bait, or for their ornamental value is widespread on the rocky coast of New South Wales (Underwood, 1993).

In Malaysia, residents collect rock oysters on big rocks during low tide (V.C. Lim, pers. obs). Edible mussels are also found on rocky shores, which locals collect in the Philippines (E. Vivian, pers. obs.). Lobsters (*Palinurus* sp.) and sea cucumbers (*Stichopus horrens*) have been recorded in rocky habitats in SE Asia (Purcell* et al., 2012).

Category	Score	Justification
Ecosystem service potential	1	Edible invertebrates live in rocky habitats and are gleaned
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Other materials

Rocky habitats do not provide many species that can be used for materials other than food, however gastropod shells are collected in Malaysia, for example, to make chandeliers (E. Vivian pers. obs.) or used as souvenirs or decoration. For example, the cowry *Erronea errones* is popular for this purpose (E. Vivian, pers. obs.).

Some crustaceans can be collected as pets such as hermit crabs or decorated crabs (species unknown) (V.C. Lim, pers. obs.). In Viet Nam, the collection of shells and dead coral pieces also takes place in rocky habitats.

Category	Score	Justification
Ecosystem service potential	1	Invertebrates, in particular their shells, can be found in rocky habitats and are used for decorations or as souvenirs
Confidence	1	Invertebrates, in particular their shells, can be found in rocky habitats and are used for decorations or as souvenirs

Genetic materials from animals and plants

No evidence found.

2.6.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Animals living in rocky habitats may be important for this service. For example, from other areas in the world it is known that seaweed, barnacles, bivalves and other filter feeders are important in the treatment and assimilation of wastes.

Category	Score	Justification
Ecosystem service potential	1	Organisms living on rock clean water using several methods such as filter feeding, absorption of wastes and others
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

Cliff coasts are formed from igneous or sedimentary rock and are prone to natural erosion due to slope instability, weathering and wave action. Storm waves and tsunamis have little erosive power over these types of coast (Prasetya*, 2006). It can be assumed, however, that rocky shores have similar potential for erosion control as coral reefs, but that this will be less than the potential of mangroves because they cannot attenuate wave energy. Strictly speaking this is also not a biotic ecosystem service, however, in the interest of completion, it is discussed here.

Category	Score	Justification
Ecosystem service potential	2	Similar to corals in their ability to control erosion
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Water flow regulation

A case study exploring the destructive impact of the 2004 Indian Ocean Tsunami revealed that coastal areas sheltered with rocky reefs experienced less destruction compared to other areas, as the rocky structures acted as natural barriers against the tsunami (Srinivas and Nakagawa, 2008).

Category	Score	Justification
Ecosystem service potential	1	Limited evidence to suggest that rock can contribute to the regulation of water flow
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

No evidence found.

Maintaining habitats for charismatic species

It is well known from other parts of the world that rocky shores form extensive feeding, resting, spawning and nursery areas for mobile marine animals, including fish and crustaceans, as well as birds, reptiles and mammals (Thompson et al., 2002). The intertidal areas of such rocks can provide feeding grounds for charismatic species, feeding on rock oysters for example. Small, rocky islands and marine outcrops can provide habitat for charismatic species such as birds or mammals. For example, Pulau Ling, Malaysia is an important stopover site for migrating seabirds, such as Black-naped tern *Sterna sumatrana*, Bridled tern *Onychoprion anaethetus*, and Eastern reef egret *Egretta sacra* (Hamza et al., 2016). Sea otters may visit intertidal areas for rest and feeding purposes (S. Johari & E. Jose, pers. obs.) and sometimes sea turtles rest underneath rocks (E. Jose, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Several charismatic species use rocky habitats for feeding and during migration as resting places
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Climate regulation

Scientific evidence shows the link between rock and carbon cycles (e.g. Maher and Chamberlain, 2014) but the time spans for these processes are very slow, and it is also not a biotic ecosystem service. More specifically, basaltic rocks, which are often found in terrains located near the sea, were found to contribute significantly (around 30%-35%) to the global flux of CO_2 as a result of their chemical weathering (Dessert et al., 2003). Nevertheless, there are still uncertainties in the understanding of weathering, due to the complexity of the links between many interrelated processes involving biological, tectonic, geomorphological and climatic factors (Goudie and Viles, 2012).

2.6.3. Cultural services

Places for recreation (visitors and residents)

Rocky habitats provide several opportunities for recreational activities such as seabird watching, and snorkelling safaris, which benefit from a rich biodiversity associated with rocky outcrops (Hamza et al., 2016). Recreational activities also include cliff diving.

The intertidal rocky areas in Simpang Mengayau, Kudat and Rock Islands (i.e. Supirak Island) near Kg. Malubang in Pitas are popular tourist attractions due to their aesthetic features (Burns*, 2004;

Saleh* and Jolis, 2018), while residents enjoy recreational fishing from rocky shores (V.C. Lim, pers. obs.). Rocky areas can also be important for cultural reasons such as the Tip of Borneo and Supirak Island, or because of unique rock features (Burns*, 2004; Saleh* and Jolis, 2018).

Category	Score	Justification
Ecosystem service potential	1	Limited compared to other habitats in particular to beaches
Confidence	2	General scientific support, but some uncertainty

Places for ceremonial activities

In Tampakan, Malaysia some fishermen pray to rocks for blessings before going fishing (Lim et al., 2021), and some rocks in riverine mangroves in Sg. Eloi, Malaysia are considered sacred (Min* et al., 2017). In Viet Nam, ceremonies also take place in rocky areas to wish for good fishing (T.D. Hau, pers. obs.).

Category	Score	Justification
Ecosystem service potential	Present	Evidence that some sacred sites are linked to rock (TMP) and ceremonial activities (Viet Nam)
Confidence	2	General scientific support, but some uncertainty

Places for creative activities

Though not strictly intertidal, images of rocky outcrops are widely used in tourism promotional materials and souvenirs.

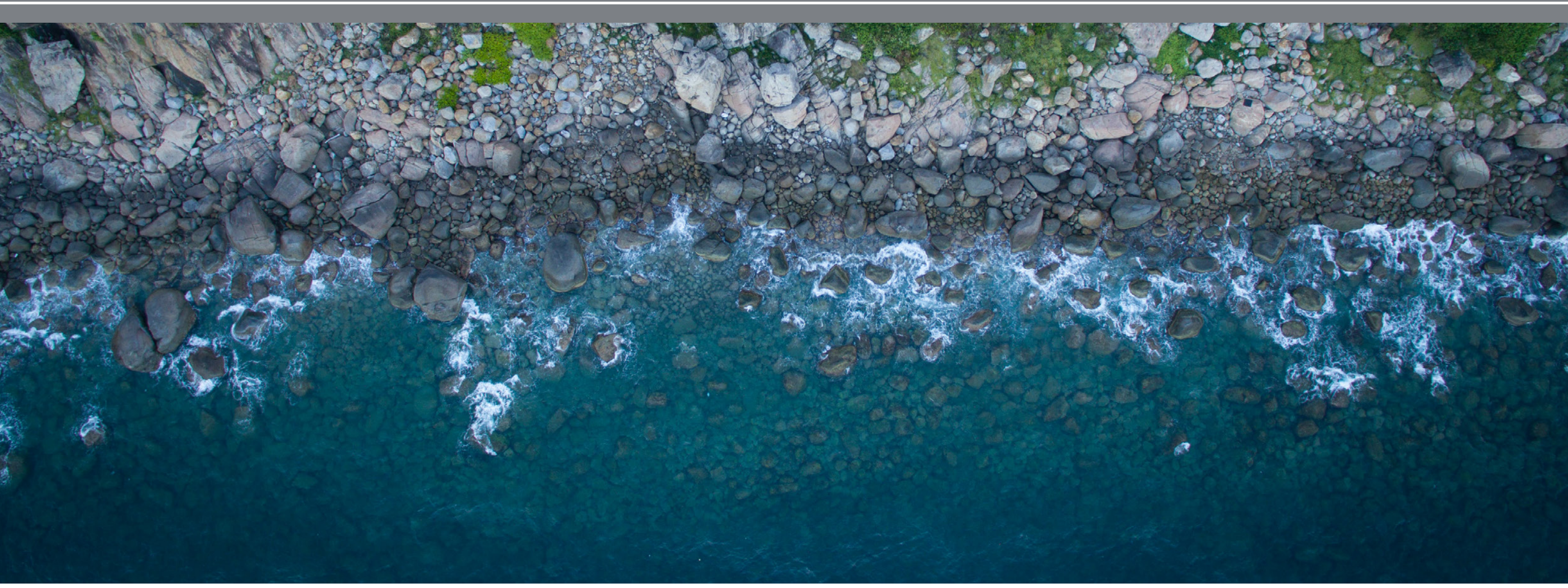
Category	Score	Justification
Ecosystem service potential	1	Used in photography, even if not only in the intertidal. Viet Nam score: 2
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for knowledge-based activities

Some rocky habitats are associated with knowledge-based activities including the study of historical peoples. For example, the Dampier Archipelago (Murujuga) in northwestern Australia contains inscriptions from peoples occupying the area 47,000 years ago when it was an inland range more than 100 km from the coast. Rosemary Island is an inscribed landscape that reveals the emergence of an arid island and provides insights into the dynamics of mobile arid hunter-fisher-gatherers in the early Holocene (McDonald et al., 2017; McDonald and Berry 2017).

Current uses of rocky habitats in Malaysia for knowledge-based activities include marine awareness programmes, rock pooling for food and fishing as well as snorkelling (S. Johari, pers. obs.). In addition, bird watching can take place in rocky habitats and children can learn to glean in such habitats too (V.C. Lim, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Rock pooling and gleaning of food and fishing, and bird watching, and snorkelling
Confidence	2	General scientific support, but some uncertainty



2.7. Coarse habitats

Coarse habitats are sedimentary habitats comprising gravel, mobile pebbles and cobbles and can occur in the intertidal or subtidal. In this review, coral rubble has been distinguished from other coarse habitats and information on the coral rubble can be found in the *coral section*. They are not well studied, especially in tropical areas and the extent of this habitat type in SE Asia is unknown. Very little information was found on the potential for these habitats to provide ecosystem services within SE Asia. This may result from the habitat not providing much living space for many species due to the instability of the coarse sediments. Where possible, expert opinion has been used, drawing upon knowledge from other areas.

2.7.1. Provisioning services

Food, energy or other materials from plants

No evidence found.

Food or other materials from animals

Food

Evidence for the provision of food from coarse habitats was limited to personal observations and expert opinion.

Pelagic

Pelagic fish may swim into coarse habitats. In Malaysia, fishermen use fish aggregation devices to attract fish into such habitats (V.C. Lim, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Pelagic species move around and may at times appear over coarse as well as other habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

Demersal fish may come into coarse habitats occasionally.

Category	Score	Justification
Ecosystem service potential	1	Potential transient habitat for demersal fish
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

Lobsters (*Palinurus* sp.) and giant clams have been recorded in subtidal coarse habitats (S. Johari pers. obs.)

Category	Score	Justification
Ecosystem service potential	1	Not very suitable habitat, some evidence for lobsters and clams
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Other materials

The gastropod *Cassis cornuta* lives in intertidal to subtidal areas, including coarse habitats. They are used for various purposes including handicrafts/souvenirs and medicine in Indonesia (Nijman, 2019; Nijman et al., 2015). Shells collected in coarse habitats in Malaysia are not considered as attractive compared to those found on sandy beaches (S. Johari, pers. obs.). In Viet Nam, shells and dead corals are also collected in such habitats.

Category	Score	Justification
Ecosystem service potential	1	The potential for this service is limited compared to other habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Genetic materials from animals and plants

No evidence found.

2.7.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Coarse habitats may make a minor contribution to this service because coarse particles may trap plastic particles and the surface area provides space for biofilms which may take up wastes.

Category	Score	Justification
Ecosystem service potential	1	May trap plastics, surface area provides space for biofilm
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

This habitat can provide some erosion control but it is only comparable to sand and mud.

Category	Score	Justification
Ecosystem service potential	1	Likely comparable to mud and sand
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Water flow regulation

The potential for coarse habitats is likely similar to sand and mud. The energy used to move pieces of coarse material in the water column will reduce the force of waves and thereby reduce water flow.

Category	Score	Justification
Ecosystem service potential	1	Has capacity to absorb energy
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

No evidence found.

Maintaining habitats for charismatic species

No evidence found.

Climate regulation

No evidence was found.

2.7.3. Cultural services

Places for recreation (visitors and residents)

No evidence found.

Places for ceremonial activities

No evidence found.

Places for creative activities

Children and adults collect pebbles for fun at Malubang, Malaysia (V.C. Lim pers. obs).

Category	Score	Justification
Ecosystem service potential	1	People may collect pebbles
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for knowledge-based activities

In the Philippines, schools take children to coarse habitats for some teaching activities (E. Jose, pers. obs.).

Category	Score	Justification
Ecosystem service potential	1	Philippine schools conduct courses in coarse habitats
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

2.8. Pelagic habitats

The term pelagic means ‘of the open sea’. It consists of the entire water column from the sea surface to just above the seabed and can be divided by water depth and distance from the shore (Kaiser* et al., 2011). Pelagic ecosystems consist of the constantly moving water masses in which features are created by oceanographic processes such as ocean fronts and surface turbulence and can last for a variety of time scales (Dickey-Collas et al., 2017). Many marine organisms depend on the pelagic ecosystem as habitat for some or all of their life stages (Dickey-Collas et al., 2017). In clear tropical waters the photic zone may extend to a depth of 200 m (Kaiser* et al., 2011).

2.8.1. Provisioning services

Food, energy or other materials from plants

No evidence found.

Food or other materials from animals

Food

Pelagic ecosystems provide habitat for many fish and invertebrate species that are important for the food provision service.

Pelagic

Pelagic fish contribute approximately 50% to the fishery harvest of the Coral Triangle (Clifton and Foale, 2017), a number also reported from studies in the Philippines (Bacalso and Wolff, 2014; Muallil et al., 2014). The main pelagic fish species in the study area include large pelagics such as tuna, billfish and oceanic sharks and small pelagics including scad, mackerel, sardinella, trevally, anchovy and herring (Asian Development Bank*, 2014). Indonesia’s fishery production is dominated by pelagic fish, including yellow striped scad, mackerel, sardine, drum fish and mullet (Suseno et al., 2014). The pelagic fish stock in Viet Nam has been calculated to be about 2 million t year^{-1} with exploitation potential of 0.8 million t year^{-1} (Carangidae) (Son* and Thuoc, 2003). The main target groups in Viet Nam are cuttlefish, tunas, mackerels, and anchovies, all of which are seasonally caught with a peak season from December to April (Nguyen et al., 2009).

Manta ray is also targeted and their meat is available in local fish markets in the Philippines and Indonesia (O’Malley et al., 2013).

Category	Score	Justification
Ecosystem service potential	3	High potential yield from this habitat, but not necessarily uniform due to seasonal features such as upwelling fronts
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Demersal

No published evidence was found, but lack of disaggregation in fisheries statistics may disguise any capture of demersal species in pelagic zones. It is possible that demersal species may enter the pelagic and be caught there.

Category	Score	Justification
Ecosystem service potential	1	Some demersal species may be caught in the pelagic
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

A squid fishery occurs in Cum Lao Cham. Both cuttlefish and squid are caught by several means with an annual yield of 700-800 t (T. D. Hau, pers. obs.). Taytay, Palawan (Philippines) and neighbouring municipalities also have a squid fishery (L. Creencia, pers. obs.). In Malaysia, the squid fishery is small scale (S. Johari pers. obs.). A jellyfish fishery exists in SE Asia, it is important for export to Japan and other Asian countries as well as the USA (Omori and Nakano, 2001; Syazwan et al., 2020).

Blue swimming crabs (*Portunus pelagicus*) also form an important fishery in the SE Asia region. As crabs are typically caught in the pelagic zone they are considered a pelagic species. Total catch in 2017 for this species was reported to be 406,413 t, with Indonesia (269,795) being the largest producer (FAO FishStat, 2017). This level of catch is reported to be unsustainable and a number of fisheries improvement projects are underway in the region (Partnership*, 2020; Sustainable Fisheries Partnership*, 2020).

Category	Score	Justification
Ecosystem service potential	3	Squid, jellyfish, cuttlefish and blue swimming crab fisheries are present in case study area. High volume commercial fishery supported, but not as diverse as mangrove and coral
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Other marine animals

Based on an older publication, pelagic species other than fish and invertebrates have been targeted in the SE Asia region (Perrin* et al., 2002). In 1996-1997 two tiger nets in the Lembeh Strait, Indonesia killed a large number of megafauna including manta rays, whale sharks, other unidentified sharks, pilot whales, baleen whales, dolphins, marlin and turtles, none of these groups were identified to species level. All the animals were processed and sold for the pet food trade (Perrin* et al., 2002). Also, captured live dolphins, porpoises, dugongs and false killer whales were sold to oceanaria in Indonesia and abroad (Perrin* et al., 2002). In the Philippines, dolphins are consumed as part of a traditional diet by some indigenous people in the South (Perrin* et al., 2002). Cetaceans are also either targeted or if caught as bycatch used for bait in the increasing shark fin fishery (Perrin* et al., 2002). Dolphins are caught for meat in Sabah, Malaysia (Perrin* et al., 2002).

Other materials

Bycatch is usually considered trash fish in Viet Nam and used to feed livestock or fish in aquaculture. Small fish are also specifically caught for this purpose (aquaculture feed) using a variety of methods, for example anchovies are caught with an encircling net or paired trawlers and may comprise up to 60% of the total catch (Edwards et al., 2004). Other bycatch such as marine mammals and sharks can be used for materials such as medicine, shark liver for oil and other uses. Mobulid rays (*Manta* sp. and *Mobula* sp. are caught for their gill rakes which are used in Chinese traditional medicine (Booth et al., 2020; Zeng et al., 2016).

Category	Score	Justification
Ecosystem service potential	2	Animals used for fishmeal, medicine, food supplements (shark livers)
Confidence	2	General scientific support, but some uncertainty

Genetic materials from animals and plants

Broodstock collection of various fish species, including milkfish (*Chanos chanos*) takes place in pelagic ecosystems (Emata and Marte, 1993).

Category	Score	Justification
Ecosystem service potential	1	Potential to remove broodstock for aquaculture exemplified by milkfish
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

2.8.2. Regulating services

Waste treatment and assimilation

Pelagic plant species, such as phytoplankton or macroalgae such as *Sargassum* sp. can help to reduce the nutrient levels in seawater (Hanson, 1977).

Category	Score	Justification
Ecosystem service potential	1	Sargassum and phytoplankton, zooplankton can reduce nutrient levels in the water
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

Not applicable.

Water flow regulation

Not applicable.

Maintaining nursery habitats

Many marine species have complex life cycles which include a demersal or benthic adult phase and a pelagic larval phase (Roughgarden et al., 1988; Saenz-Agudelo et al., 2012). The pelagic larval phase ensures dispersal and population connectivity of a species (Nanninga et al., 2014). Many commercially important fish (e.g. anchovies and sardines) are only found in the pelagic zone while demersal fish also have larvae in the water column. The popular yet increasingly rare live reef fish trade species in Tun Mustapha Park, *Cheilinus undulatus*, have been reported producing eggs in the pelagic zone (Sadovy et al., 2003).

Category	Score	Justification
Ecosystem service potential	3	The pelagic zone is an important nursery area for many fish and invertebrate species including commercial species
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Maintaining habitats for charismatic species

Several species considered to be charismatic can be found in the pelagic ecosystem. Ray and shark species can be seen regularly in SE Asia. The reef manta ray (*Mobula alfredi*) has been reported in the Bohol Sea, Philippines and previously also at Tubbataha Reefs, Palawan (Rambahiniarison et al., 2016). The oceanic manta ray (*Mobula birostris*) has restricted movement in the Indo Pacific contrary to previous assumptions of their large-scale migratory lifestyle (Stewart et al., 2016). This species has also been continually present in the waters of Komodo Marine Park, Indonesia (Dewar et al., 2008). Whale sharks and various other species of sharks are reported to be regularly spotted in the Western and Eastern part of Indonesian seas (Dharmadi et al., 2017; Stacey et al., 2012; White and Cavanagh, 2007).

Cetaceans can also be spotted in SE Asian pelagic habitats. The spinner dolphin (*Stenella longirostris*) and other cetaceans inhabit the tropical waters of East Kalimantan and West Papua (Borsa and Nugroho, 2010; Kreb, 2005; O'Connor* et al., 2009). Pygmy blue whales (*Balaenoptera musculus brevicauda*) are found to make migratory movements between Australia and Indonesia regularly (Double et al., 2014).

Category	Score	Justification
Ecosystem service potential	2	Sharks, rays and cetaceans inhabit the pelagic
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Climate regulation

Based on the definition for this service used in this report, the pelagic ecosystem contributes little to this service as no long-term storage takes place in the water column. In the pelagic, carbon is sequestered primarily through three pathways of carbon fluxes to which the pelagic ecosystem contributes: remineralisation within the euphotic zone, food-web transfer (from plankton organisms to larger metazoans) and sinking of organic particles to depth (Legendre and Michaud, 1998; Legendre and Rassoulzadegan, 1996). In addition, dissolved inorganic carbon can be entrained into deeper waters by currents, a process taking place over centuries (Sabine et al., 2004; Sabine et al., 2002).

Category	Score	Justification
Ecosystem service potential	1	Based on the definition of this service in this report, a contribution is made in the form of CO_2 uptake, for example by phytoplankton
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

2.8.3. Cultural services

Places for recreation (visitors and residents)

SE Asian pelagic habitats offer space for several recreational activities, especially for encountering charismatic megafauna, such as diving with charismatic megafauna, whale watching and recreational fishing. O'Malley et al. (2013) report on the economic benefits of manta ray diving operations in the Philippines and Indonesia. Whale and dolphin watching is a popular tourist activity (Mustika et al., 2013). The Eastern Tropical Pacific has an economically important pelagic recreational fishery (Martin et al., 2016). Whale sharks are also used in tourism promotion in the Philippines (e.g. Quiros, 2007) and a substantial tourism industry exists around wildlife watching and encounters (O'Connor* et al., 2009).

Category	Score	Justification
Ecosystem service potential	2	Several activities are based in the pelagic
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for ceremonial activities

Whale sharks and other large marine creatures are considered taboo for killing by the Sama-Bajo people in Indonesia (Stacey et al., 2012). In South and Central Viet Nam fishermen build temples to worship cetaceans as they believe that they will help them during times of distress and also aid them catch more fish (Perrin* et al., 2002). A village in the Mekong Delta, Viet Nam, holds a whale festival (Perrin* et al., 2002).

A Bajau Pelauh (nomadic seafaring people) tradition is for a young man to go out and hunt a dugong, a dolphin or a whale to prove his manhood (Perrin* et al., 2002). Cetaceans are also used by the Bajau Pelauh for other ceremonial purposes such as weddings and dowries. Perrin* et al. (2002) describe an incident where Bajau Pelauh men were caught by police for killing 12 spinner dolphins for a wedding feast and as dowry for the bride. In addition, in some traditions in SE Asia, the ashes of dead relatives are scattered at sea.

Category	Score	Justification
Ecosystem service potential	Present	This habitat does support some ceremonial activities but it is limited to specific ethnic groups
Confidence	2	General scientific support, but some uncertainty

Places for creative activities

Pelagic jellyfish species provide a source of inspiration and subjects for artistic underwater photography (Alaimo, 2013). Also, other animals such as turtles, cetaceans and other charismatic species are inspiration for arts projects.

Category	Score	Justification
Ecosystem service potential	2	The pelagic and the animals that live here do provide inspiration for creative activities but this is lesser than corals
Confidence	2	General scientific support, but some uncertainty

Places for knowledge-based activities

The pelagic zone is the focus of many research activities, especially in the context of fisheries and other resource management. For example, stock assessments have been undertaken for pelagic fish such as tuna (e.g. Siriraksophon* et al., 2013). Araujo et al. (2017) use photos of whale sharks from social media platforms, file sharing and search engines to assess population size and structure of whale sharks in the Philippines. While this is not strictly citizen science, the photos were useful in knowledge creation. Pelagic ecosystems are also used as the inspiration for the creation of virtual marine museums for educational purposes by (Tarng et al., 2008).

Category	Score	Justification
Ecosystem service potential	2	Research into pelagic species stocks as well as creation of documentary movies. Malaysia score: 1.
Confidence	2	General scientific support, but some uncertainty

3. Modified habitats

A selection of modified habitats are addressed in this study, those which occur in the case study sites. Here they are defined as habitats that have artificial substrata introduced. Intertidal clam culture and mangrove plantations were not included in modified habitats, since no artificial structures are introduced in either case.

3.1. Seaweed farms

Seaweed aquaculture beds are artificial systems in which seaweeds are attached as germlings (germinated algal spores) to cultivation lines, rafts or nets connected to buoys or poles and then allowed to grow until they are of harvestable size. These structures cover extensive shallow coastal areas, particularly in the Asia-Pacific region (Chung et al., 2017).

3.1.1. Provisioning services

Food, energy or other materials from plants

In 2016, 31.2 million t of aquatic plants were harvested, of which 96.5% were cultivated (FAO*, 2018). This production is overwhelmingly dominated by seaweed species. About 100 seaweed taxa have been cultivated in many areas globally, but approximately 98% of global seaweed production is accounted for by a smaller range of species from such genera as *Saccharina*, *Undaria*, *Pyropia*, *Eucheuma*/*Kappaphycus* and *Gracilaria* (Sondak et al., 2017). Seaweed cultivation is now practiced around the world wherever maritime coastlines are suitable, although it originated in, and continues to be dominant in, the Asian-Pacific region (Hafting et al., 2015). Asia has produced 89% of seaweed globally for over 20 years (FAO*, 2018).

Food

In 2016, 30 million t of seaweeds were produced through aquaculture, of which some species such as *Undaria pinnatifida, Porphyra* spp. and *Caulerpa* spp. are grown for human consumption (FAO*, 2018) but also in the production of medicine, toothpaste and other uses (Valderrama* et al., 2013).

Indonesia is now considered a major producer (only China produces more) of cultured seaweeds (Buschmann et al., 2017); it increased its output of farmed seaweed of *Kappaphycus alvarezii* and *Eucheuma* spp. from 4 million t in 2010 to 11 million t in 2016 (FAO*, 2018). These two species are then used for carrageenan extraction (FAO*, 2018). Philippines are the third biggest producer of farmed seaweed, with a production of 1.4 million t in 2016 (FAO*, 2018). Both Malaysia and Viet Nam produce seaweed through cultivation, but to a much lesser extent: 206,000 and 10,000 t respectively in 2016 (FAO*, 2018).

Category	Score	Justification
Ecosystem service potential	3	Where seaweed farming occurs, it contributes to food and food products
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Energy and other materials

Energy: No evidence found.

Other uses for seaweed include fertilizers and soil conditioners, animal feed, fish feed, biomass for fuel (Duarte et al., 2017), and cosmetics (FAO*, 2003; Hafting et al., 2015; Roesijadi et al., 2010).

Gracilaria sp. is cultivated for agar in the Philippines (13,447t per annum dry wt.) (Chung et al., 2011). Agar is a gelling agent used in food, microbiological research and medicine. Red and brown seaweeds are also used to produce hydrocolloids which are used as thickening and gelling agents, including alginate (textile printing, food, pharmaceutical and medical uses), agar (food, bacterial research) and carrageenan (dairy products, water-based foods, meat products, pet food, toothpaste) (FAO*, 2003).

Ascophyllum Marine Plant Extract Powder (AMPEP), a commercial extract from the brown seaweed *Ascophyllum nodosum* was used as a biostimulant in tests in the Philippines during the micropropagation and field cultivation of *K. alvarezii*, an important red seaweed found on the coasts of tropical to sub-tropical waters. Results indicate that AMPEP increases the biomass production of *K. alvarezii*, and can ultimately enhance the income of seaweed farmers (Hurtado and Critchley, 2018).

Category	Score	Justification
Ecosystem service potential	3	Where seaweed farming occurs, it contributes to the production of many non-food materials
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Food, energy or other materials from animals

Food

No evidence found.

Pelagic

No evidence found.

Demersal

Seaweed farms and coral reefs sometimes co-exist; for example, seaweed farms have been set up over coral reefs in Indonesia and the Philippines where they effectively create a no-take fishing zone (Crawford*, 2002; Sievanen et al., 2005). Some marine organisms gain an extra food source from seaweed farms. This can lead for example to increased rabbitfish catches near seaweed farms (Sievanen et al., 2005).

Danajon Bank, Bohol, is a major producer of farmed seaweed in the Philippines. Using data from the Philippine Bureau of Agricultural Statistics (PBAS), Hehre and Meeuwig (2016) compared reef fish landings across the central Philippines, revealing that the catch of siganids was positively correlated to farmed seaweed production. In a related study, using regional FAO data, Hehre and Meeuwig (2016) also showed a positive correlation between farmed seaweeds and siganids in Indonesia (seaweed species *Eucheuma* spp. and *Gracilaria* spp.) and Malaysia (*Eucheuma* spp. and *K. alvarezii*).

Category	Score	Justification
Ecosystem service potential	1	Probably more attractive to demersal fish than pelagic, but they may be caught too. Rabbitfish exploit seaweed farms opportunistically
Confidence	2	General scientific support, but some uncertainty

Invertebrates

No evidence found.

Other materials

No evidence found.

Genetic materials from animals and plants

Vegetative propagation is the most common way of establishing seaweed farms whereby branches of wild or cultivated seaweeds are harvested and tied to long-lines, rafts or nets. To improve genetic traits, productivity and disease resistance, considerable attention has been given to micropropagation of seaweeds. While this has been demonstrated to be successful in laboratory settings, the economic viability of this process in the field requires further testing. To date, the genetics of 85 seaweed species have been reported. This was originally focused on improving seaweed species for aquaculture, but effort has more recently been given to the production of high-value chemicals of importance for pharmaceuticals, nutraceuticals and biorefinery (FAO*, 2017).

Category	Score	Justification
Ecosystem service potential	2	Branches from existing cultivated seaweeds are commonly used to establish and replant seaweed farms
Confidence	2	General scientific support, but some uncertainty

3.1.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Seaweed cultivation enhances primary production and in this way contributes to global carbon, oxygen and nutrient cycles in addition to reducing eutrophication and greenhouse gases, such as the release of methane (Buschmann et al., 2017). Coastal eutrophication, deoxygenation and ocean acidification could be reduced by the commercial production of seaweeds (Chung et al., 2017; Duan et al., 2019; Duarte et al., 2017; Kim et al., 2017; Vásquez et al., 2014). By integrating seaweed farms with finfish aquaculture the amount of nutrients released from fish cages can be reduced improving local water quality (Kim et al., 2017; Neori et al., 2004; Troell* et al., 1999). Seaweeds can also take up heavy metals from seawater (Chan et al., 2003; Misheer et al., 2006), for example mercury (Kwon et al., 2009). They are therefore used for the monitoring of environmental toxicity (Kim et al., 2017) however, this may mean that produce may not be safe to eat.

Category	Score	Justification
Ecosystem service potential	2	There is potential of seaweed farms to contribute to this service. This potential is dependent on their size which can be considerable
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Erosion control

No evidence has been found for erosion control by seaweed farms in tropical settings, although it is well known that coastal vegetation can reduce wave energy and hence reduce coastal erosion (Duarte et al., 2017). One important difference between seaweed farms and natural seaweed stands is that seaweed farms are suspended rather than benthic. The capacity of a seaweed farm to control erosion is likely dependent upon its size, configuration and the erosive forces the farm is exposed to.

Category	Score	Justification
Ecosystem service potential	1	No evidence but knowledge of how natural seaweed stands and artificial structures can affect water flows suggests that seaweed farms can potentially contribute to this service to some extent
Confidence	1	No evidence but knowledge of how natural seaweed stands and artificial structures can affect water flows suggests that seaweed farms can potentially contribute to this service to some extent

Water flow regulation

In a similar way to the designed planting of mangroves, the design structure of seaweed aquaculture structures could facilitate coastal protection by damping wave energy (Duarte et al., 2017). However, they are usually found in sheltered areas and as for erosion control, the size and configuration of the seaweed farm will have implications for its ability to regulate water flows.

Category	Score	Justification
Ecosystem service potential	1	No evidence but knowledge of how natural seaweed stands and artificial structures can affect water flows suggests that seaweed farms can potentially contribute to this service to some extent
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

Seaweed farms can provide habitat for fish spawning and may function as nursery areas for juvenile fish (Kraan, 2013).

Category	Score	Justification
Ecosystem service potential	1	Only one study has investigated and found that seaweed farms create good habitat for fish spawning and shelter for juvenile fish
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining habitats for charismatic species

Seaweed farms are created on top of coral reefs in Indonesia and the Philippines and while this can be a threat to coral reefs due to structural damage, they can also protect reefs from fishing by effectively creating a no-take zone (Crawford*, 2002; Sievanen et al., 2005). Turtles come into seaweed farms to feed on the seaweed (Teh, L. pers. comm.).

Category	Score	Justification
Ecosystem service potential	1	When considering corals as charismatic species, seaweed farms may contribute in some way to their protection (although with the caveats noted above). Also, turtles may visit occasionally.
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Climate regulation

There is some debate regarding the status of seaweed assemblages, be they natural or seaweed farms, as genuine blue carbon habitats with respect to their ability to sequester carbon for meaningful periods of time. They are suspected to decompose in the oceans liberating the CO_2 back into the atmosphere (Duarte et al., 2017). However, this view has been challenged and seaweeds are now considered to contribute to marine carbon sinks (Krause-Jensen and Duarte, 2016).

The use of commercial seaweed production in CO_2 mitigation efforts has been proposed in Asian countries (Sondak et al., 2017), with some attempts made to quantify the potential benefits from carbon sequestration by seaweed as justification for industry expansion (Kim et al., 2017; Sondak et al., 2017; Tang et al., 2011; Weitzman, 2019).

Seaweeds can help regulate local seawater conditions by raising the pH of the surrounding seawater during daylight hours thereby reducing the effects of ocean acidification (Chung et al., 2017; Duarte et al., 2017; Kim et al., 2017). Mongin et al. (2016), using a modelling approach around Heron Island reef, north east Australia, showed that an optimally located and harvested seaweed farm can increase reef-building aragonite saturation, hence delaying the impacts of global ocean acidification. Such a seaweed farm, however, would have to be several kilometres long to be effective (Mongin et al., 2016).

Other effects of climate change include hypoxia and warming seawater temperatures (Duarte et al., 2017; Keeling et al., 2010). Seaweed farms can provide oxygen-rich environments and, due to the removal of their biomass once grown to marketable size, deoxygenation through remineralisation of their biomass is prevented (Duarte et al., 2017).

An experimental study has also demonstrated that modified seaweed beds are able to decrease the concentration of dissolved inorganic carbon in the water column, through incremental biomass accumulation (Chung et al., 2013).

Category	Score	Justification
Ecosystem service potential	1	Agreement has not been reached in the academic literature
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

3.1.3. Cultural services

Places for recreation (visitors and residents)

Chung et al. (2017) identify seaweed aquaculture beds as locations for recreation and ecotourism. In Indonesia, seaweed farms have become common stops on tours by the ecotourism industry (Alleway et al., 2019).

Category	Score	Justification
Ecosystem service potential	1	Limited opportunities available
Confidence	2	General scientific support, but some uncertainty

Places for ceremonial activities

No evidence found.

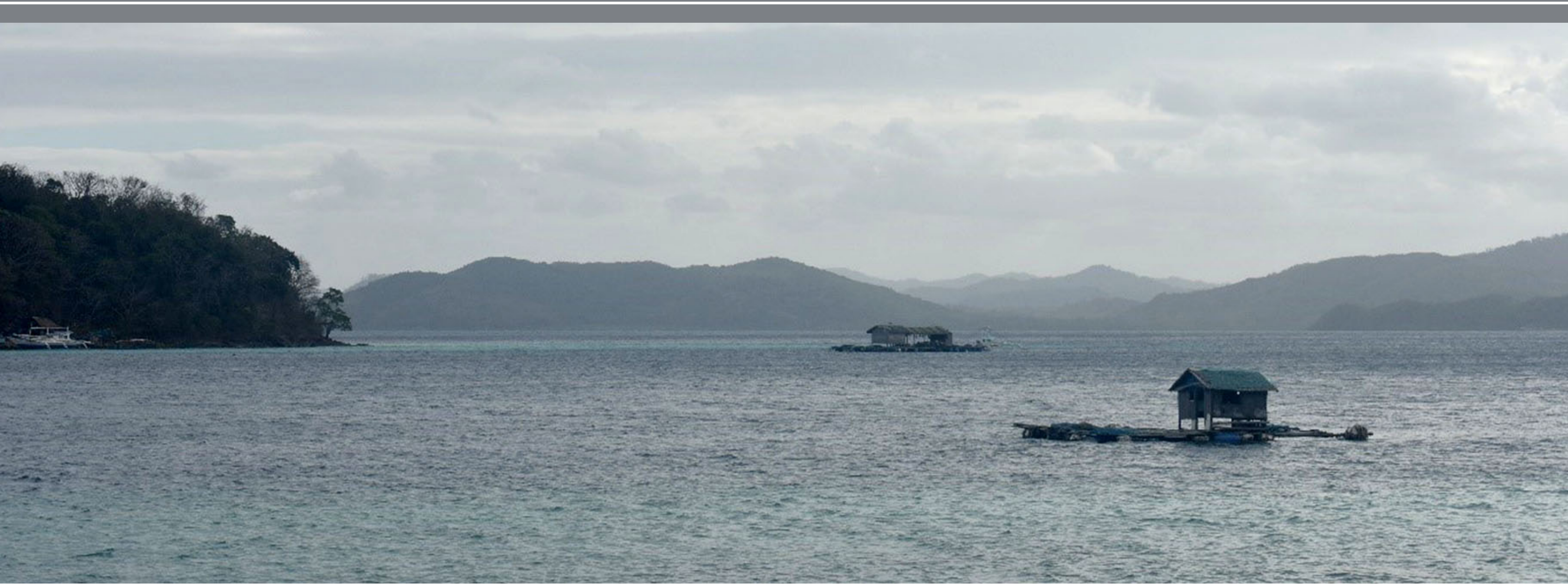
Places for creative activities

No evidence found.

Places for knowledge-based activities

Chung et al. (2017) list educational services as provided by seaweed farms. There is also considerable research into seaweed farming as noted above (FAO*, 2017 and references therein).

Category	Score	Justification
Ecosystem service potential	1	Evidence of active research into seaweed farming including in SE Asia
Confidence	2	General scientific support, but some uncertainty



3.2. Aquaculture for finfish species (fish cages)

Fish cages are often positioned in low energy environments to protect their structures. In tropical countries, this is commonly near coral reefs (e.g. in Viet Nam and Philippines) and in brackish mangrove-lined estuaries (in Malaysia) as they present favourable environmental conditions, in terms of depth and water quality, for fish cages (Hedberg et al., 2015; Hedberg et al., 2017). Fish cages are integrated within the ecosystem in which they occur and can support some of the same fundamental goods and services provided by nature (Alleway et al., 2019). This may be particularly true for provisioning services, the provision of habitat for wild fish populations and some cultural services.

3.2.1. Provisioning service

Food, energy or other materials from plants

Food

No evidence was found but it is possible that seaweeds growing on fish cages could be collected for subsistence use.

Category	Score	Justification
Ecosystem service potential	1	Possible collection of seaweed growing on fish cages for subsistence purposes
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Energy and other materials

No evidence found.

Food, energy or other materials from animals

Food

Asia produced 3.7 million t of finfish through marine and coastal aquaculture in 2016 (FAO*, 2018). The main species cultivated include groupers, snappers, cobia, pomfret, milkfish, trevally and spinefoot (Cruz-Trinidad et al., 2011). Discussions amongst the authors confirmed this list as being still valid today.

Grouper aquaculture is highly developed in Asia, attracting high commercial value in the markets of Hong Kong, Singapore and Taiwan. Most grouper species are cultured in floating net cages either in the open sea or at the seaward end of estuaries. In 2008, 12.5% of carnivorous marine finfish production in SE Asia was grouper alone (FAO*, 2014a; b). To give an idea of grouper aquaculture production, Indonesia has produced 10200 t of groupers in 2019 (FAO estimate), Malaysia has produced 3026 t (FAO estimate) and the Philippines have produced 103 tons (FIGIS - Fisheries Statistics - Aquaculture (*fao.org*), accessed 01/09/2021).

In addition to food produced in the cages, the aggregation of wild fish around fish farms is well documented. For example, Sudirman et al. (2009) found that the biomass of wild fish surrounding the Awarange Bay farm, South Sulawesi, Indonesia, was large compared to the biomass of fish within the cages. Some of the species of wild fish recorded were, themselves, highly valued as food, e.g. demersal spinefoot (*Siganus* sp.), humphead wrasse (*Cheilinus undulatus*), and surgeonfish (*Acanthurus grammoptilus*), as well as pelagic jacks (*Caranx papuensis*). The wild fish were attracted to the uneaten food pellets, the cage structure itself and the food resources associated with the cage structure, or the presence of other fishes. The dietary demand of the total wild fish community was calculated to be 20 kg d^{-1} wet weight of organic material, equivalent to the biomass of pellets lost from the cages.

Pelagic fish

The main pelagic fish species cultured in SE Asia are cobia (Rachycentridae) and trevally (Carangidae). In 2008, Viet Nam was the third biggest producer of cobia (Nguyen et al., 2011) in the World. However, production may have since plummeted.

Category	Score	Justification
Ecosystem service potential	1	Cobia and trevally are the only pelagic species cultured, often offshore. Other pelagic fish that come near the cages to eat excess fish food may be caught for human consumption
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal fish

Several demersal fish species are being cultured for human consumption such as groupers (Serranidae) and snappers (Lutjanidae) (FAO*, 2014a). Milkfish (*Chanos chanos*) and seabass (*Lates* sp.) are also important (Hishamunda* et al., 2009).

Category	Score	Justification
Ecosystem service potential	3	Fish cages are set up for the purpose of producing fish for human consumption
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Invertebrates

No evidence was found, but as for seaweeds, it is possible that biofouling species are collected for subsistence purposes. Aquaculture for commercial invertebrate species is addressed in *section 3.3*.

Category	Score	Justification
Ecosystem service potential	1	Possible collection of edible biofouling species for human consumption
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Other materials

No evidence found.

Genetic materials from animals and plants

No evidence found.

Brood stock for fish cage aquaculture is typically caught from the wild (e.g. snappers, cobia, pomfret) or produced in hatcheries (e.g. milkfish), rather than collected from the fish cages themselves (BC partners, pers. obs.). For groupers, the depletion of wild seed stock has led to the development of grouper hatchery technology in the region, particularly in China, Indonesia, Malaysia, Taiwan and Thailand (Pierre et al., 2008).

3.2.2. Regulating services

Treatment and assimilation of wastes or toxic substances

Fish cages create a negative environmental impact through their presence because of excess feed falling out of the cages as well as increased nutrients due to metabolic wastes of the fish inside, their effects can be negated to an extent by the actions of the fouling communities the infrastructure attracts.

In Malaysia and Singapore, fish cages are used for cleaning up eutrophic waters through the culture of planktivorous fish species in cages (Beveridge*, 1984).

Category	Score	Justification
Ecosystem service potential	1	Fish cages are known to input organic matter into seawater and to the benthos, therefore they are a pressure rather than a service
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

No evidence found. Furthermore, to protect their structure, fish cages are located in low energy areas where erosion is unlikely to be a problem.

Water flow regulation

Any artificial structure introduced into the marine environment will influence the flow of water to some extent and potentially reduce wave energy. Fish cages are floating structures found in low energy environments. Their ability to influence water flow is therefore likely to be limited and dependent upon the dimensions of the fish cage.

Category	Score	Justification
Ecosystem service potential	1	Very localised, small scale and sheltered areas of the open sea
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

Cage aquaculture provides nursery habitats for juvenile wild fish as the cages carry epibionts such as numerous crustacean and algal species which the juvenile fish species can feed on (Costa-Pierce and Bridger, 2002).

Category	Score	Justification
Ecosystem service potential	1	Fish cages can provide some shelter and food supply to juveniles
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining habitats for charismatic species

The extra availability of food and shelter may attract additional species including charismatic species such as whale sharks.

Category	Score	Justification
Ecosystem service potential	1	Very specific to site and species, whale sharks are attracted to fish cages because of the food put into the cages
Confidence	2	General scientific support, but some uncertainty

Climate regulation

No evidence found.

3.2.3. Cultural services

Places for recreation (visitors and residents)

No evidence found.

Places for ceremonial activities

No evidence found.

Places for creative activities

No evidence found.

Places for knowledge-based activities

There is considerable research effort into the improvement of fish cage aquaculture production.

Category	Score	Justification
Ecosystem service potential	1	Research carried out on fish cages to improve aquaculture
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

3.3. Invertebrate aquaculture farms

Invertebrate aquaculture is an important sector in SE Asia. In 2017, SE Asian countries produced over 2.5 million t of invertebrates through aquaculture, primarily shrimps, but also clams, cockles, ark shells, mussels and oysters (FAOSTAT*, 2017) Invertebrates are cultivated through a variety of methods (*Table 16*). The effects of pearl oyster farms on ecosystem services are well studied compared to other types of aquaculture in the region, in particular within the case study sites.

Table 16: Common invertebrate species/groups grown in aquaculture in SE Asia

Group/species	Culture method(s)	References
Pearl oyster	Long lines	Cartier and Carpenter, 2014; Gifford et al., 2004; Lucas*, 2008; Sims*, 1992
Mud crab	Tanks, ponds, hapa nets within pond, open or closed enclosures, also in polyculture with milkfish	Agbayani, 2001; Shelley*, 2008
Shrimp	Ponds or tanks	Paclibare*, 2005
Green mussel (*Perna viridis*)	Poles, ropes, nets	Nair*, 2001
Blood cockle (*Tegillarca granosa*)	Culture beds in mudflats, spat collection in the wild	Kechik*, 1995

3.3.1. Provisioning services

Food, energy or other materials from plants

No evidence was found but it is possible that seaweeds growing on invertebrate aquaculture systems could be collected for subsistence use.

Category	Score	Justification
Ecosystem service potential	1	Possible collection of seaweed growing on aquaculture systems for subsistence purposes
Confidence	1	Evidence is limited. Considerable uncertainty, inconsistency or variability in the evidence

Food or other materials from animals

Food

Pearl oyster farming in a Polynesian lagoon had a slight positive effect on fish abundance and no effect on diversity or community composition (Cartier and Carpenter, 2014) suggesting that they do not act as fish aggregating devices.

Pelagic

No evidence found.

Demersal

In Palawan (Philippines), pearl farms provide shelter to several species of demersal fish species that are of commercial and subsistence use (Baltazar and Dalusung-Rodriguez, 2016). Specifically, the nets and baskets used in protecting the pearl oysters provide shelter to small fish from predators and substratum to fish larvae and juveniles. The biofouling organisms attached to the nets and pearl oysters also provide additional biomass and food to fish (Cartier and Carpenter, 2014). Thus, it increases fish abundance through increased structure or shelter of the pearl farm ("artificial reef") and increased proximal food availability (Cartier and Carpenter, 2014). This is affirmed by studies in Ahe, French Polynesia and Palawan, Philippines. Heavily impacted sites by pearl oyster farms in the western area of the Ahe lagoon, French Polynesia, had significantly higher reef fish abundance than sites not directly impacted by pearl oyster farms (Cartier and Carpenter, 2014). In the province of Palawan, the 12 pearl farms have moderate to high abundance of reef fish (750 to 9,773 individuals per 1000 m^2) (Baltazar and Dalusung-Rodriguez, 2016).

No evidence found for other forms of invertebrate aquaculture in the case study sites.

Category	Score	Justification
Ecosystem service potential	1	Some evidence of increases in demersal species of interest for human consumption but only from pearl farms
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Invertebrates

Invertebrate aquaculture is widespread in SE Asia. The table below indicates the production through aquaculture of marine invertebrates for Indonesia, Malaysia, the Philippines and Viet Nam for 2017 (FAO STAT 2020).

Country	Species	t	Value (USD 000)
Indonesia*	Mussels	50,000*	149*
	Clams, cockles, ark shells	200*	37,367*
Malaysia	Clams, cockles, ark shells	12,482	15,034
	Mussels	2,274	2,036
	Oysters	1,402	1,534
Philippines	Indo-Pacific swamp crab	3	40
	Mussels	19,209	6,860
	Oysters	22,944	5,144
Viet Nam	Miscellaneous marine molluscs	284,966	284,966

* FAO estimates

Category	Score	Justification
Ecosystem service potential	3	Production of invertebrates is the purpose of these farms
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Other materials

Pearl oysters (*Pinctada* spp.) and Mabe oyster *Pteria penguin* (for half pearl production) are farmed for the production of pearls in most countries in Southeast Asia (Nair*, 2001). Mother of pearl has also traditionally been used to make hooks, tools and ornaments in some parts of the world such as the Pacific Islands (Sims*, 1992).

Category	Score	Justification
Ecosystem service potential	1	Pearl and mother of pearl are produced in pearl farms, no evidence of other forms of invertebrate aquaculture was found in the case study sites
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Genetic materials from animals and plants

No evidence found. Spat and brood stock for invertebrate aquaculture are typically harvested from the wild or produced in hatcheries and are not collected from the culture sites.

3.3.2. Regulating services

Waste treatment and assimilation

All bivalves are filter feeders and it is well established in the literature that bivalves can contribute to the removal of wastes and pathogens from the water column although their capacity to do so will vary by species and location (van der Schatte Olivier et al., 2020).

Pearl oyster farms may aid in the management of water quality in coastal systems. Pearl oysters can take up substantial amounts of metals, nitrogen and phosphorus as well as lowering the concentration of pathogens from the seawater (Gifford et al., 2005; Gifford et al., 2004). Specifically, each tonne of Akoya pearl oysters harvested in Port Stephens, Australia removed 7.4 kg of nitrogen, 0.5 kg of phosphorus and up to 0.7 kg of metals from the water (Gifford et al., 2005). The farms also function as an important buffer and regulator of water purity and quality. One *Pinctada margaritifera* oyster in French Polynesia can filter between 11.5 and 25.9 litres per hour per gram of tissue dry weight (Lucas*, 2008).

Category	Score	Justification
Ecosystem service potential	2	Higher than seaweed farm, similar to mud
Confidence	2	General scientific support, but some uncertainty

Erosion control

Bed culture is known to increase seabed roughness and, outside of the study area, its potential to reduce erosive forces has been recognised (van der Schatte Olivier et al., 2020). However, invertebrate aquaculture typically occurs in sheltered areas where erosive forces are unlikely to be strong. The capacity to control erosive forces will also depend on the structure introduced.

Category	Score	Justification
Ecosystem service potential	1	Some limited evidence for bivalve aquaculture
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Water flow regulation

As for erosion control, increases seabed roughness through bivalve bed culture has the potential to reduce erosive forces (van der Schatte Olivier et al., 2020). It can also be assumed that any aquaculture infrastructure will have similar impacts on water flow regulation to other introduced structures such as fish cages and seaweed farms.

Category	Score	Justification
Ecosystem service potential	1	Some limited evidence for bivalve aquaculture
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

Elsewhere mussel beds, including those used for aquaculture, are recognised for their contribution to spawning and nursery habitat for commercially important fish species (Seitz et al., 2013). While much of this evidence is primarily derived from locations outside of SE Asia, it is not unreasonable to assume that bivalve beds in SE Asia will offer the same services.

Category	Score	Justification
Ecosystem service potential	1	Provides shelter and food supply
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining habitats for charismatic species

No evidence found.

Climate regulation

During shell production, bivalves are known to sequester carbon, but the calcification process also produces carbon dioxide. There is currently a dispute in the literature over the long-term net effect on carbon storage (van der Schatte Olivier et al., 2020 and references therein).

Category	Score	Justification
Ecosystem service potential	1	Compared to the other habitats, this is likely to be a minor contribution
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

3.3.3. Cultural ecosystem services

Places for recreation (visitors and residents)

No evidence found.

Places for ceremonial activities

In Tun Mustapha Park, Malaysia, one community (Kg. Mapan-Mapan) performs a ceremonial activity linked to their sea cucumber farms. To bless their harvest, community members throw yellow rice grains at their sea cucumber farms to pray for a larger yield (S. Johari and E. Vivian pers. obs.).

Category	Score	Justification
Ecosystem service potential	Present	Very limited evidence for only one location. No evidence for this practice being widespread
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

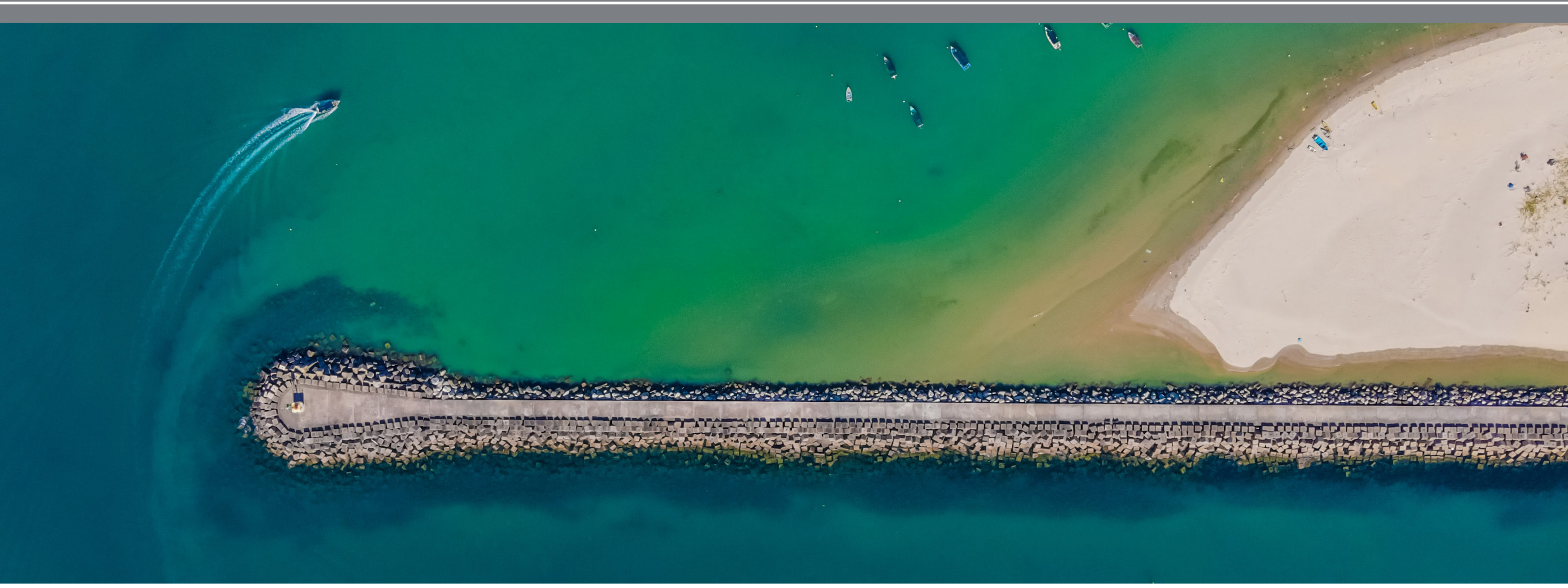
Places for creative activities

No evidence found. While the products from bivalve aquaculture can be used for creative purposes, there is no evidence to suggest that the aquaculture sites themselves are used for creative activities.

Places for knowledge-based activities

Substantial research has focused on the culture of mud crabs, pearls and other bivalves in the SE Asia region.

Category	Score	Justification
Ecosystem service potential	1	Teaching of new staff and research carried out to improve aquaculture production
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence



3.4. Artificial substrates

'Artificial substrates' is a catch-all term used here to capture structures used in coastal management, such as seawalls, groynes and breakwaters, as well as structures that facilitate the use of the marine environment such as jetties, pontoons and pier pilings. All comprise hard, artificial surfaces introduced into the marine and coastal environment. It is documented worldwide that such structures provide a habitat for a variety of epibenthic organisms, including macroalgae, invertebrates and fish (Bulleri and Airoldi, 2005). Their ability to provide ecosystem services will vary according to the substrate in which they are built, the natural habitats in which they are found and the materials from which they are made and how they are maintained (Bulleri and Airoldi, 2005; Lindegarth, 2001). Evidence from Australia suggests that, in a seawall setting, species may be similar to surrounding natural habitats, but abundance and frequency of occurrence may differ (Chapman and Bulleri, 2003). In a similar Australian study focusing on marinas, species found within and outside the marina were quite different, with fewer taxa with longer-lived larvae inside the marina (Rivero et al., 2013).

3.4.1. Provisioning services

Food, energy and other materials from plants

No evidence found.

Food or other materials from animals

Pelagic

Some evidence from Australia that species such as *Acanthopagrus australis* (yellowfin bream) and *Girella tricuspidata* (parore) move between marine structures and open water (Clynick, 2008). They and other fish are thus available to anglers.

Category	Score	Justification
Ecosystem service potential	1	This habitat provides a minor contribution to this service
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Demersal

No evidence found.

Invertebrates

No evidence found, but gleaning is an important activity in SE Asia and artificial substrates, where they are accessible, may provide a source of invertebrates.

Category	Score	Justification
Ecosystem service potential	1	This habitat provides a minor contribution to this service
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Other materials

No evidence found.

Genetic materials from animals and plants

No evidence found.

3.4.2. Regulating services

Waste treatment and regulation

Where epibenthic assemblages contain species that filter feed, artificial substrates may contribute to waste treatment and regulation.

Category	Score	Justification
Ecosystem service potential	1	This habitat provides a minor contribution to this service, similar to rock
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Erosion control

Not all artificial structures will effectively control erosion, but seawalls, groynes and breakwaters are commonly used coastal defence mechanisms that are designed to reduce erosion and protect assets on the landward side. Seaweed planting along with beach nourishment, sand stabilisation and utilisation of groynes has been recommended as a strategy to control erosion in coastal areas of Goa (Parab et al., 2011).

Category	Score	Justification
Ecosystem service potential	2	Many artificial structures are built for this purpose, although it is recognised that not all structures will be equally effective
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Water flow regulation

Not all artificial structures will effectively regulate water flows, but seawalls, groynes and breakwaters are commonly used coastal defence mechanisms that are designed to influence water flows and protect assets on the landward side.

Category	Score	Justification
Ecosystem service potential	3	Breakwaters and seawalls do attenuate waves, but others such as jetties and pontoons are not built for this purpose
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Maintaining nursery habitats

No literature found, but schools of fish are often sighted at jetties. Juvenile fish feed on algae growing on jetties and other artificial substrates. These structures also protect juveniles from predators. The potential for artificial substrates to provide this service will depend on the maintenance of the structure and whether antifouling chemicals are used to prevent growth of biofouling communities.

Category	Score	Justification
Ecosystem service potential	1	Some potential to support juvenile fish based on field observations and from other regions of the world. It is assumed to be similar to rock
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining habitats for charismatic species

No evidence found.

Category	Score	Justification
Ecosystem service potential	2	Provides some habitat for reef associated species
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Climate regulation

No evidence found.

3.4.3. Cultural Services

Places for recreation (visitors and residents)

Many artificial structures facilitate access into the marine environment for recreational visitors, such as jetties, pontoons and marinas. Some are also used for recreational angling. This will, however, be very context specific.

Category	Score	Justification
Ecosystem service potential	NA	Providing access to the marine and coastal environment for recreation is the purpose of some artificial structures, but they do not provide recreational space in their own right
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Places for ceremonial activities

No evidence found.

Places for creative activities

No evidence found.

Places for knowledge-based activities

There is very limited research into the environmental aspects of artificial substrates in Asia, although research exists on the design of coastal management structures and jetties, pontoons and pilings.

Category	Score	Justification
Ecosystem service potential	1	Designed based on research
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

3.5. Artificial beaches

Artificial beaches are habitats designed for coastal management that are sometimes preferred to hard structures (Katz*, 1993) and are classed as an ecological engineering solution to coastal erosion (Nguyen et al., 2015). Marine leisure areas in tourist destinations may include artificial beaches as a feature (Mottaghi et al., 2017). They can be affected by regular beach nourishment. Where increasing demand from tourism occurs alongside coastal degradation, it is increasingly common for marine leisure areas to be developed, which may include artificial beaches (Chee et al., 2017). Such developments can lead to negative environmental impacts (Mottaghi et al., 2017).

3.5.1. Provisioning services

Food, energy and other materials from plants

No evidence found.

Food or other materials from animals

Food

No evidence found.

Pelagic

No evidence found.

Demersal

No evidence found.

Invertebrates

No evidence found.

Other materials

No evidence found.

Genetic materials from animals and plants

No evidence found.

3.5.2. Regulating services

Waste treatment and regulation

No evidence found but it likely acts like sand.

Erosion control

Documented evidence is available globally for the success of artificial beaches and beach nourishment in combating coastal erosion (e.g. Finkl, 1981; Hanson et al., 2002).

Category	Score	Justification
Ecosystem service potential	1	Though evidence is available, research in other regions of the world are inconclusive about the effectiveness of beach nourishment and artificial beaches in erosion control
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Water flow regulation

Artificial beaches are used as a strategy to reduce the impact of storms and sea level rise (Bush* et al., 2001; Finkl* and Walker, 2018). It can therefore be assumed that the creation of a new beach will impact water flows.

Category	Score	Justification
Ecosystem service potential	1	Artificial beaches have some capacity to absorb energy and attenuate waves
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Maintaining nursery habitats

No evidence found.

Maintaining habitats for charismatic species

There is some evidence that artificial beaches can provide habitat for coastal species, including turtles (Crain et al., 1995), but the creation of these artificial habitats can also disrupt opportunities for these species if the beach morphology becomes too steep (Brown* and McLachlan, 2006).

Category	Score	Justification
Ecosystem service potential	1	Evidence is conflicted and the ability of artificial beaches to provide habitat will vary by species and level of disturbance
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

Climate regulation

No evidence found.

3.5.3. Cultural services

Places for recreation (visitors and residents)

Many artificial beaches and beach nourishment activities are undertaken to preserve and enhance recreational opportunities (Nicholls and Leatherman, 1995).

Category	Score	Justification
Ecosystem service potential	3	Often artificial beaches and beach nourishment are created to increase recreational potential in an area
Confidence	3	Strong, consistent evidence and/or intuitive scientific support

Places for ceremonial activities

No evidence found.

Places for creative activities

Category	Score	Justification
Ecosystem service potential	2	Same as natural sandy beaches
Confidence	2	General scientific support, but some uncertainty

Places for knowledge-based activities

Considerable research effort goes into the design of artificial beaches to ensure their success (e.g. Hsu et al., 2008).

Category	Score	Justification
Ecosystem service potential	1	Research has been undertaken on artificial beaches to improve their design and understand their effects on ecology
Confidence	1	Evidence is limited and there is considerable uncertainty, inconsistency, or variability in the evidence

4. Overview of final scores

In total, 477 references were used in this report. In addition, personal observations of the author team and personal communication with regional experts were used to find as much relevant information as possible to achieve this report.

Table 17: Final scores and confidence given to each habitat for each ecosystem service

Key

Potential for ecosystem service
High potential
Medium potential
Low potential
No potential
No evidence
Present

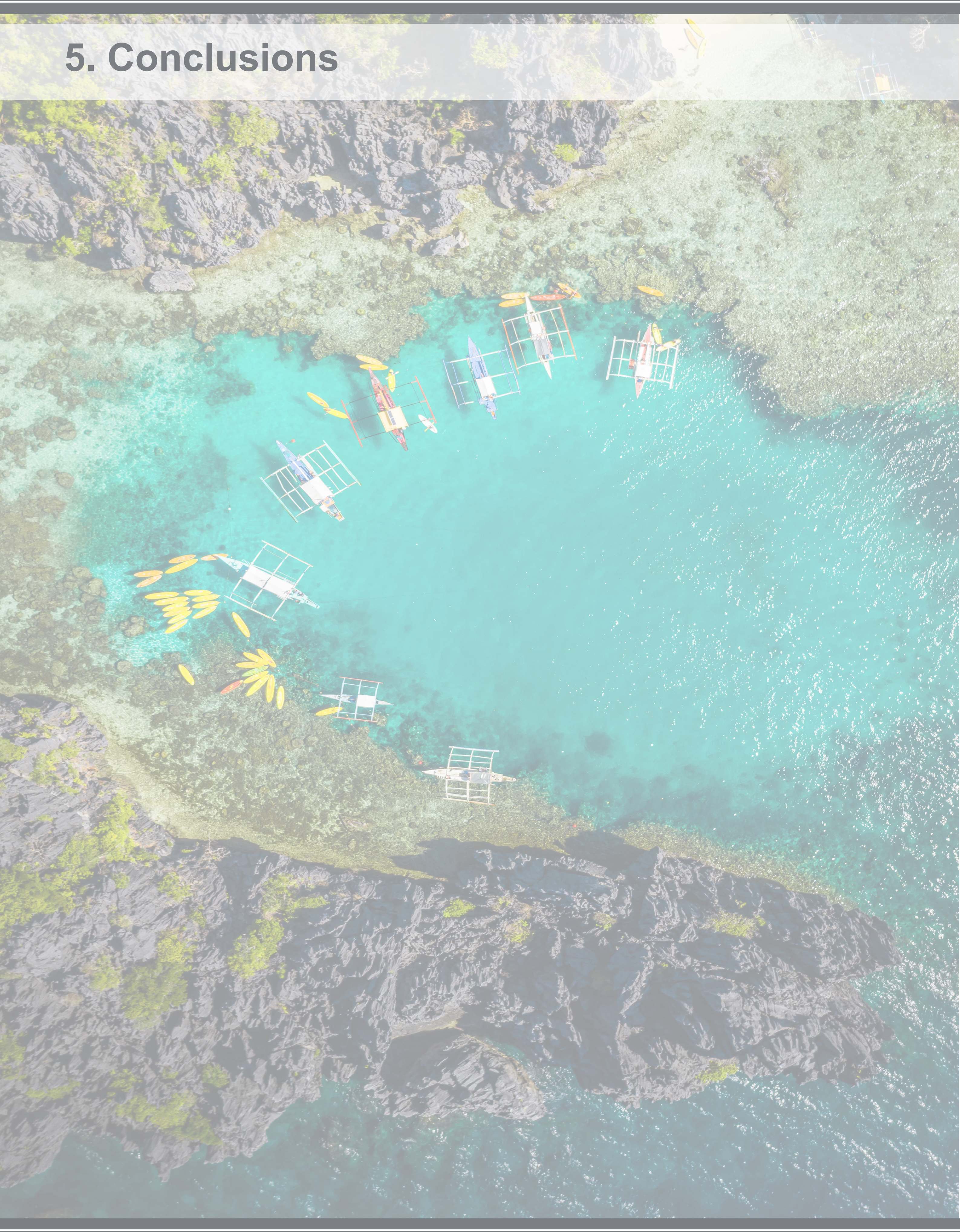
Confidence score	
3	High confidence
2	Medium confidence
1	Low confidence
NA	NA = not applicable as habitat does not provide the service

Other indicators	
In	Indonesia
It	Intertidal
St	Subtidal
M	Malaysia
V	Viet Nam

Table 17.

	Habitat	Mangrove	Coral	Seagrass	Sand	Mud	Rock	Overall coarse	Pelagic	Seaweed farms	Fish cages	Invertebrate aquaculture	Artificial substrate	Artificial beaches
Cultural services	Places for knowledge based activities	3	3	1	2	1	2	1	2 *It* / *M*	2	1	1	1	1
	Places for creative activities	3 / *In*	2	1	2	1	1 / *V*	1	2					2
	Places for ceremonial activities	3	2	1	2	1	2		2			1		
	Places for recreation	3	3	1	3 *It* / 1 *St*	1 / *V* NA	2		3	2			1	3
Regulating services	Climate regulation	3	2	3	2	1			1	1		1		
	Maintaining habitats for charismatic species	3	3	3	2	2	1		3	1	2		1	1
	Maintaining nursery habitats	3	3	3	2	2 *It* / 1 *St*			3	1	1	1	1	
	Water flow regulation	3	2	2	2	1	1	1		1	1	1	3	1
	Erosion control	3	2	2	2	1	1	1		1		1	3	1
	Treatment and assimilation of wastes or toxic substances	3		3	1	3	1	1	1	3	1	2	1	
Provisioning services	Genetic material from animals	3	3	3	1	3			1	2				
	Other materials from animals	2	3	2	3	1	1	1	2			1		
	Food from other invertebrates	3	3	2	2	3	1	1	3		1	3	1	
	Food from demersal fish	1	3	1	1	2	1	1	1	2	3	1		
	Food from pelagic animals	1	1	1	1	1	1	1	3		1		1	
	Other materials from plants	3	1	2		NA	1			3				
	Energy from plants	3				NA								
	Food from plants	3	1	1	1	NA	1			3	1	1		

5. Conclusions



Marine tropical habitats provide many different ecosystem services to people in SE Asia as evidenced in this report. This result is also reflected in the MEA* (2005) and more recently the biodiversity and ecosystem service assessment carried out for the Asian Pacific region by the International Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES*, 2018).

Mangroves, coral reefs and seagrass beds were found to be comparatively well studied, with a large literature base evidencing their potential to supply ecosystem services. Sedimentary, rock and artificial habitats are less well studied in the region and hence scores for these habitats rely more heavily on expert opinion. Likewise, microhabitats are not well represented in the literature and therefore most habitats were assessed on the macrolevel only, except mud and sand which were split into intertidal and subtidal microhabitats.

Ecosystem services are also not all studied equally. Provisioning ecosystem services seem to be the most well understood, compared to regulating and cultural. This is a common problem globally, and one reason to use an ecosystem service approach is to raise awareness for the less obvious ecosystem services such as regulating and cultural ones and then include them in any management measures. Only then can linkages between them be assessed and the protection of those services prioritised that are important in regional and local settings (for example by protecting mangroves to ensure flood defences in flood prone areas). This ensures an ecosystem-based management approach can be taken, where multiple economic sectors are regulated with the common goal of protecting a larger set of ecosystem services, than when only one sector (such as fishing) is managed.

For some regulating services, expert opinion was used based on knowledge drawn from other regions. This was not possible for cultural services, however, because they can be very dependent on the context and the culture and traditions of the people living within each case study site. One important discussion observation made during this work was the interconnectivity of cultural services amongst themselves and to other services. This made assessment difficult but needs highlighting. For example, some recreational activities carried out by tourists in SE Asia are also creating knowledge for the participants such as bird-watching or SCUBA diving. Watching a ceremonial activity taking place in the mangroves also creates knowledge for the resident participants and visitors who watch it. In this study, we decided to assess each service separately, even where they co-occur within a habitat and are used by the same individual. This may be seen as double counting, but we argue that this way no service is undervalued or omitted entirely and therefore potentially overlooked in management measures. In addition, this report does not carry out a valuation and therefore double counting does not take place here.

Cultural ecosystem services are also not distributed equally across all habitats and – for that matter – Southeast Asia. Depending on local community traditions, a particular habitat may be more important for ceremonial activities than in another locality even though the habitats are otherwise comparable. This may be true for all ecosystem services and therefore regional and local approaches are important to help assess ecosystem services as accurately as possible.

This work did not assess pressures to ecosystems and the services they provide. This will be the subject of a separate study because it can be helpful to have split both aspects to be able to decipher the complexity of marine ecosystems. Therefore, climate change or invasive alien species are not mentioned even though they are both recognized as strong pressures that are reducing biodiversity and ecosystem services – globally and in SE Asia (IPBES*, 2018).

The objective of this work is to help inform sustainable management of the rich marine biodiversity and ecosystem services in SE Asia. This can be achieved by informing policy makers, managers and stakeholders how ecosystems differ in the provision of ecosystem services. In its simplest form, this knowledge can be taken into consideration when the possible effects of potential management options on ecosystems are weighed against each other. Trade-offs can also be visualised and assessed in a more advanced manner, for example by creating management scenarios that can then be compared to each other in network analysis such as Bayesian Belief Networks. However, this report alone cannot achieve sustainable management, other factors need to be aligned, for example there must be political will to adapt a sustainable management approach, stakeholders such as fishermen must be able to afford changes to their practices etc. Therefore, this work alone cannot achieve sustainable outcomes, but it is hoped that it is an important factor in it.

6. Acknowledgements

The authors would like to thank Dr Lydia Teh, Dr Justine Saunders, Dr Natasha Bhatia and Dr Paul Somerfield for feedback on the first draft which significantly improved the report. This work was funded by the Global Challenges Research Fund (GCRF) via the United Kingdom Research and Innovation (UKRI) under grant agreement reference NE/P021107/1 to the Blue Communities Programme.

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8. Images

Page number	Image caption
Front cover ii & 1	Philippines. Dr Timur Jack-Kadioglu, former Blue Communities Early Career Researcher
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