



ecomarine-project.eu

[f facebook.com/Ecomarine.project](https://facebook.com/Ecomarine.project)

[t twitter.com/ecomarine_](https://twitter.com/ecomarine_)

D1.1 Marine ecosystem monitoring in Malaysia and India



Co-funded by the
Erasmus+ Programme
of the European Union

This project has been funded with support from the European Commission. This document reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

PROJECT INFORMATION

| | |
|------------------|--|
| Project Acronym | EcoMarine |
| Project title | Building a Comprehensive Mechanism for Preserving Marine Ecosystems and Life from the negative consequences of Climate Change and the disposal of Plastic Debris |
| Agreement number | 619158-EPP-1-2020-1-CY-EPPKA2-CBHE-JP |
| EU programme | Capacity Building for Higher Education (EAC/A02-2019-CBHE) |
| Project website | www.ecomarine-project.eu |

PREPARED BY

| | |
|---------------------|---|
| Organization | Universiti Malaysia Terengganu (Malaysia) Universiti Kebangsaan Malaysia (Malaysia) Andhra University (India) Adarsh Foundation (India) Universidad De Oviedo (Spain) |
| Authors | Kesaven Bhubalan Fredolin Tanggang Simple Doshi Janakiram Pasupuleti José Manuel Rico (Uniovi) Alba Ardura (Uniovi) Yaisel J. Borrell (Uniovi) |
| Date | 23 June 2021 |
| Version | V 2.0 |
| Dissemination Level | Restricted to other E+ Programme participants (including EACEA, Commission services and project reviewers) |

| | |
|------------------|---|
| Reviewed by | Dr Georgios Georgiou |
| Date of Review | |
| Acceptance level | Accepted <input type="checkbox"/> To be reviewed <input type="checkbox"/> Rejected <input type="checkbox"/> |



Table of Contents

| | |
|---|----|
| 1.Executive Summary | 4 |
| 2.Marine Ecosystem Monitoring in the European Union (EU)..... | 5 |
| 2.1. Introduction. | 5 |
| 2.2. Detailing the MSFD European descriptors to Monitor Marine Ecosystems. | 6 |
| 2.2. The European strategy to address the impacts on marine ecosystem (Climate Change, Blue Carbon, Marine Litter and Protected Marine Ecosystems)..... | 15 |
| 3.Marine ecosystem monitoring in Malaysia..... | 17 |
| 3.1. Introduction | 17 |
| 3.2. Situation on marine ecosystem impacts..... | 17 |
| 3.2.1. Climate change | 17 |
| 3.2.2. Ocean acidification | 21 |
| 3.2.3. Blue Carbon | 22 |
| 3.2.4. Coral reef, seagrass meadows, and mangroves | 24 |
| 3.2.5. Microplastic debris in marine ecosystem | 29 |
| 3.3. Marine monitoring facilities | 31 |
| 4.Marine ecosystem monitoring in India | 34 |
| 4.1. Introduction | 34 |
| 4.2. Threats to Coastal/marine Ecosystems | 36 |
| 4.2.1. Climate monitoring..... | 36 |
| 4.2.2. Ocean acidification and temperature rise | 37 |
| 4.2.3. Blue carbon monitoring | 37 |
| 4.2.4. Coral reef, seagrass and mangroves assessment | 38 |
| 4.2.5. Monitoring the abundance of plastic debris | 40 |
| 4.3. Marine monitoring facilities | 42 |
| 5.Conclusions | 45 |
| 6.References..... | 46 |
| 7. Appendix | 52 |
| 7.1 List of Tables..... | 52 |

| | |
|---------------------------|----|
| 7.2 List of Figures | 52 |
|---------------------------|----|

1. Executive Summary

Monitoring can be defined as the systematic measurement of biotic and abiotic parameters of the marine environment, with predefined spatial and temporal schedule, having the purpose to produce data sets that can be used for application of assessment methods and derive credible conclusions on whether the desired state (Good Environmental Status; GES) is achieved or not and on the trend of changes for the marine area concerned (Zampoukas et al., 2012). Since 2014, the Marine Strategy Framework Directive requires from European Union Member States to establish ecological monitoring programmes covering all their marine waters and therefore extend existing monitoring and include additional elements such as GES descriptors. In this document we revised the principles of integrated monitoring and large scale approaches established for the European Union. In particular, we addressed the European strategy to address the impacts on marine ecosystem related with Climate Change, Blue Carbon, Marine Litter and Protected Marine Ecosystems. The same objective is then pursued for Malaysia and India after revising current studies, strategies and findings when monitoring Asian marine ecosystems.

Several knowledge and methodological gaps arise from this study. The main concerns are related with poor information about changes in species composition and abundance over time in the countries ecosystems and the lack of baseline data for fisheries and aquaculture impacts, blue carbon assessments and plastic contamination by coastal ecosystems/regions. The ECOMARINE project intends to create full operationally marine conservation monitoring labs in Malaysia and India. Monitoring must include and defined the elements to measure, the location of sampling sites, the periodicity of sampling, the collection of field samples and data, processing of the samples in the laboratory and the compilation and management of the data. The ECOMARINE project, besides establishing the four Marine Laboratory Labs, will also develop both, in situ and in Europe, educational strategies (including theoretical and practical lessons) that help in the training of researchers and in the development of updated assessment methods and classification of GES in the Malaysia and India marine ecosystems under study.



2. Marine Ecosystem Monitoring in the European Union (EU).

2.1. Introduction.

The basis of marine monitoring in European countries belonging to the European Union is set in the Marine Strategy Framework Directive 2008/56/EC (MSFD) which sets a target of “Good Environmental Status” (GES) to be reached (as in the initial document) by 2020. Each member state has, in order to meet this target, to develop an effective description of the state of its marine environment, a definition of GES at regional level and the establishment of clear environmental targets and monitoring programmes. GES is determined using a set of 11 descriptors, which were defined in a Commission decision on the 1st of September 2010 (2010/477/EU) on descriptors and are the following (text in bold is the literal descriptor of GES) (see also Table 1):

Table 1. The MSFD descriptors to determine Good Environmental status in the EU.

| MSFD Descriptor | Climate change relevance | Blue Carbon relevance | Marine litter relevance | Protected marine ecosystems relevance |
|-------------------------------|--|--|-------------------------|---|
| D1. Biological diversity | The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions | Relevant habitats: saltmarshes and seagrass beds | | Changes in distribution and abundance of species, alteration of habitats and ecosystems |
| D2. Non indigenous species | | | | Ecological effects of NIAS |
| D3. Commercial species | Alterations in size distribution and/or population parameters | | | |
| D4. Marine food webs | Alterations in food web structure and productivity | Productivity of primary producers, food web structure | | |
| D5. Eutrophication | | Alterations in biogeochemical marine cycles | | |
| D6. Seafloor integrity | Stability of benthic ecosystems | Productivity of sensitive benthic ecosystems | | Ecological effects of human activities on protected marine ecosystems |
| D7. Hydrographical conditions | Basic baseline information of physical and chemical factors | Impact of extreme events on shallow coastal soft bottom ecosystems | | Changes in coastal dynamics Sea level rise Acidification |
| D8. Contaminants | | | | Maintenance of pristine conditions |
| D9. Contaminants in fish | | | | Socioeconomic effects on artisanal fisheries |
| D10. Marine litter | | | Directly relevant | Maintenance of pristine conditions |
| D11. Energy and noise | | | | Maintenance of pristine conditions Competition for coastal resources |

2.2. Detailing the MSFD European descriptors to Monitor Marine Ecosystems.

Descriptor 1: BIODIVERSITY

Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions.

The assessment for this descriptor should include different levels of organization, from species to ecosystems, and accordingly must be monitored at the level of species, habitats and ecosystems. At each level, different criteria need to be met. At the species level, and once each coastal region per member state has identified the target species, the indicators are **species distribution**, **population size** and **population condition**. In relation to biodiversity at the level of species, the three criteria for assessing progress towards good environmental status, as well as the indicators related respectively to them, are the following:

1.1. Species distribution

—Distributional range (1.1.1)

—Distributional pattern within the latter, where appropriate (1.1.2) — Area covered by the species (for sessile/benthic species) (1.1.3)

1.2. Population size

—Population abundance and/or biomass, as appropriate (1.2.1)

1.3. Population condition

—Population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity rates, survival/ mortality rates) (1.3.1)

—Population genetic structure, where appropriate (1.3.2).

At the habitat level, a set of habitat types needs to be drawn per region, addressing both the abiotic characteristics and the biotic assemblage. At this level adequate mapping of these habitats, in a coherent classification scheme, is essential for good measurement of this subdescriptor for biodiversity. For each habitat, the criteria and indicators are:

1.4. Habitat distribution

—Distributional range (1.4.1)

—Distributional pattern (1.4.2)



Co-funded by the
Erasmus+ Programme
of the European Union

This project has been funded with support from the European Commission. This document reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

1.5. Habitat extent

- Habitat area (1.5.1)
- Habitat volume, where relevant (1.5.2)

1.6. Habitat condition

- Condition of the typical species and communities (1.6.1)
- Relative abundance and/or biomass, as appropriate (1.6.2)
- Physical, hydrological and chemical conditions (1.6.3)

At the ecosystem level, addressing functional relationships between the different elements in each ecosystems, as well as considering connectivity and resilience, are considered essential.

1.7. Ecosystem structure

- Composition and relative proportions of ecosystem components (habitats and species) (1.7.1)

Descriptor 2: NON-INDIGENOUS SPECIES

Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem.

For this descriptor a previous knowledge of the pathways for introduction of marine non indigenous species is needed, as is also of the vectors for their spread. It is acknowledged that the precise evaluation of the environmental consequences of exotic species introductions is still not fully understood, although some tools like the Environmental Impact Classification of Alien Taxa (EICAT) which is the IUCN Standard for the classification of the impact of alien species on the environment can be adopted. Accordingly, the criteria and indicators are:

2.1. Abundance and state characterization of non-indigenous species, in particular invasive species

- Trends in abundance, temporal occurrence and spatial distribution in the wild of non-indigenous species, particularly invasive non-indigenous species, notably in risk areas, in relation to the main vectors and pathways of spreading of such species (2.1.1)

2.2. Environmental impact of invasive non-indigenous species

- Ratio between invasive non-indigenous species and native species in some well-studied taxonomic groups (e.g. fish, macroalgae, molluscs) that may provide a measure of change in species composition (e.g. further to the displacement of native species) (2.2.1)



— Impacts of non-indigenous invasive species at the level of species, habitats and ecosystem, where feasible (2.2.2).

Descriptor 3: COMMERCIAL SPECIES

Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.

The implications for this descriptor are that commercial species are exploited sustainably, and that full reproductive capacity and the proportion of larger and older individuals are maintained for all living resources targeted for an economic profit. For this descriptor, primary and secondary indicators are included, acknowledging the difficulties of adequate data collection in several cases.

3.1. Level of pressure of the fishing activity.

—*Primary indicator:* Fishing mortality (F) (3.1.1), which should be equal or lower to that assuring Maximum Sustainable Yield (MSY).

—*Secondary indicator:* Ratio between catch and biomass index ('catch/biomass ratio') (3.1.2).

3.2. Reproductive capacity of the stock.

—*Primary indicator:* Spawning Stock Biomass (SSB) (3.2.1).

—*Secondary indicator:* Biomass indices (3.2.2)

3.3. Population age and size distribution*Primary indicators.*

—Proportion of fish larger than the mean size of first sexual maturation (3.3.1)

—Mean maximum length across all species found in research vessel surveys (3.3.2)

—95 % percentile of the fish length distribution observed in research vessel surveys (3.3.3).

Secondary indicators:

—Size at first sexual maturation, which may reflect the extent of undesirable genetic effects of exploitation (3.3.4).

Descriptor 4: MARINE FOOD WEBS

All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long term abundance of the species and the retention of their full reproductive capacity.

The aim of this descriptor is to measure the health of food chains and food webs, that is, the network of biotic interactions between different species in the ecosystem. This descriptor represents one of the most complex and unknown aspects of marine ecosystems, since the identification of simple indicators able to assess the status of the system with dynamic species interactions and the identification of underlying responses to pressures, is difficult, provided that reducing the complexity of dynamic species interactions to a simple figure has proven difficult in most cases, and network analysis of biotic systems, a novel tool for this analysis, is resilient to simplified outputs. Having this in mind, the proposed indicators are based on functional aspects such as energy flow and food web structure, but further developments will be needed to reach a consensus set of indicators.

4.1. Productivity (production per unit biomass) of key species or trophic groups

—Performance of key predator species using their production per unit biomass (productivity) (4.1.1).

4.2. Proportion of selected species at the top of food webs

—Large fish (by weight) (4.2.1).

4.3. Abundance/distribution of key trophic groups/species

—Abundance trends of functionally important selected groups/species (4.3.1).

- groups with fast turnover rates (e.g. phytoplankton, zooplankton, jellyfish, bivalve molluscs, short-living pelagic fish) that will respond quickly to ecosystem change and are useful as early warning indicators,
- groups/species that are targeted by human activities or that are indirectly affected by them (in particular, by-catch and discards),
- habitat-defining groups/species,
- Groups/species at the top of the food web,
- long-distance anadromous and catadromous migrating species,
- Groups/species that are tightly linked to specific groups/species at another trophic level.

Descriptor 5: HUMAN-INDUCED EUTROPHICATION

Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.

This descriptor indicates directly one of the main anthropogenic effects for biodiversity loss and alteration in the marine environment. Since the process is originated by excess supply of nutrients, mainly Nitrogen and Phosphorus, to coastal environments, the indicators are mostly biogeochemical, and in EU countries, the assessment of GES for this descriptor is closely linked to the Water Framework Directive applied to transitional waters.

5.1. Nutrients levels

—Nutrients concentration in the water column (5.1.1)

—Nutrient ratios (silica, nitrogen and phosphorus), where appropriate (5.1.2)

5.2. Direct effects of nutrient enrichment

- Chlorophyll concentration in the water column (5.2.1)
- Water transparency related to increase in suspended algae, where relevant (5.2.2)
- Abundance of opportunistic macroalgae (5.2.3)
- Species shift in floristic composition such as diatom to flagellate ratio, benthic to pelagic shifts, as well as bloom events of nuisance/toxic algal blooms (e.g. cyanobacteria) caused by human activities (5.2.4)

5.3. Indirect effects of nutrient enrichment

- Abundance of perennial seaweeds and seagrasses (e.g. fucoids, eelgrass and Neptune grass) adversely impacted by decrease in water transparency (5.3.1)
- Dissolved oxygen, i.e. changes due to increased organic matter decomposition and size of the area concerned (5.3.2).

Descriptor 6: SEAFLOOR INTEGRITY

Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.

Only 5 % of the bottom of the oceans has been mapped and explored, and this descriptor calls for an initial screening of threats and risks from human activities, and a monitoring that considers the



patchy nature of benthic habitats. The indicators should address the magnitude and importance of impacts to the seabed, and the assessment of the condition of healthy benthic communities and a detailed mapping and description of biogenic bottom substrates.

6.1. Physical damage, having regard to substrate characteristics

- Type, abundance, biomass and areal extent of relevant biogenic substrate (6.1.1)

- Extent of the seabed significantly affected by human activities for the different substrate types (6.1.2).

6.2. Condition of benthic community

- Presence of particularly sensitive and/or tolerant species (6.2.1)

- Multi-metric indexes assessing benthic community condition and functionality, such as species diversity and richness, proportion of opportunistic to sensitive species (6.2.2)

- Proportion of biomass or number of individuals in the macrobenthos above some specified length/size (6.2.3)

- Parameters describing the characteristics (shape, slope and intercept) of the size spectrum of the benthic community (6.2.4).

Descriptor 7: HYDROGRAPHICAL CONDITIONS

Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.

Physical characteristics such as temperature, salinity, depth, currents, tidal regime and many other can be significantly modified by human activities, and the aim of this descriptor is the evaluation of the extent of this changes and their potential effects on the structure and function of marine ecosystems, and on their biodiversity. Environmental impacts assessment tools and rules, as well as integrated coastal zone management strategies, are the basis for the indicators.

7.1. Spatial characterization of permanent alterations

- Extent of area affected by permanent alterations (7.1.1)

7.2. Impact of permanent hydrographical changes

- Spatial extent of habitats affected by the permanent alteration (7.2.1)



—Changes in habitats, in particular the functions provided (e.g. spawning, breeding and feeding areas and migration routes of fish, birds and mammals), due to altered hydrographical conditions (7.2.2).

Descriptor 8: CONTAMINANTS

Contaminants are at a level not giving rise to pollution effects.

This descriptor evaluates the presence and concentrations of all potential contaminants, as defined by the Water Framework Directive, i. e., *substances (i.e. chemical elements and compounds) or groups of substances that are toxic, persistent and liable to bio-accumulate and other substances or groups of substances which give rise to an equivalent level of concern*. The Stockholm Convention on organic toxic persistent pollutants includes already a list of some of these compounds, but it has to be expanded to accommodate several other, organic and inorganic, that meet the three above mentioned characteristics: toxicity, persistence in the environment and the ability to bioaccumulate. The group of substances should also consider EU legislation and that of member states on Water Quality Standards to set the detection ranges for this substances. Note that inorganic pollution related only to eutrophication is addressed by descriptor 5.

8.1. Concentration of contaminants

—Concentration of the contaminants mentioned above, measured in the relevant matrix (such as biota, sediment and water) in a way that ensures comparability with the assessments under Directive 2000/60/EC (8.1.1)

8.2. Effects of contaminants

—Levels of pollution effects on the ecosystem components concerned, having regard to the selected biological processes and taxonomic groups where a cause/effect relationship has been established and needs to be monitored (8.2.1)

—Occurrence, origin (where possible), extent of significant acute pollution events (e.g. slicks from oil and oil products) and their impact on biota physically affected by this pollution (8.2.2).

Descriptor 9: CONTAMINATION OF FISH AND SEAFOODS

Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

Food security is an essential aspect of food production. Capture fisheries of fishes and shellfish for the European consumer must not pose a risk to human health, and accordingly, member states should assure that capture fisheries and aquaculture products from marine environments have



levels of contaminants always below those set by EU, national and regional authorities for products used for human consumption.

9.1. Levels, number and frequency of contaminants

—Actual levels of contaminants that have been detected and number of contaminants which have exceeded maximum regulatory levels (9.1.1)

—Frequency of regulatory levels being exceeded (9.1.2).

Descriptor 10: MARINE LITTER

Properties and quantities of marine litter do not cause harm to the coastal and marine environment

Marine litter is becoming one of the major sources of impact on the marine environment, both in high seas and in coastal environments. The presence of macroplastics from terrestrial origin and from marine sources (ghost nets, for instance) are increasingly interfering with marine life, and have become also vectors for the introduction of marine non indigenous species via oceanic currents. Microplastics that result from the degradation of these macroplastics, and from industrial sources, are of particular concern due to their small size but high toxicity and bioaccumulation in digestive tracts of top predators, which eventually may be also used for human consumption. Although some indicators are already included, there is still further research needed on new indicators, notably those relating to biological impacts and to micro-particles, as well as for the enhanced assessment of their potential toxicity.

10.1. Characteristics of litter in the marine and coastal environment

—Trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source (10.1.1)

—Trends in the amount of litter in the water column (including floating at the surface) and deposited on the sea-floor, including analysis of its composition, spatial distribution and, where possible, source (10.1.2)

—Trends in the amount, distribution and, where possible, composition of micro-particles (in particular micro-plastics) (10.1.3)

10.2. Impacts of litter on marine life

—Trends in the amount and composition of litter ingested by marine animals (e.g. stomach analysis) (10.2.1).



Descriptor 11: ENERGY AND NOISE

Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Technical developments for the exploration of the sea, novel energy production and transport systems, telecommunications and even maritime transport generate anthropogenic sources of energy (like short pulses for seismic exploration, explosions when building coastal structures, operation of offshore wind turbines) and noise that may affect marine life.

11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds

—Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re $1\mu\text{Pa}^2\cdot\text{s}$) or as peak sound pressure level (in dB re $1\mu\text{Pa}_{\text{peak}}$) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)

11.2. Continuous low frequency sound

—Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re $1\mu\text{Pa}$ RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (11.2.1).



2.2. The European strategy to address the impacts on marine ecosystem (Climate Change, Blue Carbon, Marine Litter and Protected Marine Ecosystems)

CLIMATE CHANGE

The strategy addressing climate change in Europe is defined in the European Green Deal, which is a communication from the European commission defining the framework and objectives for achieving climate neutrality by 2050. It commits to the implementation of an EU 2030 Biodiversity Strategy, a Zero Pollution Action Plan, a Farm to Fork Strategy, a Circular Economy Action Plan, and a Climate Law. As part of this plan, the first initiatives include:

- European Climate Law to enshrine the 2050 climate-neutrality objective into EU law
- European Climate Pact to engage citizens and all parts of society in climate action
- 2030 Climate Target Plan to further reduce net greenhouse gas emissions by at least 55% by 2030
- New EU Strategy on Climate Adaptation to make Europe a climate-resilient society by 2050, fully adapted to the unavoidable impacts of climate change.

The MSFD is consistent with this Green Deal, and as seen in the table attached, descriptors 1, 3, 4, 6 and 7 contain indicators relevant for this action.

BLUE CARBON

Europe needs to integrate blue carbon ecosystems into the policies for the mitigation of climate change, and to give marine ecosystems the same relevance as terrestrial ones in this sense. The European Parliament Intergroup on *Climate Change, Biodiversity, and Sustainable Development*, has a Working Group on Biodiversity and Ecosystem Services. One of the conclusions in the first report from this Working Group, after a seminar held in 2018, is that no EU country has any reference to coastal ecosystems (and blue carbon storage) in their National Determined Contributions. The roadmap for inclusion of wetlands into the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF) by 2026 will help to update the role of these ecosystems at EU level and the national contributions (NDCs and national GHG inventory submissions) by countries. Descriptors 1, 4, 5, 6 y 7 include relevant indicators for the measurement of blue carbon sequestration in Europe.



MARINE LITTER (PLASTICS AND MICROPLASTICS)

The problem with monitoring marine litter (Descriptor 10) is that it needs, as underwater noise (Descriptor 11), novel monitoring programs that were not previously developed under any of the previous Directives. There is appropriate spatial coverage and frequency of monitoring litter on the beach. In the North-East Atlantic Ocean, ingested litter is also monitored systematically in seabird strandings. A satisfactory degree of consistency in monitoring programmes is found in most marine regions, and links to international and regional standards are clear. Most Member States refer to the monitoring guidance developed by the MSFD Technical Group on Marine Litter, which provides the necessary harmonization.

Nevertheless, there are several areas that need urgent improvement. For instance, litter monitoring in the seabed and water surface and monitoring of micro-litter is far from adequate. There is no systematic and comparable monitoring of the impact of litter on marine animals and nature. Localization and the extent of human activities generating marine litter are often not covered by the monitoring programmes in place.

Finally, there are no agreed baselines or thresholds for litter and micro-litter, which makes the monitoring of progress towards good environmental status difficult. This will also affect the EU's ability to meet internal (7th Environment Action Programme to 2020, Circular Economy action plan) and international commitments.

PROTECTED MARINE ECOSYSTEMS

Marine Protected Areas in Europe have been the subject, in some cases, priority, of several Directives, mainly the Habitats Directive launched in 1992, but also the Birds Directive, the Marine Natura 2000 development of the Natura 2000 and Directive 2014/89/EU establishing a framework for maritime spatial planning. The EU Biodiversity Strategy to 2020, launched in 2011, was created to complete the establishment of the Natura 2000 network and ensure good management, and the MSFD has the target to include spatial protection measures contributing to coherent and representative networks of MPAs, adequately covering constituent ecosystems. Descriptor 1 specifically addresses the need to monitor habitat indicators and ecosystem structure indicators, and Descriptors 2 and 6-11 contain the indicators useful for assessing the Good Environmental Status of pristine and protected ecosystems with regard to specific aspects such as alien species introductions (D2) or competition for alternative uses (D10).



3. Marine ecosystem monitoring in Malaysia

3.1. Introduction

Malaysian marine ecosystem is among the most diverse ecosystem with wide range of habitats such as mangrove, coral reef, mudflats, estuaries, and seagrass which encompasses of 42,330 km² of coastal zone, 4,675 km of coastline and 549,500 km² of sea (Yusoff et al., 2006). These marine ecosystems are extensively influenced by anthropogenic activities such as fishing, tourism, marine transportation and port activities, urban development which generates significant economic output for Malaysia and. In tandem with climate change, the increasing anthropogenic activities results in environmental damages such as coastal erosion, coral reef bleaching, water and plastic pollution and depletion of marine resources from fishing activities which could lead to catastrophic effects that can harm the population that is reliant on its resources. Over the years, governmental initiatives were undertaken to protect and conserve the marine ecosystem while managing marine reliant economic activities through measures such as establishment of governmental agencies such as Department of Fisheries, Department of Environment, Malaysian Maritime Enforcement Agency, and Marine Department. Furthermore, Malaysia is also signatory of various international conventions that deal with marine ecosystem such as United Nations Convention on the Law of the Sea (1982, https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf), International Convention for the Prevention of Pollution from Ships (MARPOL) (1973, [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-\(MARPOL\).aspx#:~:text=The%20International%20Convention%20for%20the,2%20November%201973%20at%20IMO](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx#:~:text=The%20International%20Convention%20for%20the,2%20November%201973%20at%20IMO)) and Aichi Biodiversity Targets- Convention of Biological Diversity (<https://www.cbd.int/sp/targets/>).

However, any conservation and mitigation efforts require understanding of impacts at ground level to ensure effective and inclusive measures can be implemented. This report will report on different aspects of documented works in marine ecosystem impact assessment in Malaysian waters.

3.2. Situation on marine ecosystem impacts

3.2.1. Climate change

Climate change issue is potentially an existential level threat currently being faced by the planet. Unprecedented level of anthropogenic activities has sped the rate of climate change and ocean ecosystem is facing changes in terms of sea surface temperature, changes in marine organisms' distribution and diversity shift. Climate changes have consequences on marine ecosystem structure and functioning that is essential for humanities survival. Therefore, research on climate change in marine environment is important to understand the extent of changes and mitigation measures that can be undertaken to protect the marine ecosystem.

Studies on climate change has been approached at various angles but the most common approach is thru analysis of weather data such as sea surface temperature (SST), rainfall, annual



temperature, and greenhouse gasses (GHG) over long term period (**Figure 1**) (Aziz et al., 2016; Isa et al., 2020; Tang, 2019). General findings reported on increase in SST, annual temperature and GHG emissions that will negatively impact the ecosystem and the associated services. Measurement of these parameters also yields prediction on future weather conditions that enable relevant authorities to prepare to face or mitigate the climate change effects.

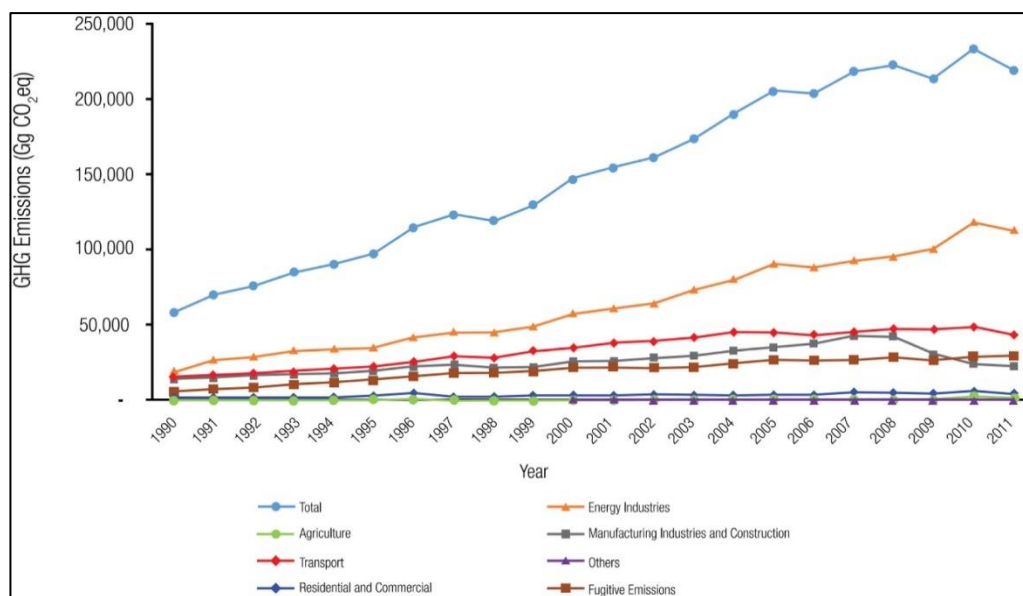


Figure 1. GHGs emission of the energy sector from 1990 to 2011 in Malaysia (Tang, 2019).

For instance, Tang (2019) reviewed the observation data on mean daily temperature, extreme weather, rainfall, and mean sea level and predicted the future weather conditions. It is reported that changes in annual mean temperature, occurrences of extreme weather events and mean sea level are rising while rainfall shows variability. In a latest paper Tan et al. (2021) clearly showed that mean and extreme temperature has been increasing since the last four decades, consistent with the global increase. Whereas future projections point to continuous rise of temperature and mean sea level till the end of the 21st century, highly variable rainfall, and increased frequency of extreme weather events. Tangang et al. (2018) showed that mean temperature increases in Southeast Asia including Malaysia by the end of the 21st century would be expected to be around 4.5oC above the pre-industrial level if the world fails to mitigate climate change (**Figure 2**). Tangang et al. (2020) and Supari et al. (2020) also projected significant changes of mean and extreme rainfall in decades to come if warming increases beyond 2oC (**Figures 3 and 4**). As such, climate change impacts particularly on agriculture, forestry, biodiversity, water resources, coastal and marine resources, public health, and energy. It was pointed out that mitigation of and adaptations to climate change in Malaysia revolve around policy setting, enactment of laws, formulation and implementation of plans and programs, as well as global and regional collaborations, particularly for energy, water resources, agriculture, and biodiversity. There are apparent shortcomings in continuous improvement and monitoring of the programs as well as enforcement of the relevant laws.

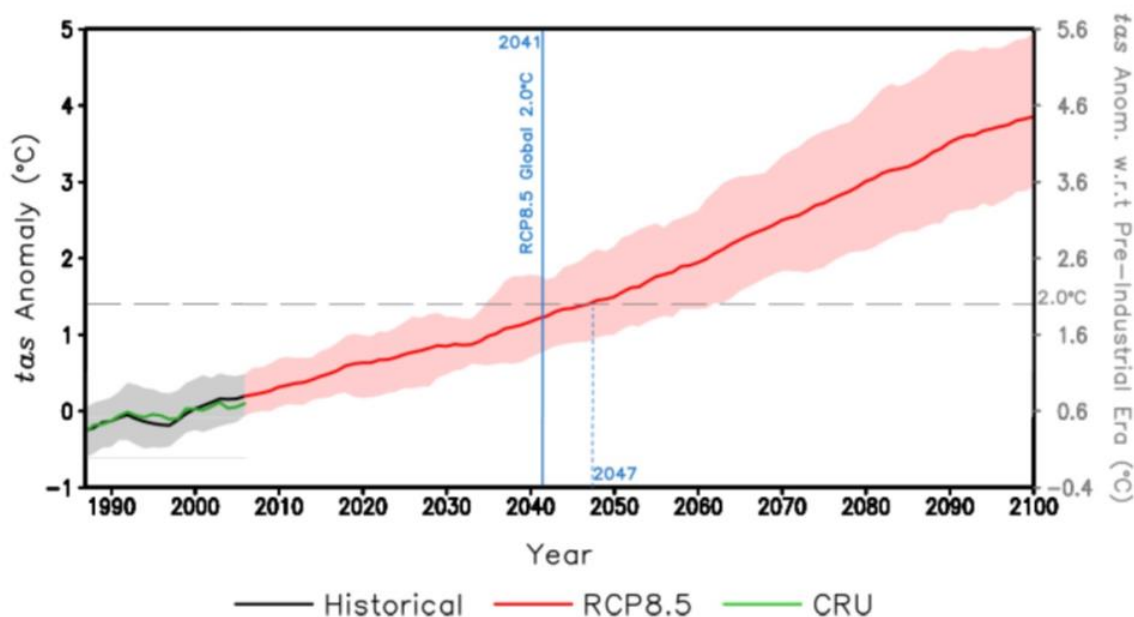


Figure 2. Projected increases of temperature averaged over Southeast Asia including Malaysia under the worst-case emission scenario of RCP8.5 (Tangang et al., 2018).

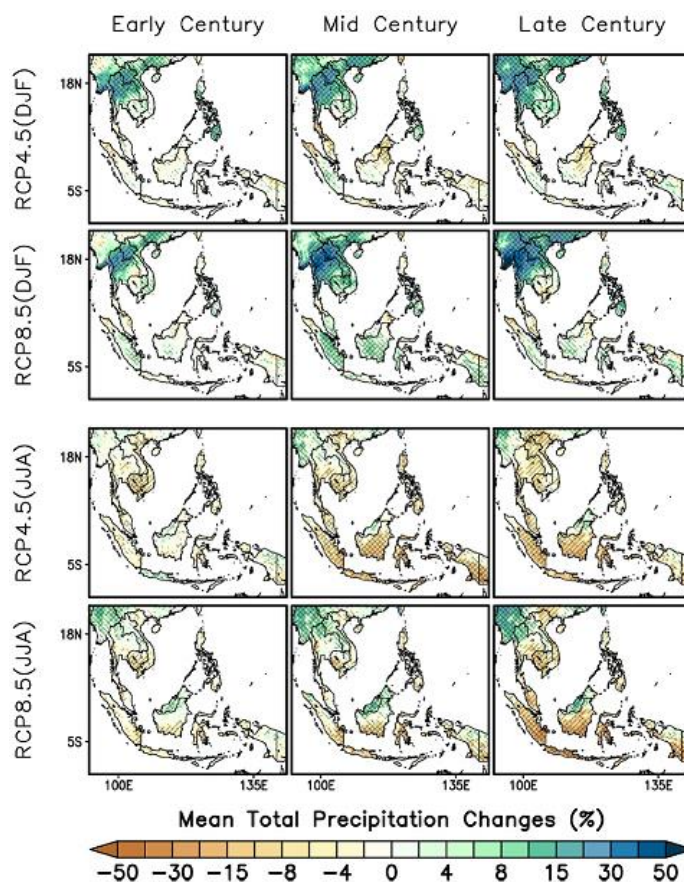


Figure 3. The projected changes of rainfall for June-July-August (JJA) and December-January-February (DJF) for middle emission scenario (RCP4.5) and worse-case-emission scenario (RCP8.5) for early, mid and late 21st century over Southeast Asia including Malaysia (Tangang et al., 2020).

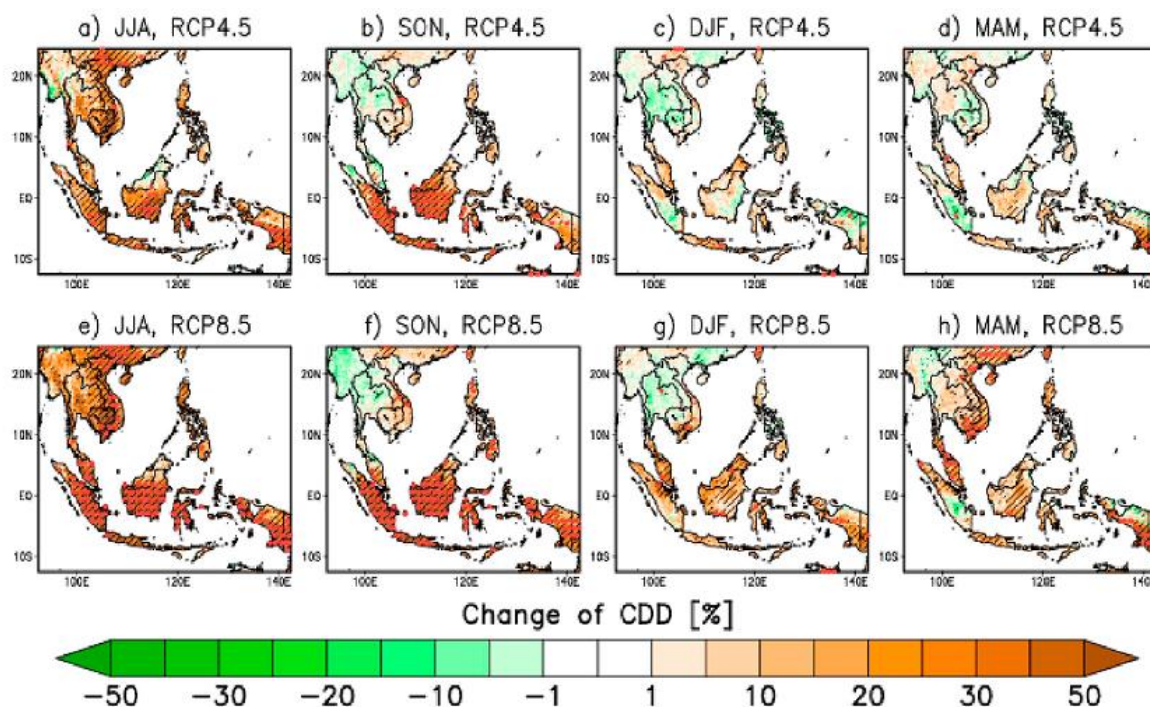


Figure 4. Projected changes of consecutive dry days (CDD, indicator of dryness and drought) over Southeast Asia including Malaysia for the end of the 21st century under RCP8.5 scenario (Supari et al., 2020).

Aside from overall approached in studying climate change, some researchers opted to investigate the impact of climate change on selected ecosystem or economic activities for specific understanding (Chew and Chong, 2016; Praveena et al., 2012). Chew and Chong (2016) investigated implication of climate change towards copepods and Praveena et al. (2012) reviewed on impacts of climate change on coral cover where it was reported that coral reefs in Malaysia are being damaged at an increasing rate where it faces natural and anthropogenic stresses. The 1998–1999 bleaching event also affected coral reefs in Malaysia due to climate change which portrays the future situation on coral reefs.

The anthropogenic impacts are basically aligned with bad practices which results in increasing GHG emissions. The effort of energy sectors to cater for the demand in global energy requirement results in ever increasing levels of GHGs. The Department of Environment together with Ministry of Energy and Natural Resources Malaysia are constantly monitoring and taking preventive measures towards curbing illegal and excess release of GHGs by industries and economic sectors to mitigate future impact on climate change. Efforts are also devoted by academics and researchers from governmental and private institutions to conduct monitoring studies on climate changes and its environmental impacts. Some organizations are also conducting awareness programs through

corporate social responsibility platforms to educate common people on the impacts of climate changes and also their role on maintaining the environment especially marine ecosystem. Many studies have highlighted the impact of climate change towards marine ecosystem specifically towards Malaysia.

3.2.2. Ocean acidification

Ocean is the major sink for CO₂ which absorbs nearly 30% of atmospheric CO₂. However, the rapid and continuously increasing CO₂ levels since the industrial revolution led to ocean acidification where acidity increased (lower pH) and reduced carbonate ion levels due to oceanic absorption of CO₂. The main preparator for ocean acidification is human activities fossil fuel (Caldeira and Wickett, 2003). Ocean acidification is among major threat towards marine organism and ecosystem and the associated services that is valuable such as fisheries, aquaculture, and shoreline protection as shown in **Figure 5** (Doney et al., 2020; Kapsenberg and Cyronak, 2019).

Various research focused on hydrological parameter measurement to study ocean acidification (Müller-Dum et al., 2019; Rojana-Anawat and Snidvongs, 1999). Rojana-anawat and Snidvongs (1999) studied on dissolved oxygen and carbonate system in seawater in Gulf of Thailand and the east coast of Peninsular Malaysia. They reported that-pycnocline water in the Gulf had the chemistry that was distinctly different from the mixed layer as well as from sub-pycnocline water in the South China Sea near the mouth of the Gulf, even with the same depth. There were some evidences that intermediate water in the South China Sea might flow into the Gulf along the central axis and the coast of Vietnam and Cambodia, and exited the Gulf along the Thai-Malay Peninsular coast. The chemistry of deep water in the South China Sea off the coast of Western Malaysia varied its chemistry by a great deal among seasons which might be due to the prevailing monsoon. Seawater in the Gulf of Thailand and South China Sea was supersaturated with respected to the mineral calcite.

Acidification of water bodies in Malaysia with its high coastal human populations is under enormous pressure from both climactic and anthropogenic drivers. Studies conducted in this aspect found that in sampled locations acidification of ocean is occurring and the effect towards the organisms such as marine microbes, organisms of calcifying groups (coral, sea urchin, mussel, oyster), phytoplankton, fish (Tan et al., 2019). Cherrie-Teh et al. (2016) compared the biochemical components of tropical oyster, *Crassostrea belcheri* at two culture sites and reported that the storage and the utilization of biochemical components of the oysters were observed to be different at different culture sites which might be due to ocean acidification. These influences the nutritional and edible values of the oysters that could potentially affect the fisheries economy and environmental conditions that is influenced by the ecosystem services provided the oysters. Aside from that, the highly diverse habitats of coral reefs are subjected to frequent coral bleaching events with many reefs showing signs of degradation reflected in their loss in diversity and total coverage. Reduction in pH values in ocean will lead to reduced calcification rate of calcifying species such as coral which could lead to extinction events. Ongoing works in Malaysia revolves around the measurement of hydrological parameters such as carbonate, CO₂ along with studies on implication towards organism during changes in pH for understanding the potential impact of this phenomenon

towards the Malaysian ecosystem.(Cherrie-Teh et al., 2016; Taylor et al., 2016; Müller-Dum et al., 2019).

Aside from investigating the ocean acidification and the ramifications, efforts are taken to enhance the awareness on the impact of this phenomenon by Centre for Marine and Coastal Studies (CEMACS), Universiti Sains Malaysia. In 2017 the Centre for Marine and Coastal Studies, Universiti Sains Malaysia kick started an awareness action-oriented programs engaging young professionals, students, and management cohorts on specific issues of marine sustainable development affecting the nation and the region while addressing Sustainable Development Goal 14 of the UN to the regional and local scale. Furthermore, the Malaysian government has joined the Paris Agreement in 2016 with the goal of reducing GHG emission by 35% relative 2005 levels by 2030 (Haiges et al., 2019). The accelerated decarbonization effort will potentially reduce acidification of ocean (Magnan et al., 2016).

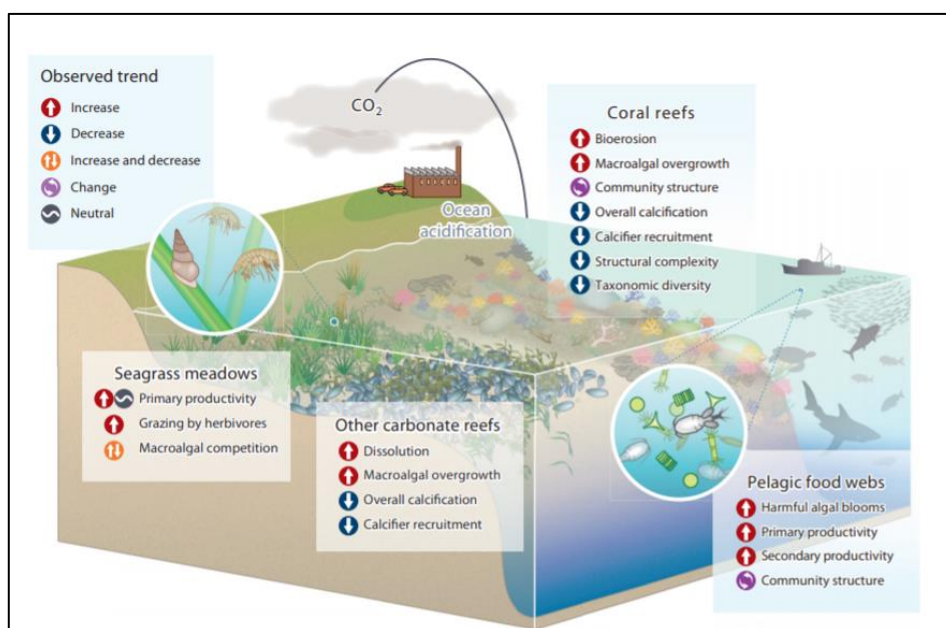


Figure 5. General trends in key community and ecosystem properties and processes in response to ocean acidification in seagrass meadows, coral reefs, other carbonate reef ecosystems, and pelagic food webs (Doney et al., 2020).

3.2.3. Blue Carbon

Blue carbon science broadly consists of applying carbon storage quantities in the habitats of mangrove forests, seagrass meadows and salt marshes into climate change mitigation and carbon accounting mechanisms (**Figure 6**). In Malaysia, the focus is mostly on mangrove blue carbon, with sparse work into seagrass blue carbon and only very few on macroalgal storage. A considerable proportion of research (more than 19 studies from since 2000) has been done in the Matang Mangrove Forests (Perak) and for the seagrass meadows, the focus was mostly on the Sungai Pulai estuary (Johor).

The work by Stankovic et al. (2021) assessed the contribution of seagrasses on climate change mitigation in selected countries of Southeast Asia including Malaysia. The study reported

that the seagrass meadows of this region have the capacity to accumulate 5.85–6.80 Tg C yr⁻¹, which accounts for \$214.6–249.4 million USD. This evaluates the potential of conservation and enhance restoration practices by highlighting them as natural way to combat climate change. On the other hand, meta-analysis on mangroves ecosystem valuation including carbon sequestration under baseline scenario between 2000-2050 where the services valued at 4185 USD/ha/year and continuous loss in mangrove ecosystem could lead to loss in US\$ 279 million per year (Brander et al., 2012). Most of the studies attempted to value the carbon storage capacity of the studied environment to highlight the crucial role played in mitigating climate change.

Some of the Malaysia-sources data had contributed to at least 7 articles for regional-global level analysis. Currently, the main policy document relevant to blue carbon, although not explicitly specifying mangrove forests and seagrass meadows, relates to the Climate Change Policy, Malaysia. Although there have been attempts to include carbon accounting into REDD+ (Reducing Emissions from Deforestation and forest Degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks) mechanisms, far more needs to be done before Malaysia's blue carbon stocks can be incorporated into discrete climate mitigation measures and policy-level implementation.

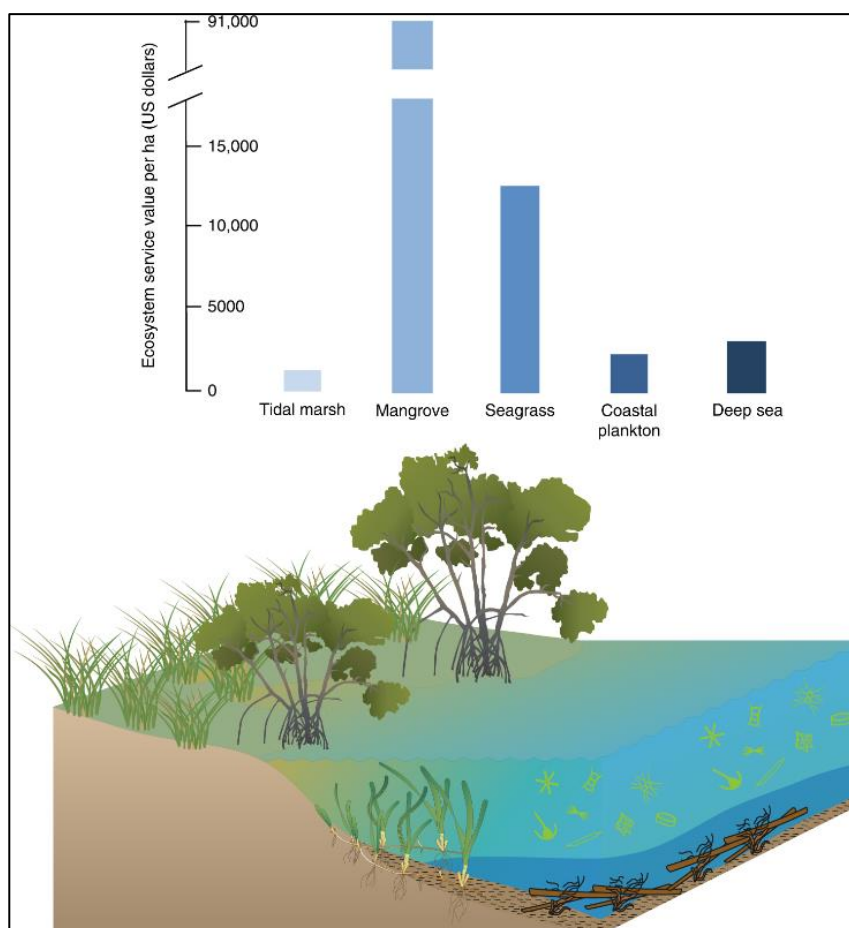


Figure 6. Estimates of the economic value of blue carbon ecosystems per hectare. Data from ref. (Nellemann et al., 2009) and references therein. Symbols and images are courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/) (Macreadie et al., 2019).

3.2.4. Coral reef, seagrass meadows, and mangroves

CORAL REEFS

Coral reefs are biologically diverse ecosystem (**Figure 7**). Malaysia is blessed abundantly with where more than 30% of global coral reefs are located in Coral Triangle which Malaysia shares with other nations combined with distribution in other parts of the country (Praveena et al., 2012). The ecosystem services provided includes fisheries, tourism, food source, and flood protection. However, just like other marine ecosystems coral reefs are being threaten by natural and artificial stress results in habitat destruction and the collapse of associated services (**Figure 8**).



Figure 7. Image of coral reef in Pulau Tinggi, Johor, Malaysia (Ooi et al., 2017).

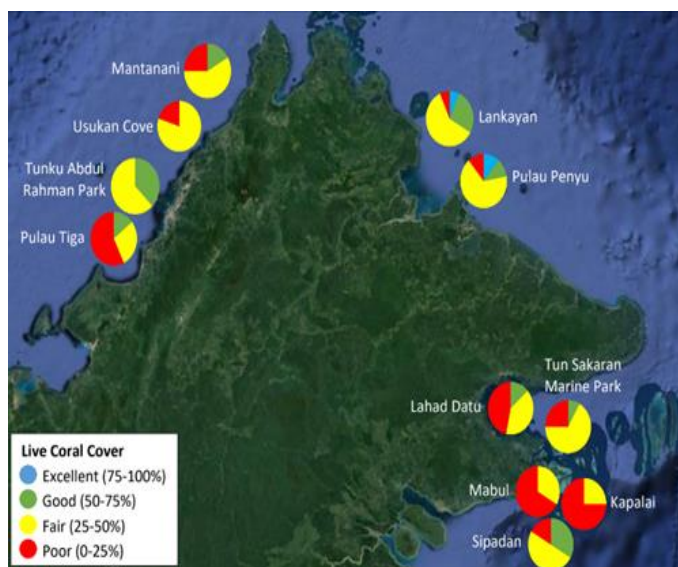


Figure 8. Map showing the reef health composition of each survey islands in Peninsular Malaysia and Sabah based on their live coral cover (Reef Check Malaysia, 2020).

MANGROVES

Mangroves are woody tree or shrub that lives along coastlines that are sheltered at tropical and sub-tropical regions (**Figure 9**). Mangroves being among most productive ecosystem provides valuable ecosystem services carbon sequestration, flood protection, fisheries resources and habitat for diverse organisms (Menéndez et al., 2020).



Figure 9. Monospecific stand of *Sonneratia alba* along a tidal river in Capiz, central Philippines (Primavera et al., 2019).

Despite their importance, globally mangrove habitats are under threat mainly from land use changes where the area coverage declined from 139,777 km² in 2000 to 131,931 km² in 2014, shown in **Figure 10** (Hamilton and Casey, 2016). Universities and research institutions have implemented many studies on the monitoring of mangroves in Malaysia. Universities and in collaboration with government institutions have been implementing research on mangroves using satellite imageries and GIS. Studies have been done on the importance of mangroves as a habitat for many marine species. Most studies indicate the reduction in mangrove ecosystems influenced by anthropogenic and climate change (**Figure 11**). All studies stress the importance of conserving and managing the mangrove ecosystem. The National Water Research Institute of Malaysia (NAHRIM) studies are related to mangroves significance for coastal stability. Forest Research Institute of Malaysia (FRIM) researched the importance of specific genetic diversity in conserving mangrove ecosystems.

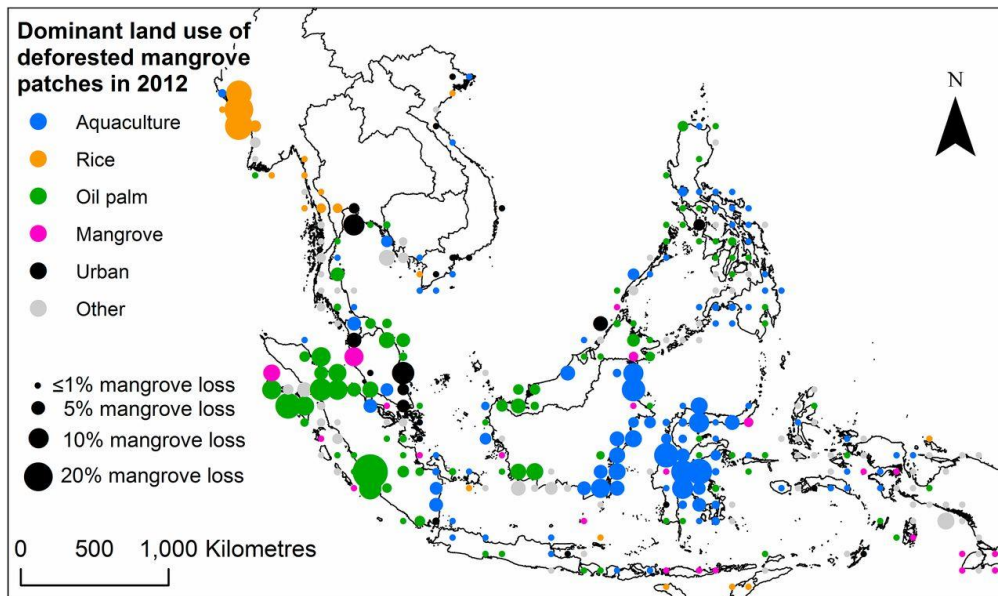


Figure 10. Mangrove deforestation between 2000 and 2012. Deforestation is summarized within each 1 decimal degree square (Richards and Friess, 2016).

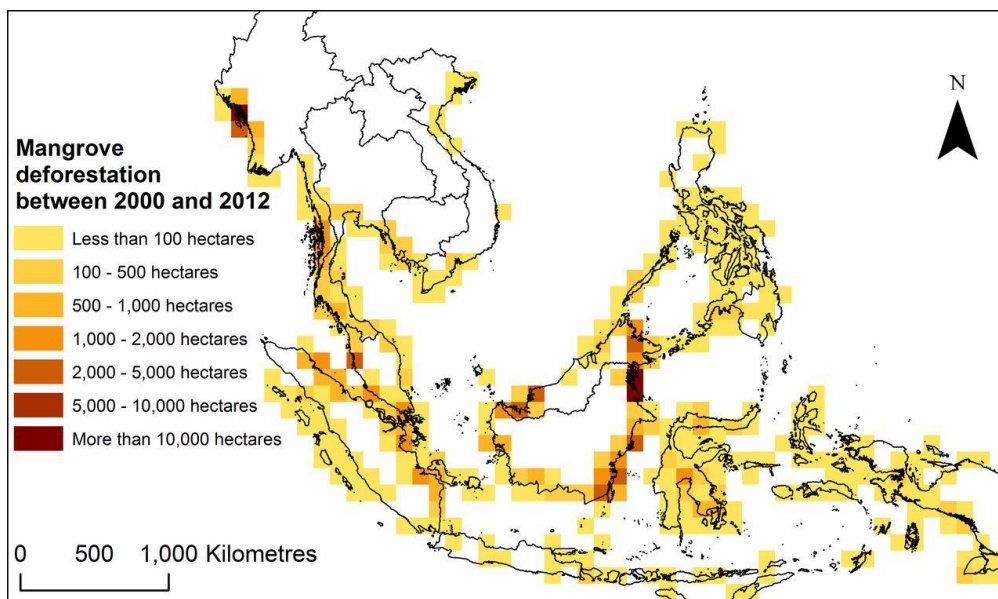


Figure 11. Percentage mangrove deforestation between 2000 and 2012, and dominant land uses of deforested areas in 2012. Land uses are summarized as the converted land use with the greatest area within each 1 decimal degree grid square. Circles are located in the center of each grid square, and circle size represents the percentage of the mangrove area in 2000 that has been lost (Richards and Friess, 2016).

D 1.1. Marine ecosystem monitoring in India and Malaysia

SEAGRASS

Seagrasses are submerged aquatic flowering plants that are commonly found in coastal waters of tropical, sub-tropical and temperate regions (Hossain et al., 2015) (**Figure 12**). Seagrasses play an important role in marine ecosystem where they provide shelter for fishes and marine reptiles and mammals, coastal protection through loose sediment trapping and carbon sequestration (Hossain et al., 2015; Yusoff et al., 2006).



Figure 12. Image of seagrass bed *Halodule uninervis* in Pulau Mentigi, Johor, Malaysia (Ooi et al., 2017).

Over the years, seagrass meadows are under threat from natural and anthropogenic impacts that result in habitat degradation. Natural threats such as windblown waves, sediment movement, algal invasion combined with anthropogenic activities such as coastal land-use and cover (LUC) development, destructive fishing and pollutions resulted in Malaysia losing extensive range of seagrass meadows (Hossain et al., 2015; Rozaimi et al., 2017). The degradation of seagrass meadows will negatively impact the marine ecosystem which in turn harms the humans who are benefiting directly and indirectly from the ecosystem services it provides. Various studies on seagrass meadows have been conducted to document the temporal and spatial changes of seagrass meadows, habitat degradation and restoration along with valuation of ecosystem services as shown in **Figure 13**.

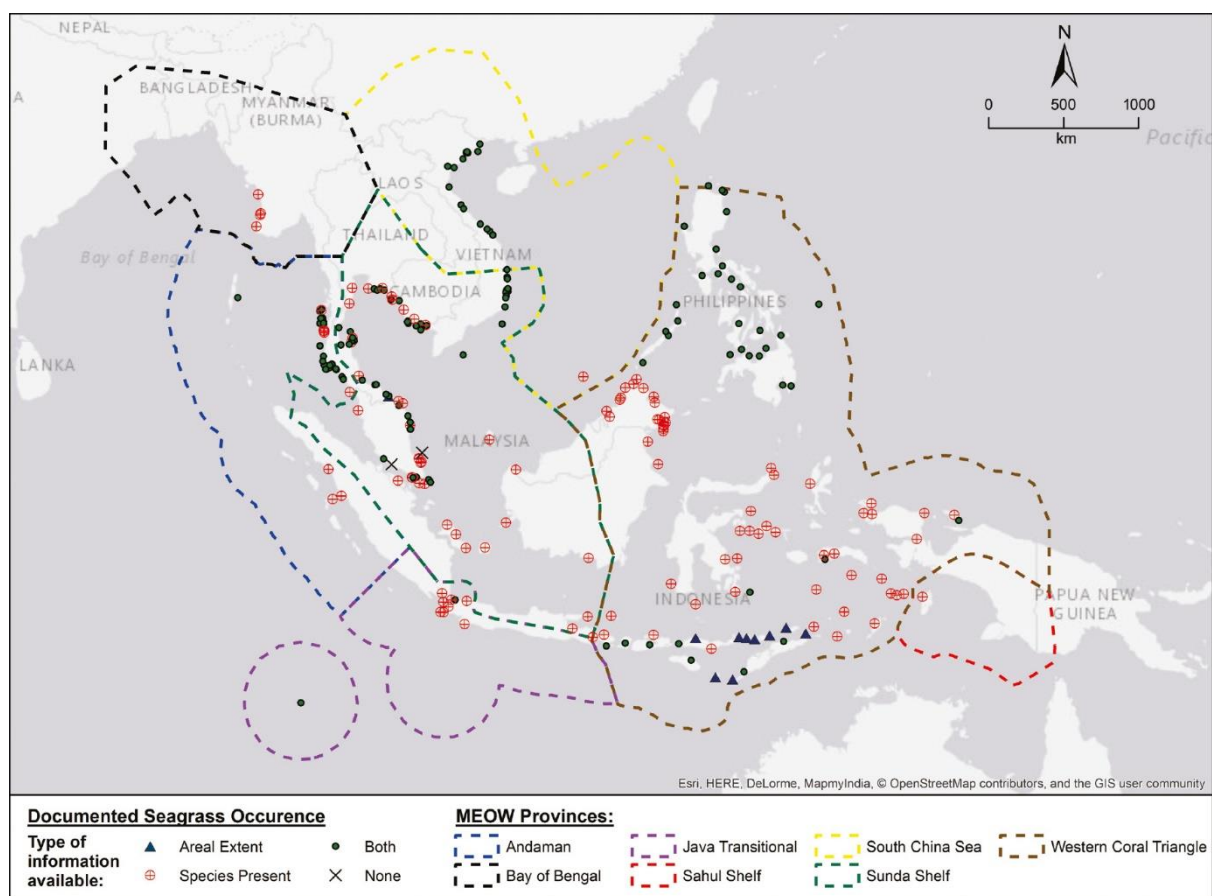


Figure 13. Level of seagrass information available within the Southeast Asian region (Fortes et al., 2018).

Studies have been conducted based in collected data from as early as 1920 where the research focuses on the changes in coverage of these ecosystem over the years based on satellite imagery or available data set collected based on established protocols (Putz and Chan, 1986; Ahmad-Kamil et al., 2013; Jusoff, 2013; Hossain et al., 2015; Richards and Friess, 2016; Ooi et al., 2017). Overall, Malaysia is experiencing a decline the area of coverage due to anthropogenic activities that can be detrimental and appropriate mitigation measures are required.

Conservation, preservation and rehabilitation of seagrasses, mangrove and coral reefs is a topic of interest in Malaysia and various institutions (government, universities, non-governmental organization) are playing crucial role in this effort. Conservation of these ecosystem are conducted through establishment of Marine Protected Area (MPA) and the management of MPA is done by Department of Marine Parks. Mangrove conservations on other hand is handled by Forestry Department by gazetting mangrove ecosystem as forest reserves. Best example of mangrove forest management is Larut Matang Mangrove Forest Reserve, Perak where sustainable management is conducted and timber industry is thriving under the guidance and supervision of forestry

department from district, state to federal levels. Furthermore, the conservation efforts are backed by non-governmental entities such as Reef Check Malaysia that collaborates with Department of Marine Park to assess the coral health status on yearly basis with provides essential data for conservation and preservation efforts.

3.2.5. Microplastic debris in marine ecosystem

Microplastic pollution in marine environment is emerging pollution concern since the usage and improper disposal of plastics in rampant. It is estimated that more than five trillion plastics debris are afloat at sea (Eriksen et al., 2014). Furthermore, the concern associated with microplastics is most serious because they can easily take in by human and animals due to their small size. Microplastics are formed from either disintegration of larger plastic particle or sourced from human consumption such as personal care products and electronic equipment (Barboza et al., 2018). To curb microplastic pollution, it is important to reach an understanding of not only the source of microplastic but also its transportation, degradation, and the possible solutions of microplastic pollution. The complex transportation and distribution processes of microplastic include the ocean dynamics (i.e., surface drifting, vertical mixing, beaching, settling, and entrainment) and the physical characteristics of microplastic (i.e. size, shape, and density) (Kanhai et al., 2018; Guo et al., 2020; Li et al., 2020)

Furthermore, marine microplastic can be ingested and introduced to the biological systems of a wide range of organisms from herbivores and secondary consumers to the predators of higher trophic levels, such as microorganisms, planktons (Amelia et al., 2020; Md Amin et al., 2020), benthic invertebrates (Ibrahim et al., 2016), fish (Savoca et al., 2019), deep ocean biota (Courtene-Jones et al., 2017), and larger mammals (Wang et al., 2020), causing neurotoxicity, genotoxicity, as well as reduced feeding, filtration, survival, and reproductive abilities that is illustrated in **Figure 14**. These effects decrease the quantity and quality of the food supply to humans and other aquatic organisms. Moreover, microorganisms including pathogens were discovered to be associated with microplastic (Syranidou et al., 2017; Brandon et al., 2018). Among the bacteria groups detected in microplastic were *Bacillus* sp. *Paenibacillus* sp., Actinobacteria, and Firmicutes (Huerta-Lwanga et al., 2018; Park and Kim, 2019).

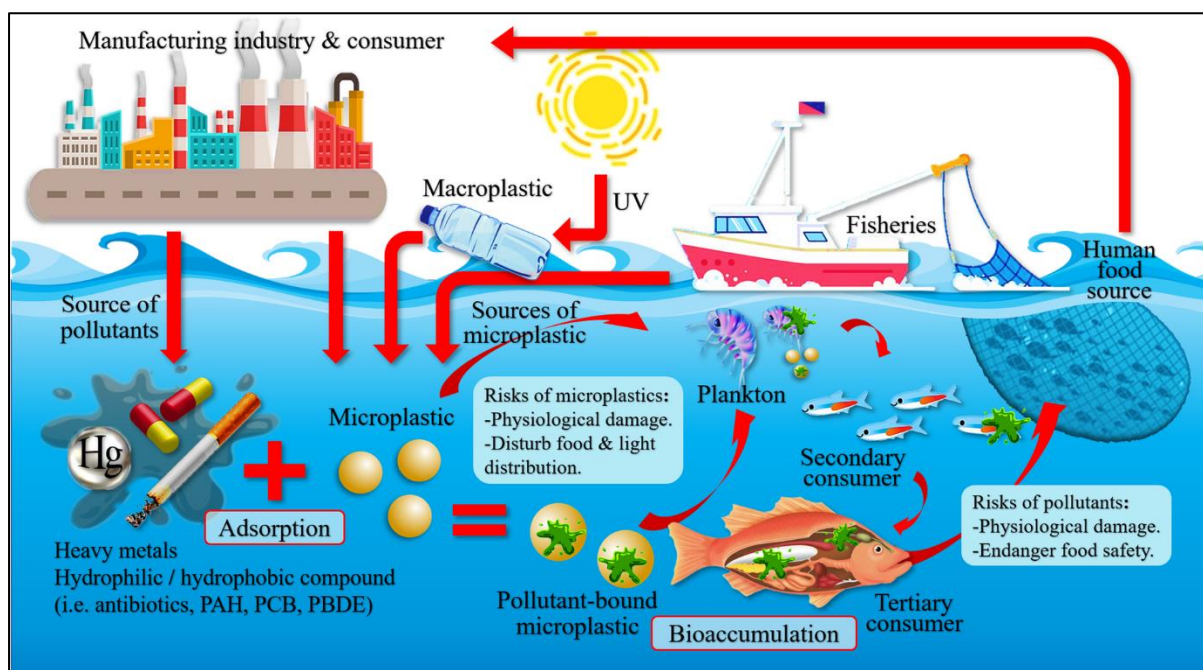


Figure 14. Illustration of the pathways of microplastic and its general impact to the marine ecosystem and organisms (Amelia et al., 2021).

Although microplastic can persist in the environment and resist degradation, some microplastic-associated bacteria can degrade microplastic (Kim et al., 2017; Yuan et al., 2020). Different bacteria consortia have different microplastic degradation abilities depending on the types of bacteria and enzymes (Tsiota et al., 2018). Reports have also shown that bacteria not exclusively associated with plastic have been colonizing microplastic, which included the families of Rhodobacteraceae, Hyphomonadaceae, and Sphingomonadaceae (Mata et al., 2017; Oberbeckmann et al., 2017; Moura et al., 2018).

Furthermore, microplastic is a vector of harmful pollutants such as persistent organic pollutants (POP) and heavy metals, capable of transporting contaminants to the ecosystem via the food chain as shown in **Figure 15** (Kwon et al., 2017; Wang et al., 2020; Zhang et al., 2020). Microplastic can hence increase the bioavailability of pollutants to ecosystems and organisms through sorption and bioaccumulation (Horton et al., 2017; Guzzetti et al., 2018).

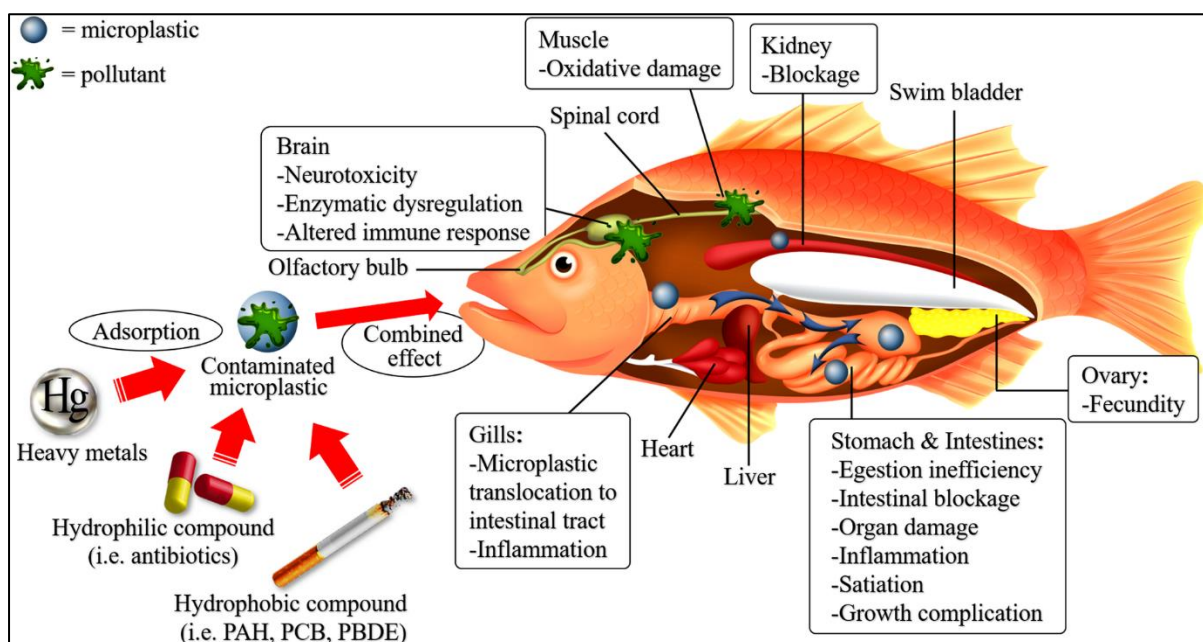


Figure 15. Impacts and combined effects of microplastic and pollutants toward marine organism (Amelia et al., 2021).

Therefore, concerns regarding microplastic pollution has led to research in Malaysia since 2014 in terms of understanding the source, distribution, and implication of the microplastics pollution (Karbalaee et al., 2019; Najihah et al., 2020; Husin et al., 2021).

3.3. Marine monitoring facilities

Marine monitoring activities in Malaysia are conducted by government departments such as Department of Environment (DOE) along with non-governmental organizations (ReefCheck, WWF, Malaysian Society of Marine Sciences (MSMS), MareCet, Marine Research Foundation) and higher education institutes. In 2019, DOE has 368 monitoring station set up in island, coastal and estuaries region to measure 29 different water quality parameters such as temperature, pH, conductivity, salinity, dissolved oxygen, turbidity, heavy metal, fecal coliform and phenol. The image below shows the distribution of DOE monitoring station across Malaysia.

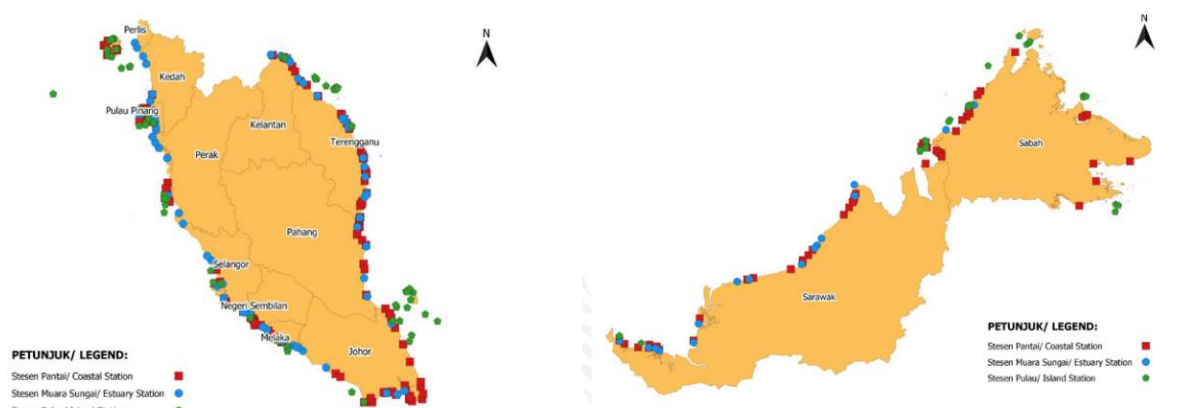


Figure 16: Distribution of marine water quality monitoring stations in Malaysia, 2019 (DOE, 2019).

Besides DOE monitoring stations, other monitoring programmes being conducted periodically or one-off that covers other marine aspects such as coral reef, mangrove or seagrass. One such periodical monitoring program is annual reef health monitoring and survey being conducted by ReefCheck Malaysia in corporation with government and non-government support along with volunteers. The table below list some of the NGO that is involved in monitoring of marine environment.

Table 2: List of NGO involved in marine monitoring.

| Organization | Monitoring Aspects |
|---|--|
| Reef Check Malaysia | <ul style="list-style-type: none"> Focused on coral reef monitoring and island based educational programs. |
| Dugong & Seagrass Conservation Project | <ul style="list-style-type: none"> Conservation and monitoring of seagrass and dugong habitat |
| Marine Research Foundation | <ul style="list-style-type: none"> Conservation of marine environment. Monitors and reports on incidents of sharks and ray by-catch in Sabah along with aerial survey of marine environment. |
| MareCet | <ul style="list-style-type: none"> Research and conservation of marine mammals in Malaysia. |
| World Wildlife Organization (WWF)- Malaysia | <ul style="list-style-type: none"> Engages with local communities, local and state government agencies, and the private sector to improve |

environmental management (

Malaysian Nature Society
(MNS)

- Official national Ramsar CEPA-NGO Focal Point which works under the CEPA (Communication, Education & Public Awareness) component of the Ramsar Convention.
- Involved in conservation and community outreach programs for wetlands and marine environment.

Tropical Research and
Conservation Centre (TRACC)

- Marine conservation organization based in the Celebes Sea dedicated to protecting sea turtles and restoring coral reefs destroyed by the local fish bombing practices.
 - Involved in coral reef and turtle survey activities.
-



4. Marine ecosystem monitoring in India

4.1. Introduction

The marine environment, which includes the adjacent coastal areas, supports productive and protective habitats such as mangroves, coral reefs, and sand dunes. India has a long coastline of more than 7500 km (**Figure 16**). Its marine resources are spread over in the Indian Ocean, Arabian Sea, and Bay of Bengal. The exclusive economic zone (EEZ) of the country has an area of 2.02 million sq km comprising 0.86 million sq km on the west coast, 0.56 million sq km on the east coast and 0.6 million sq km around the Andaman and Nicobar Islands. The east coast supports activities such as agriculture and aquaculture while several industries are supported on the west coast. Tourism has emerged as a major economic activity in coastal states such as Goa, Kerala, and Orissa.

Climate change is the main regional threat faced by the coastal and marine habitats, such as coral reefs, mangroves, sea grass meadows, estuaries, and beaches of tropical developing countries such as India. These systems are also facing severe direct human stresses due to overfishing and destructive fishing, coastal development, runoff from the land and increased sedimentation; revealing that the cost of conservation of these marine resources would be the cost of avoiding/minimizing the threats associated with each resource (**Table 3**). In many areas, localized stress is becoming increasingly severe, especially around urban centers and highly populated areas, from overfishing and pollution from the land. Hence, the present contribution provides details about methods of assessing selected coastal and marine habitats such as coral reefs, mangroves, sea grass beds, estuaries, and beaches. It also recommends methods for continuous monitoring and long-term conservation.

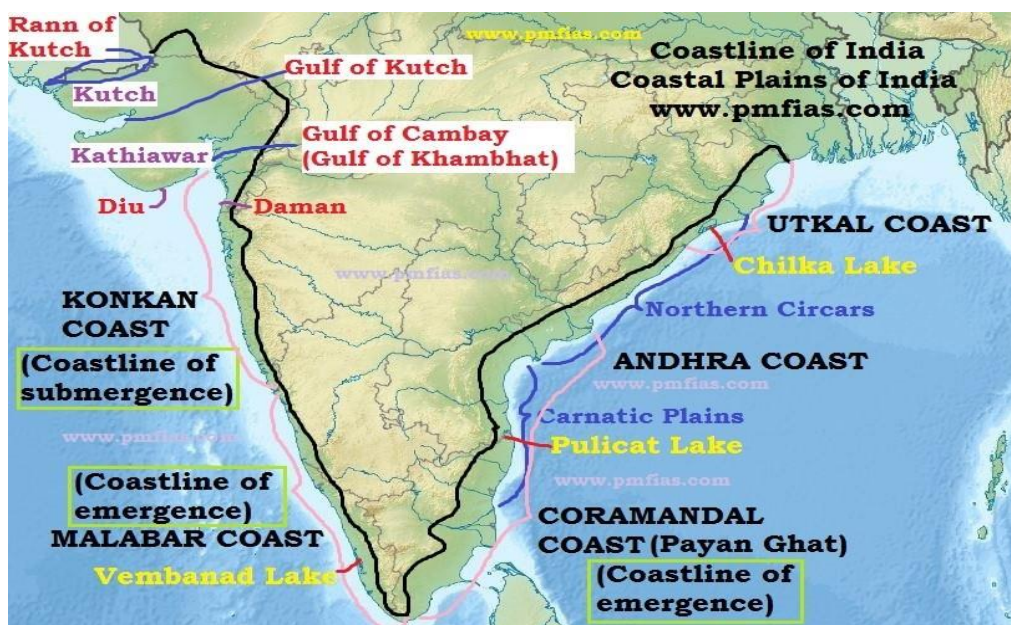


Figure 16. Coastline of India

Table 3. Principal coastal ecosystems facing threats along the Indian coast (source: Bhatta, 2019).

| ECOSYSTEMS | | THREATS |
|-------------------|---|--|
| ESTUARIES |  | Habitat destruction Pollution Unsustainable resource exploitation Harmful algal blooms / Alien species Global warming |
| MANGROVES |  | Land reclamations for construction activity, aquaculture, agriculture, tourism Industrial and domestic pollution Port development Dumping of all kinds of waste and debris Deforestation for fuel wood Over harvesting of marine resources |
| CORAL REEF |  | Destructive fishing practices/Overfishing Careless tourism Water pollution Sedimentation Coral mining Climate change |
| SANDY BEACHES |  | Erosion, SLR, construction activities for tourism, beach sand mining |
| SEAGRASS/ SEAWEED |  | Natural disasters – Cyclones and hurricanes Intensive grazing Infestation and diseases Deforestation of mangroves Construction activities Dredging Pollution |

India has about 2% of the world area but it contains nearly 18% of the biodiversity of the world. It is one amongst the 12 mega-biodiversity countries and 25 hotspots of richest and highly endangered ecoregions of the world (Myers et al., 2000). The coastlines of Bay of Bengal and Arabian Sea continue to be as rich fishing ground in the south Asian region and India is one of the world's largest marine product nations. Human activities such as destructive fishing, shipping, coastal developments, discharge of untreated effluent from industries have caused considerable damage and pose a severe threat to the coastal and marine biodiversity. In addition to that, global warming due to climate change also pose major challenges to marine biodiversity.

Solid waste management has been a great challenge to the developing nations as affluence and consumption are closely related. Increasing urbanization of coastal settlements as well as tourism development has resulted in unprecedented production of anthropogenic waste. Approximately 80% of debris originates onshore and 20% from offshore sources (Allsopp et al., 2007). These waste materials are becoming a real menace and often find their way to the ultimate sink- the sea and the suspended part of which often wash ashore as litter all along the coast and those part upon sinking will persist in the sediments for many years. Apart from the beach litter, increasing quantity of marine debris including plastics and their impacts such as ingestion by or entanglement of marine biota pose serious challenge (Gregory, 2009; Sarah et al., 2016).

The major issues involved in the sustainable use oceans, sea and marine resources for sustainable development detected in India are:

- Management and protection of marine and coastal ecosystems.
- Controlling the Marine pollution.
- Impacts of ocean acidification.
- Elimination of overfishing, manage stocks scientifically.
- Conservation of coastal and marine areas.
- Prohibit harmful fisheries subsidies.
- Ensure economic benefits from sustainable use of marine resources (e.g., fisheries, aquaculture and tourism).

4.2. Threats to Coastal/marine Ecosystems

4.2.1. Climate monitoring

India's average temperature has already increased by around 0.7 degree Celsius during the 1901–2018 period due to greenhouse gas emissions and by the end of 2100 it is expected to rise by approximately 4.4 degree Celsius (relative to 1976–2005 average, in the worst-case scenario), warns the first-ever climate change assessment report by the Indian government. India's average temperature has risen by around 0.7°C during 1901–2018. This rise in temperature is largely on account of GHG-induced warming, partially offset by forcing due to anthropogenic aerosols and changes in LULC. By the end of the twenty-first century, average temperature over India is projected to rise by approximately 4.4°C relative to the recent past (1976–2005 average). In the recent 30-year period (1986–2015), temperatures of the warmest day and the coldest night of the year have risen by about 0.63°C and 0.4°C, respectively.

By the end of the twenty-first century, these temperatures are projected to rise by approximately 4.7°C and 5.5°C, respectively, relative to the corresponding temperatures in the recent past (1976–2005 average), under the RCP8.5 scenario.

Sea surface temperature (SST) of the tropical Indian Ocean has risen by 1°C on average during 1951–2015, markedly higher than the global average SST warming of 0.7°C, over the same period. Ocean heat content in the upper 700 m (OHC700) of the tropical Indian Ocean has also



exhibited an increasing trend over the past six decades (1955–2015), with the past two decades (1998–2015) having witnessed a notably abrupt rise.

At the end of the twenty-first century, steric sea level in the NIO is projected to rise by approximately 300 mm relative to the average over 1986–2005 under the RCP4.5 scenario, with the corresponding projection for the global mean rise being approximately 180 mm.

Since the middle of the twentieth century, India has witnessed a rise in average temperature; a decrease in monsoon precipitation; a rise in extreme temperature and rainfall events, droughts, and sea levels; and an increase in the intensity of severe cyclones, alongside other changes in the monsoon system. There is compelling scientific evidence that human activities have influenced these changes in regional climate.

Human-induced climate change is expected to continue apace during the twenty-first century. To improve the accuracy of future climate projections, particularly in the context of regional forecasts, it is essential to develop strategic approaches for improving the knowledge of Earth system processes, and to continue enhancing observation systems and climate models.

4.2.2. Ocean acidification and temperature rise

Changes in seawater chemistry due to anthropogenic uptake of CO₂ by seawater results in a phenomenon termed ocean acidification. Ocean acidification has been predicted to substantially affect the exposure, behavior, mobility and fate of toxicants with significant impacts on marine organisms. The increasing atmospheric CO₂ concentration in the last few decades has resulted in a decrease in oceanic pH. In this study, we assessed the natural variability of pH in coastal waters off Goa, eastern Arabian Sea. pH showed large variability (7.6–8.1) with low pH conditions during south-west monsoon (SWM), and the variability is found to be associated with upwelling rather than freshwater runoff. Considering that marine biota inhabiting dynamic coastal waters off Goa are exposed to such wide range of natural fluctuations of pH, an acidification experiment was carried out.

Acidification is the decrease in seawater pH and closely linked shifts in the carbonate chemistry of the waters, including the aragonite saturation state, which is the main form of calcium carbonate used by key species to form shells and skeletal material.

4.2.3. Blue carbon monitoring

Coastal habitats, such as mangrove, sea grass, and salt marsh, are termed “blue carbon” and have recently gained much attention due to their high carbon sequestration capacities. Although the global area of blue carbon ecosystem is much smaller than the terrestrial ecosystem, they sequestered carbon in a much greater amount in their living biomass, as well as in the sediment. When these systems are degraded, lost or converted to other land uses, massive stores of carbon in the soils of these ecosystems are exposed and released as CO₂ into the atmosphere and/or ocean.



Although the combined global area of the three main blue carbon ecosystems – mangroves, salt marshes and sea grasses – equates to only 2–6% of the total area of tropical forest, their degradation accounts for up to 19% of carbon emissions from global deforestation (Pendleton et al., 2012). In absolute figures every year an estimated 0.15–1.02 billion tons of CO₂ is released from deforestation and degradation of blue carbon ecosystems. The constructive synergies and overlaps between blue carbon interventions and adaptation efforts are now beginning to inform policy makers worldwide. Conservation, restoration, and sustainable use of sensitive coastal ecosystems are increasingly understood in their multiple roles to support livelihoods, store carbon, and increase resilience against climate change.

And response to the ambiguous performance results of command-and-control approaches to blue carbon protection from the more ‘traditional’ sectors such as Protected Areas, countries have moved to more incentive-based instruments and to community-driven measures (Rotich, Mwangi, & Lawry, 2016). Tools and frameworks of international climate finance – from carbon trading to facilitative tools such as REDD+ (Reducing Emissions from Deforestation and forest Degradation; a mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC); Beresnev and Broadhead, 2016) – are opportunities countries are exploring and implementing in various ways and degrees (Thomson et al., 2014).

4.2.4. Coral reef, seagrass and mangroves assessment

CORAL REEF

Coral reefs are the most spectacular and diverse marine ecosystems on the planet today. Complex and productive, coral reefs can boast of hundreds of thousands of species-many are still undescribed by science. Coral reefs in India have been under stress for quite some time. The major reef formations in India are restricted to the Gulf of Mannar, Gulf of Kutch, Andaman and Nicobar Islands and Lakshadweep Island. Scattered coral growth has also been reported along certain intertidal belts and submerged banks on both the east and west coasts of the country (Venkataraman et al 2004). The condition of the reefs is generally poor and declining in near-shore waters and areas of high population densities. Sedimentation, dredging, and coral mining are damaging near-shore reefs, while the use of explosives and bottom nets in fishing are damaging offshore reefs at specific sites. The bleaching event of 1998 is reported to have increased dead coral cover to about 70% in the Gulf of Kachchh, 40-60% in the Gulf of Mannar, 60-80% in Lakshadweep and about 80% (subsequent studies do not confirm this report) in the Andaman and Nicobar Islands. Quantitative data are lacking, and few studies have been carried out to monitor the health of coral reefs. Examination of coral reef health and resilience, in an attempt to identify strategies that could be incorporated into management to enhance the ecological resilience of these ecosystems, is a recent focus of applied coral reef research (Hughes et al., 2010). Measurements of coral demographics, mortality and recruitment are combined with assessments of benthic cover types, biomass of algal functional groups, population structure of commercially valuable and ecologically relevant reef fishes, and environmental resilience indicators determined using a standardized, rapid quantitative survey protocol.

The assessments provide information on:



- (1) The status of coral reefs and species that create and help maintain the health of the reefs and associated habitats,
- (2) Local and regional threats, causes, impacts, and potential mitigation strategies.
- (3) Patterns of recovery from past disturbances. Coral reef data are compiled into a geographic information system (GIS) database with satellite imagery, habitat maps and other physical and oceanographic GIS data layers, producing a landscape-scale tool useful for marine spatial planning (Bruckner and Renaud, 2012). The rapid assessment protocol can be adopted from Global coral reef expedition protocol (Lang et al., 2003) and the IUCN Resilience Assessment of Coral Reefs protocol (Obura and Grimsditch, 2009), with additional parameters.

Quantitative data can be obtained on:

- (1) Coral community structure (diversity, size structure, partial mortality and condition), using 10 m × 1 m belt transects, and coral recruitment (five 0.25 m quadrates per 10 m transect).
- (2) Diversity, size and abundance of over 100 commercially valuable reef fishes (food and ornamental fishes) and ecologically relevant functional groups of reef fishes (e.g., herbivores, invertebrate feeders and piscivores) using 30 m × 1 m belt transects.
- (3) Cover and abundance of major functional groups of algae (turf algae, microalgae, fructose coralline algae and erect coralline algae), corals and other benthic invertebrates using a point intercept method (100 points per 10m transect).
- (4) Approximately 50 other ecological and environmental resilience indicators.

MANGROVES

India has only 2.66% of the world's mangroves, covering an estimated area of 4827 km². About 57% of this extent is found on the east coast, 23% on the west coast and the remaining 20% on the Bay Islands (Andaman and Nicobar). The insular mangroves are present in the Andaman and Nicobar Islands, where many tidal estuaries, small rivers, neritic islets, and lagoons support a rich mangrove flora. The coastal zone, in general, and the mangroves, in particular, are used for multiple purposes such as recreation, tourism, forestry, agriculture, aquaculture, housing and commercial fishing. The mangroves serve as a wildlife sanctuary, especially in the Sunderbans, Orissa and Andaman and Nicobar Islands. Mangroves are also important nursery areas for the juveniles of many commercial fish and crustacean species (Robertson and Duke, 1987) and play important roles in coastal protection and water quality (Saenger et al., 1983). Mangrove forests are one of the most productive and biodiverse wetlands on Earth. It is very important that to develop standard methods for monitoring changes in mangrove habitats.

Assessment of Mangrove Habitats

Site selection: Study sites should be selected so as to be representative of the type of habitat so that the results will also be relevant to other parts of the mangrove habitat. A predetermined number of sites should be delineated within the area of interest. Monitoring multiple sites (replicates) will help account for natural variability. Monitoring transects over time is the recommended approach. This means that one or more sites need to be chosen where transects can be established that can be easily located at a later date. For a statistically rigorous monitoring program, it is essential to have more than one transect at each site. The choice of the number of replicates transects will depend on the size of a given estuary or the size of the area of interest in an estuary, as well as the specific question of interest regarding a particular community group.

Frequency of Sampling

The methods outlined in the following should be used on an annual basis and all the parameters should be sampled at the same time of the year, as much as possible. The reason for this is that the production, survival, and growth of mangrove seedlings have a seasonal component.

SEAGRASS

Sea grass ecosystems in the tropics, particularly in India, have been given low priority by the scientific community and environmentalists (Jagtap, 1996). The expanse and density of sea grasses have significantly declined in most of these regions, including India (Thangaradjou et al., 2008; Sridhar et al., 2010). Although they extend over less than 1% of the ocean, they play an important role in the coast zone and provide ecosystem services and goods that have higher values compared with other marine habitats (Costanza et al., 1997; Duarte et al., 2005). Furthermore, recent studies have demonstrated that seagrasses can reduce the impacts of ocean acidification (Semesi et al., 2009) and act as an important carbon sink in the marine environment (McKenzie and Unsworth, 2009).

4.2.5. Monitoring the abundance of plastic debris

Plastic debris has significant environmental and economic impacts in marine systems. Monitoring is crucial to assess the efficacy of measures implemented to reduce the abundance of plastic debris, but it is complicated by large spatial and temporal heterogeneity in the amounts of plastic debris and by our limited understanding of the pathways followed by plastic debris and its long-term fate (**Figure 17**). Microplastics are less than five millimeters in size they have been detected on the surface of every aquatic field because of improper usage and disposal of microplastics that pollute the freshwater and marine systems. Plastic can be encountered in two forms: large plastic wastes also small plastic particulates below 5 mm in size named microplastics and it is originating from the degradation of larger plastic (**Figure 18**). A major source of plastic pollution in

the aquatic environment from industrial sources. Plastic litter reported alongside the beaches of Karnataka, Caranzalem beach sands, Goa; resin pellets from Chennai and Tennakkara Island and the debris in Great Nicobar.

Kaladharan et al. (2017) have done synoptic view of study sites and the quantity of marine litter during the study period along the Indian coastline graded with appropriate color codes is presented in **Figure 17**. Samples of debris collected from beaches revealed that all the items were domestic and anthropogenic discards. Creating awareness through regular coastal clean ups and certain degree of legislation are the key elements for reducing beach litter they have done research in marine litter along the Indian beaches. The results presented indicate that plastics make up the largest component of marine litter (**Figure 17**). Plastics being buoyant, they will be seen dispersed in the water column over long distances and when they settle at the bottom, will persist in marine sediments for many years (Hansen, 1990; Goldberg, 1995; 1997).

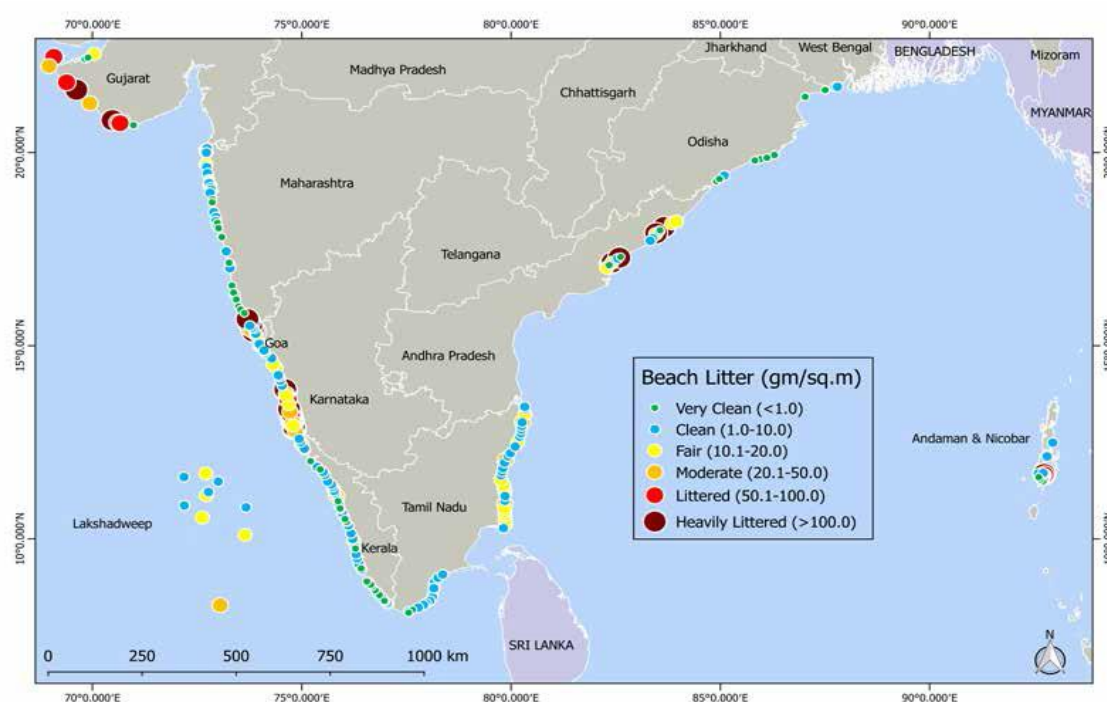


Figure 17. Study locations and their marine litter status along Indian beaches during October 2013-January 2014 (Numbers in parentheses in the inset indicates ranking of the areas under study). From Kaladharan et al. (2017).

Microplastic is highly toxic to the environment and the pollution by them makes a direct and serious threat to freshwater and marine environments. In India, people suffering from different health issues due to the impact of micro plastic. The ingestion of micro plastics by an aquatic organism has been widely studied in both field and laboratory. Plastics were accumulated in the rumen of ruminants leading to luminal impaction, recurrent tympani, indigestion, and other adverse health effects. Accumulation and fragmentation of plastic debris in the environment and benthic

invertebrates was recorded from the coastal waters of Kochi. Polyvinylchloride is the most harmful form of plastic contains bisphenol A, lead, mercury, dioxins, phthalates, and cadmium that can in puberty, neurological functions, immunity, cardiovascular health, breast cancer, prostate cancer, and even metabolic disorders.

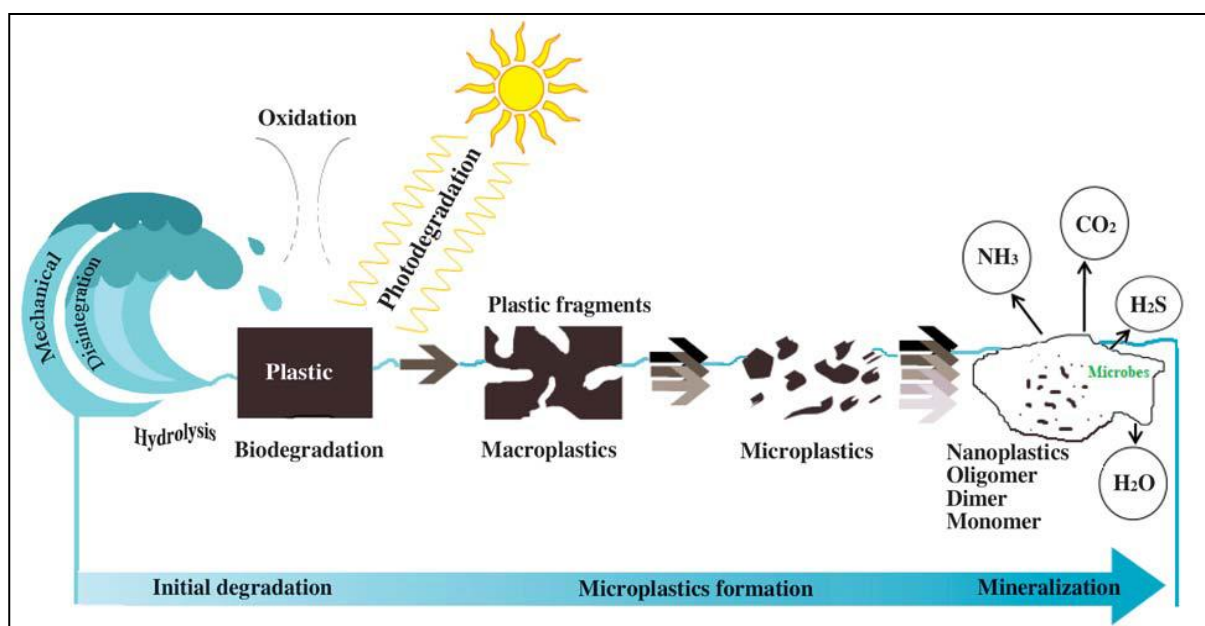


Figure 18. Degradation pathways of plastic materials in flowing water bodies with various degradation processes involved until complete mineralization (Sarkar and Bhadouriya, 2020).

4.3. Marine monitoring facilities

There are several agencies which are involved in continuous monitoring of the marine ecosystem in India, just like in Malaysia. The list of marine monitoring facilities in India is presented in the **Table 4** below.

Table 4: List of marine ecosystem monitoring facilities in India

| Organization | Monitoring Facility |
|---|---|
| National Centre for Coastal Research (NCCR) | <ul style="list-style-type: none"> Monitoring water quality, sediment, biological and microbiological parameters Inter-laboratory comparison exercise to ensure compatibility between the data acquired by various monitoring agencies To identify and preserve marine microbes and to serve as a reference facility |

| | | |
|---|------------------|--|
| | | <ul style="list-style-type: none"> Monitoring of organic compounds like Polyaromatic Hydrocarbons in selected organisms collected at selected locations along the coasts of India |
| Indian Ocean Observing System (IndOOS) | | <ul style="list-style-type: none"> Observing system that monitors basin-scale ocean-atmosphere conditions, while providing flexibility in terms of emerging technologies and scientific and societal needs, and a framework for more regional and coastal monitoring. |
| National Institute of Oceanography (NIO) | | <ul style="list-style-type: none"> Trans-disciplinary Research for improved Forecasting of Indian Marine Fisheries (TRIMFish) Maritime Archaeological studies along Indian coast Marine Biodiversity Analyses and Bioprospecting Coral Reef Monitoring and Surveillance Robot (C-Bot) |
| National Centre for Earth Science Studies (NCESS) | | <ul style="list-style-type: none"> The sedimentology laboratory is one of the core laboratories of NCESS has facility for both wet and dry sample analysis. Computer hardware and software for Dispersion modelling, Watershed modelling, Dam break analysis, Resistivity modelling, GIS modelling, and vibration modelling are being used for various ongoing projects in Air quality monitoring, Noise level monitoring, Vibration monitoring, Water quality analysis, Resistivity surveys and Photomicrographic applications. |
| Coastal Monitoring and Prediction (COMAPS) | Ocean and System | <ul style="list-style-type: none"> To monitor water quality parameters periodically in selected locations in the coastal waters of India To develop possible prediction of sea water quality in these selected locations to assess the state of marine environment |
| Reef Watch Conservation | Marine | <ul style="list-style-type: none"> It works towards protecting, restoring, and rehabilitating coral reefs in the Andaman Islands. The team rescues broken coral and helps secure these fragments using mineral accretion technology and electrolysis. |
| Society for Research and Conservation | Marine and | <ul style="list-style-type: none"> Migratory Sea Birds Monitoring' program or through the 'Save Juvenile Fishes' program |

D 1.1. Marine ecosystem monitoring in Malaysia and India

| | |
|-------------------------|---|
| Coastal impact | <ul style="list-style-type: none">• The team has found and removed a number of plastic items, garbage, and glass materials that pose a health hazard to marine creatures. |
| Terra Conscious | <ul style="list-style-type: none">• Focuses on promoting responsible tourism and marine conservation in Goa, India• To create awareness-building capacity for a number of stakeholders to enable them to effectively address marine and coastal conservation challenges and engage in grassroots action. |
| Wildlife Trust of India | <ul style="list-style-type: none">• A number of conservation efforts were undertaken to ensure that corals were not broken or harmed in any way by natural disasters or human actions. |



5. Conclusions

ECOMARINE intends to create full operationally marine conservation monitoring labs in Malaysia and India. The main goal of the project is to modernize the management and operation of marine conservation monitoring labs of the Asian HEIs of Malaysia and India. This can indeed help to preserve Marine Ecosystems and Life from the negative consequences of Climate Change and the disposal of Plastic Debris in those countries. Several knowledge gaps arise from this review:

- Even when in the last years there have been an increase in research reports from both these two Asian countries, the information about changes in species composition and abundance over time in the countries ecosystems is still fragmented and scarce and revealed the lack of baseline data by coastal ecosystems/regions.
- Genetic diversity studies of marine species and species indicators used for estimating ecosystem health are still scarce in both countries. Moreover, studies on fisheries sustainability and aquaculture effects on coastal ecosystems in both countries are still limited.
- Further investigation on the seagrass carbon stock is required in both countries.
- Limited research has been carried out in both countries on persisting microplastic contamination and its effects on the coastal environments.
- Only a few percentage of the countries Exclusive Economic Zones (EEZ) have been, or it is planned to be, designated as Marine Protected Areas (MPAs).

The describe situation clearly justified the implementation of a research/education strategy to collect long-term data from coastal ecosystems/regions that allow to face the aforementioned issues. ECOMARINE should develop innovative knowledge for marine conservation monitoring in both countries transfer the knowledge to students, society and the rest of stakeholders using R&D activities designed towards effective marine conservation and climate change mitigation goals. To this it will be necessary to establish communication channels and cooperation bonds between European Universities and Asian Universities and research laboratories through the transfer of knowledge on low cost monitoring techniques.

Taking into account the specific needs on the marine ecosystem monitoring in these two Asian countries, ECOMARINE should

- a) Procure equipment, theoretical and practical training based on the European marine monitoring strategies and directives, a homogeneous research strategy for the two Asian HEIs of Malaysia and India that cover assessments of climate change, ocean acidification, blue carbon and seagrass status and finally plastic debris contamination and related effects.**
- b) Help and contribute in the creation of 4 new Marine Monitoring Labs and their operational protocols that allow them to produce and implement baseline data to improve marine ecosystem monitoring in India and Malaysia.**

6. References

- Ahmad-Kamil, E., Ramli, R., Jaaman, S., Bali, J., & Al-Obaidi, J. (2013). The effects of water parameters on monthly seagrass percentage cover in Lawas, East Malaysia. *The Scientific World Journal*, 2013.
- Allsopp, M., Walters, A., Santillo, D., Johnston, P. (2007). Plastic debris in the World's oceans. *Greenpeace*.
- Amelia, T., Sukri, S., Jaapar, A., R., M. A., & Bhubalan, K. (2020). Uptake and egestion of polyhydroxyalkanoate microbeads in the marine copepod *Nitokra lacustris pacifica*. *Journal of Sustainability Science and Management*, 15(4), 45-53.
- Amelia, T. S. M., Khalik, W. M. A. W. M., Ong, M. C., Shao, Y. T., Pan, H.-J., & Bhubalan, K. (2021). Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. *Progress in Earth and Planetary Science*, 8(1), 12.
- Aziz, M., Omar, K. M., Din, A., & Reba, M. (2016). *Pre-analysis assessment of Sea Surface Temperature (SST) products in the region of Malaysian coastal water*. Paper presented at the IOP Conference Series: Earth and Environmental Science.
- Barboza, L. G. A., Dick Vethaak, A., Lavorante, B. R. B. O., Lundebye, A.-K., & Guilhermino, L. (2018). Marine microplastic debris: An emerging issue for food security, food safety and human health. *Marine Pollution Bulletin*, 133, 336-348.
- Beresnev, N., Broadhead, J. (2016). Financing for mangrove protection with emphasis on Pakistan. FAO and IUCN: Thailand and VietNam.
- Bhatta, R. 2019. (2019). Life below water. Department of planning, program monitoring and statistics Government of Karnataka Bengaluru 560001.
- Brander, M.L., J. Wagtendonk, A., S. Hussain, S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. *Ecosystem Services*, 1(1), 62-69.
- Brandon, A. M., Gao, S. H., Tian, R., Ning, D., Yang, S. S., Zhou, J., Wu, W. M., & Criddle, C. S. (2018). Biodegradation of Polyethylene and Plastic Mixtures in Mealworms (Larvae of *Tenebrio molitor*) and Effects on the Gut Microbiome. *Environmental science & technology*, 52(11), 6526-6533.
- Bruckner, A.W., Renaud, P. (2012). Applying habitat maps and biodiversity assessments to coral reef management. *Proceedings of the 12th International Coral Reef Symposium*, Cairns, Australia.
- Caldeira, K., & Wickett, M. E. (2003). Anthropogenic carbon and ocean pH. *Nature*, 425(6956), 365-365.
- Cherrie-Teh, C. P., Daphne-Ling, H. A., Nithiyaa, N., & Aileen Tan, S. H. (2016). *Impact of Ocean Acidification on Biochemical Components in Tropical Oyster, Crassostrea belcheri*. Paper presented at the 4th International Symposium on the Ocean in a High-CO2 World.
- Chew, L. L., & Chong, V. C. (2016). Response of marine copepods to a changing tropical environment: winners, losers and implications. *PeerJ*, 4, e2052.
- Courtene-Jones, W., Quinn, B., Gary, S. F., Mogg, A. O. M., & Narayanaswamy, B. E. (2017). Microplastic pollution identified in deep-sea water and ingested by benthic invertebrates in the Rockall Trough, North Atlantic Ocean. *Environ Pollut*, 231(Pt 1), 271-280.

- Costanza, R., d'Arge, R., de Groot, R., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253-260.
- Doney, S. C., Busch, D. S., Cooley, S. R., & Kroeker, K. J. (2020). The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities. *Annual Review of Environment and Resources*, 45(1), 83-112.
- DOE (2019). Annual Report 2019. Department of Environment (DOE), Malaysia. Retrived from: <https://enviro2.doe.gov.my/ekmc/wp-content/uploads/2021/02/V18-AR-JAS.pdf>
- Duarte, C.M., Middelburg, J., Caraco, N. (2005). Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2, 1-8.
- Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., & Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS One*, 9(12), e111913.
- Fortes, M. D., Ooi, J. L. S., Tan, Y. M., Prathep, A., Bujang, J. S., & Yaakub, S. M. (2018). Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation. *Botanica Marina*, 61(3), 269-288.
- Goldberg, E.D. (1995). The health of the oceans - a 1994 update. *Chemical Ecology* 10, 3-8.
- Goldberg, E.D. (1997). Plasticizing the seafloor: an overview. *Environmental Technology* 18, 195-202.
- Gregory, M.R. (2009). Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions B*, 364, 2013-2025.
- Guo, J. J., Huang, X. P., Xiang, L., Wang, Y. Z., Li, Y. W., Li, H., Cai, Q. Y., Mo, C. H., & Wong, M. H. (2020). Source, migration and toxicology of microplastics in soil. *Environ Int*, 137, 105263.
- Guzzetti, E., Sureda, A., Tejada, S., Faggio, C. (2018). Microplastic in marine organism: Environmental and toxicological effects. *Environmental Toxicology and Pharmacology*, 64, 164-171.
- Hansen, J. (1990). Draft position statement on plastic debris in marine environments. *Fisheries* 15, 16-17.
- Haiges, R., Wang, Y. D., Ghoshray, A., & Roskilly, A. P. (2019). Unconventional fuel pathways for decarbonizing the electrical power generation in Malaysia by 2050. *Energy Procedia*, 158, 4238-4245.
- Hamilton, S. E., & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Global Ecology and Biogeography*, 25(6), 729-738.
- Horton, A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, 586, 127-141.
- Hossain, M., Bujang, J., Zakaria, M., & Hashim, M. (2015). Application of Landsat images to seagrass areal cover change analysis for Lawas, Terengganu and Kelantan of Malaysia. *Continental Shelf Research*, 110, 124-148.
- Huerta Lwanga, E., Thapa, B., Yang, X., Gertsen, H., Salánki, T., Geissen, V., & Garbeva, P. (2018). Decay of low-density polyethylene by bacteria extracted from earthworm's guts: A potential for soil restoration. *Sci Total Environ*, 624, 753-757.
- Hughes, T.P., Graham, N.A.J., Jackson, J.B.C., et al. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution* 25(11), 633-42.
- Husin, M. J. M., Mazlan, N., Shalom, J., Saud, S. N., & Sani, M. S. A. (2021). Evaluation of Microplastics Ingested by Sea Cucumber *Stichopus Horrens* in Pulau Pangkor, Perak, Malaysia.

- Ibrahim, Y. S., Azmi, A. A., Shukor, S. A., Anuar, S. T., & Abdullah, S. A. (2016). Microplastics ingestion by *Scapharca cornea* at Setiu Wetland, Terengganu, Malaysia. *Middle-East Journal of Scientific Research*, 24(6), 2129-2136.
- Isa, N. S., Akhir, M. F., Khalil, I., Kok, P. H., & Roseli, N. H. (2020). Seasonal characteristics of the sea surface temperature and sea surface currents of the Straits of Malacca and Andaman Sea. *Journal of Sustainability Science and Management*, 15(4), 66-77.
- Jagtap, T.G. (1996). Some Quantitative Aspects of Structural Components of Seagrass Meadows from the Southeast Coast of India. Walter de Gruyter, Berlin / New York. <https://doi.org/10.1515/botm.1996.39.1-6.39>
- Jusoff, K. (2013). Malaysian Mangrove Forests and their Significance to the Coastal Marine Environment. *Polish Journal of Environmental Studies*, 22(4).
- Kanhai, D. K., Gårdfeldt, K., Lyashevskaya, O., Hassellöv, M., Thompson, R. C., & O'Connor, I. (2018). Microplastics in sub-surface waters of the Arctic Central Basin. *Marine Pollution Bulletin*, 130, 8-18.
- Kapsenberg, L., & Cyronak, T. (2019). Ocean acidification refugia in variable environments. *Global Change Biology*, 25(10), 3201-3214.
- Karbalaei, S., Golieskardi, A., Hamzah, H. B., Abdulwahid, S., Hanachi, P., Walker, T. R., & Karami, A. (2019). Abundance and characteristics of microplastics in commercial marine fish from Malaysia. *Marine Pollution Bulletin*, 148, 5-15.
- Kaladharan, P., Vijayakumaran, K., Singh, V.V., et al. (2017). Prevalence of marine litter along the Indian beaches: a preliminary account on its status and composition. *J. Mar. Biol. Assoc. India* 59, 19-24. doi:10.6024/jmbai.2017.59.1.1953-03
- Kim, D., Chae, Y., & An, Y. J. (2017). Mixture Toxicity of Nickel and Microplastics with Different Functional Groups on *Daphnia magna*. *Environmental Science and Technology*, 51(21), 12852-12858.
- Kwon, J.H., Chang, S., Hong, S.H., Shim, W.J. (2017). Microplastics as a vector of hydrophobic contaminants: Importance of hydrophobic additives. *Integrated Environmental Assessment and Management*, 13(3), 494-499. doi: 10.1002/ieam.1906. PMID: 28440943.
- Lang, J. (2003). Status of Coral Reefs in the Western Atlantic: Results of Initial Surveys, Atlantic and Gulf Rapid Reef Assessment (Agrra) Program. *Atoll Research Bulletin*, 496, 630.
- Li, Y., Zhang, H., & Tang, C. (2020). A review of possible pathways of marine microplastics transport in the ocean. *Anthropocene Coasts*, 3(1), 6-13.
- Macreadie, P. I., Anton, A., Raven, J. A., et al. (2019). The future of Blue Carbon science. *Nature Communications*, 10(1), 3998.
- Magnan, A. K., Colombier, M., Billé, R., Joos, F., Hoegh-Guldberg, O., Pörtner, H.-O., Waisman, H., Spencer, T., & Gattuso, J.-P. (2016). Implications of the Paris agreement for the ocean. *Nature Climate Change*, 6(8), 732-735.
- Mata, M. T., Luza, M. F., & Riquelme, C. E. (2017). Production of diatom–bacteria biofilm isolated from *Seriola lalandi* cultures for aquaculture application. *Aquaculture Research*, 48(8), 4308-4320.
- Md Amin, R., Sohaimi, E. S., Anuar, S. T., & Bachok, Z. (2020). Microplastic ingestion by zooplankton in Terengganu coastal waters, southern South China Sea. *Mar Poll Bull*, 150, 110616.
- Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The Global Flood Protection Benefits of Mangroves. *Scientific Reports*, 10(1), 4404.
- Moura, V., Ribeiro, I., Moriggi, P., Capão, A., Salles, C., Bitati, S., & Procópio, L. (2018). The influence of surface microbial diversity and succession on microbiologically influenced corrosion of steel in a simulated marine environment. *Arch Microbiol*, 200(10), 1447-1456.

- Müller-Dum, D., Warneke, T., Rixen, T., Müller, M., Baum, A., Christodoulou, A., Oakes, J., Eyre, B. D., & Notholt, J. (2019). Impact of peatlands on carbon dioxide (CO₂) emissions from the Rajang River and Estuary, Malaysia. *Biogeosciences*, 16(1), 17-32.
- Myers, N., Mittermeier, R., Mittermeier, C., da Fonseca, G.A.B., Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858. <https://doi.org/10.1038/35002501>
- Najihah, M., Ismail, M. S., Yap, C. K., & Ku, K. K. (2020). Microplastics Occurrence in Waters off the Northwest Coast of Peninsular Malaysia: A Spatial Difference. *Journal of Basic and Applied Sciences*, 16, 50-60.
- Nellemann, C., Corcoran, E., Duarte, C. M., Valdés, L., De Young, C., Fonseca, L., & Grimsditch, G. J. A. r. r. a. (2009). *Blue carbon*. 78.
- Oberbeckmann, S., Kreikemeyer, B., & Labrenz, M. (2017). Environmental Factors Support the Formation of Specific Bacterial Assemblages on Microplastics. *Front Microbiol*, 8, 2709.
- Obura, D., Grimsditch, G. (2009). Coral Reefs, Climate Change and Resilience An Agenda for Action from the IUCN World Conservation Congress in Barcelona, Spain.
- Ooi, J. L. S., Goh, H. C., Then, A. H. Y., Affendi, Y. A., Izarenah, M. R., & Abu Muntalib, J. (2017). Status Report on the Marine Environment of the Mersing Marine Park Island, and Indicative Proposal for a Marine Protected Area Network. Retrieved from Putrajaya:
- Park, S. Y., & Kim, C. G. (2019). Biodegradation of micro-polyethylene particles by bacterial colonization of a mixed microbial consortium isolated from a landfill site. *Chemosphere*, 222, 527-533.
- Pendleton, L., Donato, D.C., Murray, B.C., et al. (2012). Estimating Global “Blue Carbon” Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLoS ONE* 7(9), e43542. <https://doi.org/10.1371/journal.pone.0043542>
- Praveena, S. M., Siraj, S. S., & Aris, A. Z. (2012). Coral reefs studies and threats in Malaysia: a mini review. *Reviews in Environmental Science and Bio/Technology*, 11(1), 27-39.
- Primavera, J. H., Friess, D. A., Van Lavieren, H., & Lee, S. Y. (2019). Chapter 1 - The Mangrove Ecosystem. In C. Sheppard (Ed.), *World Seas: an Environmental Evaluation* (Second Edition) (pp. 1-34): Academic Press.
- Putz, F. E., & Chan, H. (1986). Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecology and Management*, 17(2-3), 211-230.
- Reef Check Malaysia. (2020). Status of Coral Reefs in Malaysia, 2020. Retrieved from Kuala Lumpur, Malaysia:
- Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proceedings of the National Academy of Sciences*, 113(2), 344.
- Robertson, A.I., Duke, N.C. (1987). Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Mar. Biol.* 96, 193–205. <https://doi.org/10.1007/BF00427019>.
- Rojana-Anawat, P., & Snidvongs, A. (1999). Dissolved oxygen and carbonate-carbon dioxide in the sea water of the South China Sea, area I: Gulf of Thailand and east coast of peninsular Malaysia. Paper presented at the Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area I: Gulf of Thailand and Peninsular Malaysia, 24-26 November 1997, Bangkok, Thailand.
- Rozaimi, M., Fairuz, M., Hakimi, T. M., Hamdan, N. H., Omar, R., Ali, M. M., & Tahirin, S. A. (2017). Carbon stores from a tropical seagrass meadow in the midst of anthropogenic disturbance. *Mar Poll Bull*, 119(2), 253-260.
- McKenzie, L.J., Unsworth, R.K.F. (2009) Great Barrier Reef water quality protection plan (Reef Rescue) - marine monitoring program: intertidal seagrass. Final report for the sampling period 1 September 2008–31 May 2009. Fisheries Queensland, Cairns.

- Nelms, S.E., Duncan, E.M., Broderick, A.C., et al. (2016). Plastic and marine turtles: a review and call for research. *ICES Journal of Marine Science*, 73(2), 165-181.
- Saenger P, Hegerl EJ, Davie JDS (eds). (1983). Global status of mangrove ecosystems. IUCN, Gland.
- Sarkar, S., Bhadouriya, A. (2020). Manufacturer competition and collusion in a two-echelon green supply chain with production trade-off between non-green and green quality. *Journal of Cleaner Production*, 253, 119904. <https://doi.org/10.1016/j.jclepro.2019.119904>.
- Savoca, S., Capillo, G., Mancuso, M., Bottari, T., Crupi, R., Branca, C., Romano, V., Faggio, C., D'Angelo, G., & Spanò, N. (2019). Microplastics occurrence in the Tyrrhenian waters and in the gastrointestinal tract of two congener species of seabreams. *Environ Toxicol Pharmacol*, 67, 35-41.
- Semesi, I.S., Beer, S., Björk, M. (2009) Seagrass photosynthesis controls rates of calcification and photosynthesis of calcareous macroalgae in a tropical seagrass meadow. *Mar Ecol Prog Ser* 382, 41-47. <https://doi.org/10.3354/meps07973>
- Sridhar, R., Thangradjou, T., Kannan, L., Astalakshmi, S. (2010), Assessment of coastal bioresources of the Palk Bay, India, using IRS-LISS-III data. *J Ind Soc Remote Sens* 38, 565-575.
- Stankovic, M., Ambo-Rappe, R., Carly, F., Dangan-Galon, F., Fortes, M. D., Hossain, M. S., Kiswa, W., Van Luong, C., Minh-Thu, P., & Mishra, A. K. (2021). Quantification of blue carbon in seagrass ecosystems of Southeast Asia and their potential for climate change mitigation. *Science of The Total Environment*, 146858.
- Supari, Tangang, F., Juneng, L., Cruz, F., Chung, J. X., Ngai, S. T., Salimun, E., Mohd, M. S. F., Santisirisomboon, J., Singhruck, P., Phanvan, T., Ngo-Duc, T., Narisma, G., Aldrian, E., Gunawan, D. & Sopaheluwakan, A. (2020). Multi-model projections of precipitation extremes in Southeast Asia based on CORDEX-Southeast Asia simulations. *Environmental Research*, 184, 109350.
- Syranidou, E., Karkanorachaki, K., Amorotti, F., Repouskou, E., Kroll, K., Kolvenbach, B., Corvini, P. F., Fava, F., & Kalogerakis, N. (2017). Development of tailored indigenous marine consortia for the degradation of naturally weathered polyethylene films. *PLoS One*, 12(8), e0183984.
- Tan, M.K., Juneng, L., Tangang, F.T., Chung, J.X., Firdaus, R.B.R. (2021). Changes in temperature extremes and their relationship with ENSO in Malaysia from 1985 to 2018. *International Journal of Climatology*, 41(Suppl. 1), E2564 - E2580.
- Tan, Y. H., Lim, P. E., Beardall, J., Poong, S. W., & Phang, S. M. (2019). A metabolomic approach to investigate effects of ocean acidification on a polar microalga *Chlorella* sp. *Aquat Toxicol*, 217, 105349.
- Tang, K. H. D. (2019). Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Sci Total Environ*, 650(Pt 2), 1858-1871.
- Tangang, F., Supari, S., Chung, J., Cruz, F., Salimun, E., Ngai, S., Juneng, L., Santisirisomboon Je., Santisirisomboon, Ja., Ngo-Duc, T., Phan-Van, T., Narisma, G., Singhruck, P., Gunawan, D., Aldrian A., Sopaheluwakan, A., Nikulin, G., Yang, H., Remedio, ARC, Sein, D., & Hein-Griggs, D. (2018). Future changes in annual precipitation extremes over Southeast Asia under global warming of 2 °C. *APN Science Bulletin*, 8(1), <https://doi.org/10.30852/sb.2018.436>.
- Tangang, F., Chung, J. X., Juneng, L., Supari, Salimun, E., Ngai, S. T., Jamaluddin, A. F., Mohd, M. S. F., Cruz, F., Narisma, G., Santisirisomboon, J., Ngo-Duc, T., Van Tan, P., Singhruck, P., Gunawan, D., Aldrian, E., Sopaheluwakan, A., Grigory, N., Remedio, A. R. C., Sein, D. V., Hein-Griggs, D., McGregor, J. L., Yang, H., Sasaki, H. & Kumar, P. (2020). Projected future changes in rainfall in Southeast Asia based on CORDEX-SEA multi-model simulations. *Climate Dynamics*, 55, 1247-1267.

- Taylor, P. D., Tan Shau-Hwai, A., Kudryavstev, A. B., & Schopf, J. W. (2016). Carbonate mineralogy of a tropical bryozoan biota and its vulnerability to ocean acidification. *Marine Biology Research*, 12(7), 776-780.
- Thangaradjou, T., Sivakuman, K., Nobi, E.P., Dilipan, E. (2010). Distribution of seagrasses along the andaman and nicobar islands : a post tsunami survey. In book: Recent Trends in Biodiversity of Andaman and Nicobar Islands. Chapter: 11. Publisher: Zoological Survey of India. Editors: R. Raghunathan and C. Sivaperuman
- Thomson, A.R., Kohn, S.C., Bulanova, G.P., et al. (2014). Origin of sub-lithospheric diamonds from the Juina-5 kimberlite (Brazil): constraints from carbon isotopes and inclusion compositions. *Contrib Mineral Petrol*, 168, 1081.
- Tsiota, P., Karkanorachaki, K., Syranidou, E., Franchini, M., & Kalogerakis, N. (2018). Microbial degradation of HDPE secondary microplastics: preliminary results. Paper presented at the Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea.
- Wang, W., Ge, J., & Yu, X. (2020). Bioavailability and toxicity of microplastics to fish species: A review. *Ecotoxicol Environ Saf*, 189, 109913.
- Yuan, J., Ma, J., Sun, Y., Zhou, T., Zhao, Y., & Yu, F. (2020). Microbial degradation and other environmental aspects of microplastics/plastics. *Sci Total Environ*, 715, 136968.
- Yusoff, F. M., Shariff, M., & Gopinath, N. (2006). Diversity of Malaysian aquatic ecosystems and resources. *Aquatic Ecosystem Health & Management*, 9(2), 119-135.
- Zampoukas N, Piha H, Bigagli E, Hoepffner N, Hanke G, Cardoso AC. (2012) Monitoring for the Marine Strategy Framework Directive: requirements and options. *JRC Scientific and Technical Reports* 68179.
- Zhang, Y., Kang, S., Allen, S., Allen, D., Gao, T., Sillanpää, M. (2020). Atmospheric microplastics: A review on current status and perspectives. *Earth-Science Reviews*, 203, 103118.

7. Appendix

7.1 List of Tables

Table 1. The MSFD descriptors to determine Good Environmental status in the EU.

Table 2. Principal coastal ecosystems facing threats along the Indian coast (source: Bhatta, 2019).

7.2 List of Figures

Figure 1. GHGs emission of the energy sector from 1990 to 2011 in Malaysia (Tang, 2019).

Figure 2. Projected increases of temperature averaged over Southeast Asia including Malaysia under the worse-case emission scenario of RCP8.5 (Tang et al., 2018).

Figure 3. The projected changes of rainfall for June-July-August (JJA) and December-January-February (DJF) for middle emission scenario (RCP4.5) and worse-case-emission scenario (RCP8.5) for early, mid and late 21st century over Southeast Asia including Malaysia (Tang et al., 2020).

Figure 4. Projected changes of consecutive dry days (CDD, indicator of dryness and drought) over Southeast Asia including Malaysia for the end of the 21st century under RCP8.5 scenario (Supari et al., 2020).

Figure 5. General trends in key community and ecosystem properties and processes in response to ocean acidification in seagrass meadows, coral reefs, other carbonate reef ecosystems, and pelagic food webs (Doney et al., 2020).

Figure 6. Estimates of the economic value of blue carbon ecosystems per hectare. Data from ref. (Nellemann et al., 2009) and references therein. Symbols and images are courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/) (Macreadie et al., 2019).

Figure 7. Image of coral reef in Pulau Tinggi, Johor, Malaysia (Ooi et al., 2017).

Figure 8. Map showing the reef health composition of each survey islands in Peninsular Malaysia and Sabah based on their live coral cover (Reef Check Malaysia, 2020).

Figure 9. Monospecific stand of *Sonneratia alba* along a tidal river in Capiz, central Philippines (Primavera et al., 2019).

Figure 10. Mangrove deforestation between 2000 and 2012. Deforestation is summarized within each 1 decimal degree square (Richards and Friess, 2016).

Figure 11. Percentage mangrove deforestation between 2000 and 2012, and dominant land uses of deforested areas in 2012. Land uses are summarized as the converted land use with the greatest area within each 1 decimal degree grid square. Circles are located in the center of each grid square,

and circle size represents the percentage of the mangrove area in 2000 that has been lost (Richards and Friess, 2016).

Figure 12. Image of seagrass bed *Halodule uninervis* in Pulau Mentigi, Johor, Malaysia (Ooi et al., 2017).

Figure 13. Level of seagrass information available within the Southeast Asian region (Fortes et al., 2018).

Figure 14. Illustration of the pathways of microplastic and its general impact to the marine ecosystem and organisms (Amelia et al., 2021).

Figure 15. Impacts and combined effects of microplastic and pollutants toward marine organism (Amelia et al., 2021).

Figure 16. Coastline of India.

Figure 17. Study locations and their marine litter status along Indian beaches during October 2013-January 2014 (Numbers in parentheses in the inset indicates ranking of the areas under study). From Kaladharan et al. (2017).

Figure 18. Degradation pathways of plastic materials in flowing water bodies with various degradation processes involved until complete mineralization (Sarkar and Bhadouriya, 2020).