2018 SINGAPORE BLUE PLAN

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WITH CONTRIBUTION FROM MARINE SCIENTISTS, KEY STAKEHOLDERS, AND THE MARINE COMMUNITY

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INTRODUCTION

1. The Singapore Blue Plan 2018 (hereafter 'The Blue Plan') is a proposal for the conservation of marine ecosystems, prepared by members of Singapore society, and submitted to the Government for consideration. It was initiated by marine biologists with academics, volunteers, stakeholders, and concerned citizens. The Blue Plan synthesizes the current state of knowledge for marine environments, reviews relevant legislature and advocates comprehensive sustainable methods to manage this important ecosystem.

COLLECTIVE STEWARDSHIP OF NATIONAL NATURAL HERITAGE

2. Successful stewardship of marine habitats in Singapore is only possible with the community and Government working collaboratively towards effective outcomes. Previous iterations of The Blue Plan received significant support from Government Agencies. The community is heartened by this strong support. Marine areas in Singapore host multiple users, ranging from industrial to recreational sectors, and on any given day, there are thousands of users. The community recognizes the commitment displayed by the Government to find a balance between infrastructure development and conservation of biodiversity and habitats. The new Blue Plan advances key themes for which the community and the Government can continue this dialogue.

3. Diverse marine habitats are present in Singapore, such as coral reefs, mangrove forests, seagrass meadows, and rocky shores, all with a very rich biodiversity. The healthy functioning of these ecosystems benefits us by providing resources and contributes to our physical and mental well-being. Over the past decade, many concerted efforts to better document marine organisms within our territorial waters have been undertaken; key among them being the Comprehensive Marine Biodiversity Survey (CMBS) organized by the National Parks Board and National University of Singapore which ran from 2010 to 2015. During this initiative, more than 350 surveys were conducted in the Johor and Singapore Strait, from depths of 0-200 m; uncovering a rich biodiversity of over 1,100 species, including many new ones.

4. Many community-led and Government-backed initiatives—Friends of the Marine Park, Pesta Ubin, coastal and reef clean-ups, and restoration efforts—foster empowerment of civil society and enhance community spirit. Consequently, the remaining natural areas are thriving. In the past decade, there has also been a dramatic increase in sightings of large marine fauna such as sharks, dolphins, turtles, otters, and crocodiles; testament to the effective management of these natural areas.

SUSTAINABLE MANAGEMENT OF BLUE AREAS

5. As Singapore strives to be a global maritime hub, sustainable management of our marine ecosystems will strengthen our reputation as a smart, eco-conscious city. The interconnected nature of marine areas is especially pertinent when discussing global-scale impacts such as climate change, ocean acidification, and global warming. The implementation of scientific, and data-driven management strategies is integral for the long-term health of our marine ecosystems. Creation of protected areas and enhancement of our coastlines can mitigate future impacts. In particular, habitat restoration and rehabilitation could play critical roles in reinstating ecological functions of degraded habitats.

6. Data from constant and long-term monitoring programmes provide environmental baseline to understand complex physical, chemical, biological and ecological responses to natural and human-induced environmental changes, notably the effects of climate change. Detection of acute, short-term changes is critical for emergency responses and mitigation of impacts. The ability to observe the small and large changes enables informed and systematic management of Singapore's marine resources.

RECOMMENDATIONS

7. A summary of the various recommendations (not prioritised in any order) proposed by the current Blue Plan is presented below.

8. **Establish formal management systems for marine environments.** A marine spatial planning regime should be established within the integrated urban coastal management framework, especially for ecologically sensitive areas, with legal provision for Strategic Environmental Assessments (SEAs), Environmental Impact Assessments (EIAs), and public participation to promote greater transparency and accountability in environmental governance, and the conservation and sustainable use of the marine environment. Formal EIA legislation should be established; its scope and content should meet applicable international standards including risks of impacts on depleted, threatened or endangered species and rare and fragile ecosystems. A legal framework for monitoring components of marine biodiversity, and making such monitoring records publicly accessible should be established.

9. **Provide sustained funds for research initiatives and long-term monitoring programmes**. Sustained funding support is crucial to effectively maintain, monitor, and manage native biodiversity and marine habitats. Basic scientific knowledge is crucial to long-term planning for the sustainable management of biodiversity and natural areas. Marine sciences have already benefitted greatly from National Research Foundation's Marine Science Research and Development Programme (MSRDP) and NParks' Technical Committee on Coastal and Marine Ecosystems (TCCME) grants. Ensuring the long-term sustainability of these and related programmes are crucial towards capacity building and the success of marine science in Singapore. Inventory efforts of marine organisms in Singapore, although underway, are far

from complete. Connectivity of organisms and habitats in Singapore and the region is at present, poorly known. Elucidating how populations of these organisms interact with those in similar habitats in Singapore and the region is important. Such knowledge allows for the identification of local and regional source and sink areas, as well as infer local and transboundary resource and pollutant movements and energy exchanges. Establishing a programme that provides access to basic water quality and baseline data is key to support environment science research. Consolidation of data procurement, and sharing of data obtained, between multiple stakeholders result allows for data consistency (see 11).

10. **Enhance legislation to protect marine biodiversity and environment.** Existing legislation and administrative practices should be amended to fill gaps in regulation and detection of offences. Updates to legislation pertaining to the marine environment can accord better protection to marine biodiversity. The Wild Animals and Birds Act ("WABA"), for example, can be amended to explicitly include aquatic and marine animals. The Fisheries Act can be amended to incorporate the Prevention of Pollution of the Sea Act offences on marine pollution applicable to fishing vessels, bringing these offences in relation to fishing vessels under the jurisdiction of Agri-food and Veterinary Authority ("**AVA**"). The storage and disposal of wastes, the import of live specimens of alien species by fish farms, and the indiscriminate disposal or abandonment of fish culture equipment can be regulated by the Fisheries (Fish Culture Farms) Rules and the Fisheries (Fishing Gear) Rules. Updating AVA species-specific product codes (Endangered Species (Import and Export) Act) can better manage the trade of endangered marine flora and fauna and regulate illegal sales. New legislation should be introduced to better regulate current and emerging threats.

On the global arena, Singapore can further enhance international cooperation to protect the marine environment. Singapore can accede to, and implement a number of treaties such as the 1979 Convention on Conservation of Migratory Species of Wild Animals and relevant Memoranda of Understanding; the 2003 Protocol to the 1992 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage; the Protocol of 1996 to amend the 1976 Convention on Limitation of Liability for Maritime Claims; the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea and its 2010 Protocol; the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its 1996 Protocol.

11. **Improve intra- and inter-agency coordination of public marine database.** Improved coordination, and streamlining processes, within and between agencies and researchers can greatly aid in management of marine areas and resources. A lead agency or co-ordinating body, supported by scientists and senior government managers, with a broad overview on the management and use of natural marine areas and biodiversity, can act as a focal point or a representative group. The committee must include tenets of marine spatial planning, and oversee EIAs related to marine areas, coordinate scientific information and efforts, and corral public participation. These efforts, if implemented from the point of permit application, to the end of the research project, can greatly aid in achieving research goals.

12. **Protect remaining natural marine habitats from unnecessary biodiversity loss.** Although marine habitats in Singapore are fragmented and small, these sites are each unique, and host high diversity. Protection of habitat types therefore, cannot be reduced to a single exemplary site; and must be extended to be as exhaustive as possible. Ideally, all pristine natural areas should be accorded protection from further development to conserve these pockets of refugia for marine organisms. In addition, these ecosystems provide us with ecosystem goods and services at present not quantified in Singapore. We identify three broad areas for immediate conservation priority—Pulau Semakau and adjacent islands, Pulau Satumu and adjacent Pulau Biola, and Ubin. We also propose two broad areas for elevated protection status—St. John's Island and adjacent islands, and Sungei Buloh Wetland Reserve. This list of proposed key conservation sites which should be considered for immediate conservation attention is presented in Part I Section 5 of The Blue Plan.

13. **Include topics on natural environment into school syllabus and promote science communication.** Being an island nation, the lives of many Singaporeans are intertwined to marine ecosystems, from enjoying the many coastal parks to fishing and diving at the southern coral reefs. Yet, there is a distinct lack of awareness on ecosystem processes surrounding these natural areas. Other than increasing science communication through various forms of public engagement, understanding of basic concepts in natural history can be inculcated in schools. Topics on biodiversity, and the natural environment can be included in the syllabus at the primary, secondary, and pre-university levels to systematically approach larger environmental issues. Only through education can we achieve a scenario where the general populace supports conservation and environmentally sustainable efforts. The success Singapore has had with the "Garden City" concept should be expanded to include the sea.

CONCLUSION

14. The Singapore Blue Plan 2018, like its predecessors, envisages a Singapore that celebrates and cherishes her marine heritage. The Blue Plan, and its contributors, are apolitical. This ground-up national initiative involves a collective whose intent is for the successful stewardship of marine areas of Singapore. It is our hope that we continue to enjoy dialogues with Government Agencies on the enhancement and implementation of these recommendations.

END OF EXECUTIVE SUMMARY

PART I

THE SINGAPORE BLUE PLAN 2018

THE SINGAPORE BLUE PLAN 2018

INTRODUCTION

The Singapore Blue Plan 2018 is a proposal for the conservation of coastal and marine ecosystems, prepared by civil society and submitted to Government. Document preparation was led by marine biologists with contributions from marine scientists, academics, nature volunteers, stakeholders, and concerned citizens. The Singapore Blue Plan 2018 comprises an executive summary, and four components of which the first is the main document and the latter three are supporting and supplementary information: Part I The Singapore Blue Plan 2018 (SBP2018); Part II Scientific Support and Data for the SBP2018; Part III Environmental Legislation Support for the SBP2018; and Part IV Stakeholders and Community Partners.

MISSION STATEMENT

The Blue Plan 2018 serves to encapsulate the state of knowledge on marine ecosystem processes and the ecology and diversity of associated organisms. Legislation governing marine ecosystems and resources are discussed. The Blue Plan 2018 advocates for the conservation, and sustainable use, of marine ecosystems and resources; and to achieve this, a proposed action plan to be pursued by government agencies in partnership with stakeholders.

Pulau Tekukor at low tide. Drone photograph by Heng Pei Yan with permission from NParks

PREMISE

Singapore's marine environment is rich and deserves conservation. The growing economy and population of Singapore necessitates rapid urbanisation, intensive coastal development and extensive modification of natural coastlines. Despite heavy impacts on all coastal ecosystems, rich biodiversity still persists in our remaining natural habitats. Within our sovereign waters, there are a wide range of coastal and shallow-water habitats: coral reefs, mangrove forests, seagrass meadows, rocky shores, and open waters.

The remaining natural coastal and marine ecosystems in Singapore are an asset, responsible for maintaining ecosystem services and public health. Healthy functioning of these ecosystems benefits us by providing resources (e.g. food and medicine), a clean and safe environment (e.g. by mitigating greenhouse gas emissions and protecting coastlines against erosion) and contributing to our physical and mental well-being (e.g. recreation, education, cultural or spiritual purposes).

Humans draw strength from natural landscapes. Being an island nation, the lives of a large percentage of the population are intertwined to marine ecosystems, from enjoying the many coastal parks to water sports, fishing, and diving at the southern coral reefs. In a crowded and rapidly changing marine landscape, conscious efforts to protect these seascapes must be made, not for the sake of nature alone, but also for our own health.

As Singapore strives to be a global maritime hub, proper management of its marine ecosystems will also strengthen Singapore's reputation as a green city. Singapore has had an excellent track record as a garden city. This honour can be easily extended to the marine areas of our island nation.

HISTORY

In 1987, three advocates for coral reefs —Professor Chou Loke Ming, Mr Francis Lee, and Mr Khoo Soo Seng—initiated the Singapore Reef Survey and Conservation Project. They identified four broad clusters worthy of conservation, and submitted these in the Reef Conservation Proposal in 1991, thereafter incorporated into the first Singapore Green Plan.

In 2001, another opportunity arose to submit a coral reef conservation plan, via Mr Edwin Khew, Chairman of Environmental Feedback Group. The proposed plan did not gain traction possibly because during this time, there were no specific government agencies overseeing conservation of marine areas.

International Year of the Reef 2008 presented another opportunity to engage policy makers on conservation of coral reefs. Mr Francis Lee chaired the overall community effort, while Mr Farid Abdul Hamid chaired the committee that produced the Singapore Blue Plan 2009. The adoption of some ideas proposed in the Blue Plan 2009 was facilitated by the establishment of a relevant government agency overseeing marine conservation within the National Parks Board.

In comparison, the Singapore Blue Plan 2018 is an iteration that benefitted from more partners, stronger scientific input, and inclusion of environmental legislation and policies pertaining to marine environment and diversity.

Like the Gorgonian goby (*Bryaninops amplus*) that must live on its host Seawhip coral (*Juncella* sp.), marine natural areas with intact ecosystem functions are integral to our well-being. Photograph by Heng Pei Yan.

OUTCOMES OF THE BLUE PLAN 2009

Over the past decade, and taking the recommendations of the Blue Plan 2009, concerted efforts have furthered our understanding of Singapore's coastal and marine organisms.

The Comprehensive Marine Biodiversity Survey (CMBS) (2010-2015) was a joint effort between the National Parks Board and the National University of Singapore. The realisation of diverse marine life at Chek Jawa and Beting Bronok in the Johor Strait, drove home the point that habitats other than coral reefs and mangroves can have impressive biodiversity. Are there any other places in Singapore with high marine biodiversity that needs protection? How many marine species occur in urbanised Singapore today? These vital questions gave much impetus to the CMBS when it was conceived.

As a result, the CMBS focused on three poorly known marine habitats in Singapore: intertidal mudflats; soft subtidal benthos; non-scleractinian components of coral reefs. While coral reefs and mangroves are increasingly given due attention since the first Blue Plan, mudflats and soft subtidal benthos – despite their prevalence - have been accorded little attention and often ignored altogether. Similarly, while scleractinian coral and fishes in coral reefs have been prominently studied, benthic occupants of coral reefs, such as sponges, sea anemones, polychaetes, crustaceans, molluscs and echinoderms have not been given equal consideration.

Under the CMBS, more than 350 surveys were conducted in coastal and marine areas within the Johor and Singapore Strait, from depths of 0-200m. Thirty-nine new species were discovered, and 306 new records were recovered for Singapore The surveys also rediscovered two species not seen in Singapore for more than 50 years. These surveys found unique sets of flora and fauna in excess of 1,100 species, including undocumented deep water populations of hydroids, sponges, bivalves, crinoids, and basket stars. Although these submerged habitats are not easily seen, they remain unique to Singapore - to date, we are not aware of similar populations elsewhere in the region. This is not surprising given the scant attention to non-coral reef areas in the past. More information on the marine organisms of Singapore, including those collected from the CMBS, can be found in Part II Chapter 2 of this document.

The CMBS also showed that citizens can contribute significantly towards biodiversity studies. By collecting specimens in the field and sorting them in the laboratory, citizens gain intimate contact with the living organisms and thus an appreciation of their diversity and form, which encourages ownership. With such experience, the more committed citizen can take on in-depth studies or participate in more complex ecological surveys. There is tremendous scope for biodiversity studies by amateurs and the general public in Singapore.

Volunteers contributed considerably toward the success of the two CMBS international workshops – more than 500 volunteers helped to collect, sort and housekeep thousands of specimens. They were particularly valuable on mudflats, where movements of any one collector is extremely limited. Many students benefited from exposure to enthusiastic scientists, and some even went on to become scientists themselves.

The Sisters' Islands, one of the areas suggested for protection in the Blue Plan 2009, was gazetted as part of a marine park that also includes the western coast of St. John's Island. The marine park was officially opened in August 2014. Managed by the National Parks Board, Singapore's first marine park serves the crucial role for conservation and restoration of marine biodiversity, as well as outreach and education of our marine heritage.

The Pacific strawberry cockle (*Fragum unedo*) can be found on our sandy shores near coral reefs. Phograph by Heng Pei Yan.

MARINE ECOSYSTEMS IN SINGAPORE

Natural dynamic processes and man-made disturbances can affect the resilience of marine ecosystems. There is increasing recognition that impacts to a habitat might not be localised. Marine habitats in Singapore and the region are connected by water currents, which transport sediments, nutrients, larvae of marine organisms and plant propagules. Urbanisation of inland freshwater systems could impact downstream coastal ecosystems. Understanding large-scale processes, i.e. hydrodynamics and habitat connectivity, presents a broader regional context to marine ecosystem functioning in Singapore.

Part II Chapter 1 provides a summary on the current state of knowledge and research on various marine and associated ecosystems in Singapore and the region. Potential impacts to existing habitats based on developments published MND Land Use Plans are outlined.

MARINE BIODIVERSITY AND ECOLOGICAL COMMUNITIES

Species are fundamental building blocks to any biological system. Establishing their identities is vital as baseline biodiversity information is fundamental to data-driven management of natural areas and conservation efforts.

Efforts to elucidate marine biodiversity in Singapore has intensified in several decades. Surveys such as the ASEAN-Australian Marine Science Project: Living Coastal Resources, and the CMBS, contributed significantly to our knowledge of native biodiversity. Comprehensive baseline information on marine organisms in Singapore also exists both in published and gray literature.

As a logical extension of biodiversity studies, the biology, ecology, and population structures of many taxa are now underway. Genomic data are now being used to infer past and present population parameters, gene flow and the species histories of key species. In addition to data obtained locally, information gleaned from studies conducted elsewhere are typically used to inform conservation measures. The work that has been performed on marine biodiversity is summarised and presented in Part II Chapter 3. The list is not exhaustive; these organisms showcase efforts concentrated in Singapore over the past decade.

Overall, more data collection and biodiversity restoration with the help of citizen scientists and volunteers are generating greater understanding of our ecological communities.

HISTORICAL ENVIRONMENTAL RECONSTRUCTION

Long-term monitoring provides an environmental baseline for understanding complex physical, chemical, biological and ecological responses to natural and human-induced environmental changes. Without long-term data sets, it will be impossible to capture natural variability, natural or otherwise, occurring at longer time scales (inter-annual; decadal). Long-term monitoring will help scientists and policy-makers better pre-empt changes to Singapore's sensitive marine ecosystems. Data from long-term monitoring stations can also serve in meeting Singapore's responsibilities under international/national standards (e.g. WHO guidelines, environmental pollution standards/thresholds).

However, available long-term observational data of Singapore's marine environment is extremely sparse and not consolidated. This makes understanding and assessing long-term ecosystem responses to natural and anthropogenic environmental changes extremely challenging. Efforts to overcome this lack of observational data include extricating information locked in the sediments or skeletons of long-lived organisms (e.g. reef-building corals) which can be used to reconstruct Singapore's marine environment. For more information on research outcomes of historical environmental reconstruction in Singapore, see Part II Chapter 4 of this document.

THREATS TO COASTAL AND MARINE ECOSYSTEMS

The marine environment in Singapore faces global, regional, and local threats. Warming seas, ocean acidification, rising sea level and changes in rainfall patterns are climate change-related impacts that are predicted to negatively affect marine ecosystems. Already, anomalously high temperature events in 1998, 2010 and 2016 resulted in mass coral bleaching and loss of live coral cover on coral reefs in Singapore. Rising sea temperatures have been associated with decadal-scale declines in coral growth rates.

In addition our marine ecosystems are also affected by local scale impacts such as declining water quality, pollution, marine debris, and invasive species. These impacts have led to major and fundamental changes to the marine environment. In recent years, the increased frequency of harmful algal bloom events resulted in losses of hundreds of tonnes of aquaculture fish, and widespread death of many wild fish species. Impacts of marine debris, in particular microplastics and abandoned fishing gear, are becoming more apparent. The South American charru mussel, *Mytella strigata* (Mytilidae), only reported from Singapore since 2012, has already spread through the northern coastline, clogging nets in fish farms, displacing native species, and changing the benthic environment.

Scientists are trying to find out how climate change and ocean acidification affect coastal and marine organisms such as this Sand-bubbler crab (*Scopimera* sp.). Phograph by Heng Pei Yan.

Large variability can be expected as local conditions continue to interact with global effects. To mitigate the negative impacts of rapid environmental changes, active conservation, management and restoration measures are becoming increasingly necessary.

The fate of Singapore's marine ecosystems will not only depend the stabilisation of planetary temperature and carbon dioxide concentrations. Local policies must manage and reduce the pressure on resources from increasing human population. Only by reducing non-climate stresses, can ecosystems have the opportunity to develop resilience to the challenges of our changing planet. More information on threats to coastal and marine environment can be found in Part II Chapter 5 of this document.

MITIGATIVE MEASURES TO CURRENT IMPACTS

Creation of protected areas for coral nurseries and marine parks, such as the Sisters' Islands Marine Park, and enhancement of ecological function of artificial coastlines can mitigate future impacts of coastal development. In particular, habitat restoration and rehabilitation could play critical roles in reverting degraded habitats to their original condition, and replacing the structure and functions that have been compromised, respectively.

Since the early 2000s, research on coral reefs have demonstrated the importance of restoration as a management strategy for areas impacted by heavy sedimentation and reef instability. Two strategies employed are deployment of artificial reef structures and propagation of corals to increase live coral cover.

Ecological Mangrove Restoration emphasises rehabilitation through ecological and biological understanding of mangroves. For example, rehabilitation site selection relies on information about the site's biophysical conditions such as hydrological regime for initial feasibility assessment and subsequent mangrove recruitment and regeneration.

Apart from natural habitats, artificial substrates such as seawalls and pontoons have the potential to host biodiversity even as the majority of Singapore's coastlines are being converted to these structures. Ecological engineering, which involves the design and building of urban infrastructure congruent with ecological principles, can help mitigate some of the most negative effects of this large-scale shoreline "hardening". For existing seawalls that cannot be removed, structural complexity including pits and crevices can be added to enhance biodiversity cost-effectively. This is an approach that has been developed and tested in Singapore. Refer to Part II Chapter 6 for more information

RECOMMENDATIONS FOR SUSTAINABLE CONSERVATION OF COASTAL AND MARINE ECOSYSTEMS

The Singapore Blue Plan 2018 advocates for the conservation, and sustainable use, of marine ecosystems and resources. Following consultations with contributors, stakeholders, and the community, six broad recommendations are proposed. The document details these six recommendations to conserve coastal and marine ecosystems in an integrative and sustainable manner.

1. Establish formal management systems for marine environments.

A marine spatial planning regime should be established within the integrated urban coastal management framework, especially for ecologically sensitive areas, with legal provision for Strategic Environmental Assessments (SEAs), Environmental Impact Assessments (EIAs), and public participation to promote greater transparency and accountability in environmental governance, and the conservation and sustainable use of the coastal and marine environment. An EIA law should be established; its scope and content should meet applicable international standards including risks of impacts on depleted, threatened or endangered species and rare and fragile ecosystems. (Part III, Sections 1.7, 6.5, and 7.4) A legal framework for monitoring components of coastal and marine biodiversity, and making such monitoring records publicly accessible should be established. (Part III Section 2.3)

2. Provide sustained funds for research initiatives and long-term monitoring programmes. Inventory efforts of marine organisms in Singapore, although underway, are far from complete. While the CMBS amassed important baseline data, the exercise revealed that there is more diversity to document. For example, diversity and distribution of several groups of marine organisms such as insects, copepods, and flatworms are still largely unknown.

Connectivity of organisms and habitats in Singapore and the region is still poorly known. Elucidating this allows the identification of local and regional source and sink areas, as well as infer local and transboundary resource and pollutant movements and energy exchanges.

Regular monitoring and assessment of coastal habitats, both natural and artificial, are important to identify and mitigate impacts in a timely manner and to guide effective management.

Long-term monitoring of environment parameters and marine organisms is crucial to chart how our marine ecosystems adapt and respond to impacts over longer time scales, and to make predictions of changes in the health of our marine ecosystems.

Long-term monitoring of biodiversity and habitats are important for the sound management of marine organisms and ecosystems. Photograph of a Hawksbill turtle from Pulau Hantu by Heng Pei Yan.

Establishing a programme that provides open-access basic water quality and baseline data to support environment science research is key. Consolidation of data procurement, and sharing of data obtained, between multiple stakeholders results in data consistency. Data from such monitoring programmes provide environmental baseline to understand complex physical, chemical, biological and ecological responses to natural and human-induced environmental changes.

Detection of acute, short-term changes is critical for emergency responses and mitigation of impacts; but because of the vastness of the seas, these impacts are reflected in increments of small chronic changes. The ability to observe such small changes enables informed, and systematic management of marine resources especially important for survival of island states in the face of global challenges and climate change.

Sustained funding support is required to effectively maintain, monitor, and manage native biodiversity and marine habitats. Marine sciences already benefitted greatly from National Research Foundation's Marine Science Research and Development Programme (MSRDP). and Technical Committee for Coastal and Marine Ecosystems (TCCME). However, ensuring diversity in funding avenues , including continued support from agencies, is crucial for the resilience and success of marine science in Singapore.

3. Enhance legislation to protect marine biodiversity and environment.
Existing legislation and administrative practices should be amended to fill gaps in regulation and detection of offences. The definition of "wild animals and birds" in the Wild Animals and Birds Act ("WABA") should be defined to explicitly cover marine and aquatic wild animals including invertebrates (unless an activity or marine wild animal is specifically excluded from regulation) beyond the activities and species currently regulated under the Fisheries Act; and provide guidelines on acceptable recreational fishing practices, where such activities are to be permitted under WABA (Part III Section 2.3). The Fisheries Act should be amended to explicitly incorporate the Prevention of Pollution of the Sea Act offences on marine pollution applicable to fishing vessels, bringing these offences in relation to fishing vessels under the jurisdiction of Agri-food and Veterinary Authority ("**AVA**") (Part III Section 4.2.1). The Fisheries (Fish Culture Farms) Rules should also be amended to regulate the storage and disposal of wastes, the import of live specimens of alien species by fish farms, and the indiscriminate disposal or abandonment of fish culture equipment. The Fisheries (Fishing Gear) Rules should be amended to regulate the indiscriminate disposal or abandonment of fishing gear (Part III Section 4.2.1). The AVA species-specific product codes should be updated to include all Endangered Species (Import and Export) Act listed scheduled species of marine fauna and flora to ensure that illegal wildlife trade is not overlooked by the lack of product code specification and to facilitate public access to species-specific trade data (Part III Section 2.3). New legislation should be introduced to better regulate current and emerging threats; and updates to be made for the provision for compensation for damage. In particular, activities in the sea and seabed areas that constitute marine parks with the involvement of stakeholders should be regulated (Part III Section 3.1). A ban or tax on the manufacture, import and/or use of single-use plastics should be introduced (Part III Section 5.7).

The recent announcement for the restructuring of the AVA, to be effected in April 2019, indicates an opportune time to critically review and update existing and introduce new legislations.

On the global arena, Singapore can further enhance international cooperation to protect the marine environment. Singapore can accede to, and implement a number of treaties, namely, the 1979 Convention on Conservation of Migratory Species of Wild Animals and relevant Memoranda of Understanding; the 2003 Protocol to the 1992 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage; the Protocol of 1996 to amend the 1976 Convention on Limitation of Liability for Maritime Claims; the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea and its 2010 Protocol; the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its 1996 Protocol (Part III Sections 2.3 and 4.1.4).

4. Improve intra- and inter-agency coordination of public marine database.
Improved coordination, and streamlining processes, within and between agencies and researchers can greatly aid in management of marine areas and resources. A lead agency, supported by scientists, with a broad overview on the management and use of natural marine areas and biodiversity, can act as a focal point or a representative group. The Committee on Coastal and Marine Environment (TCCME) has already started this initiative, albeit on a smaller scale. Some key deliverables can include coordinating various government agencies and stakeholders to streamline processes relating to or resulting from the use of natural marine areas and biodiversity. This committee can implement a structured and systematic approach to manage conflicting uses of coastlines and marine areas. The committee must include tenets of marine spatial planning, and oversee EIAs related to coastal and marine areas, coordinate scientific information and efforts, and corral public participation. Such efforts, if implemented from the point of permit application, to the end of the research project, can greatly aid in achieving research goals.

Access to restricted sites can plug knowledge gaps (e.g. baseline biodiversity and population level information) that currently exist. Increasing administrative red tape, while upholding protection of natural areas, can over time be detrimental to sound and sustainable management of such areas.

Ideally, relevant information in past studies from government agencies and/or external bodies (e.g. consultancy companies) should be made available to scientists and stakeholders. Sharing available data will benefit the collective management of habitats and resources. Regular dialogue among agencies and stakeholders can harness the collective biodiversity knowledge.

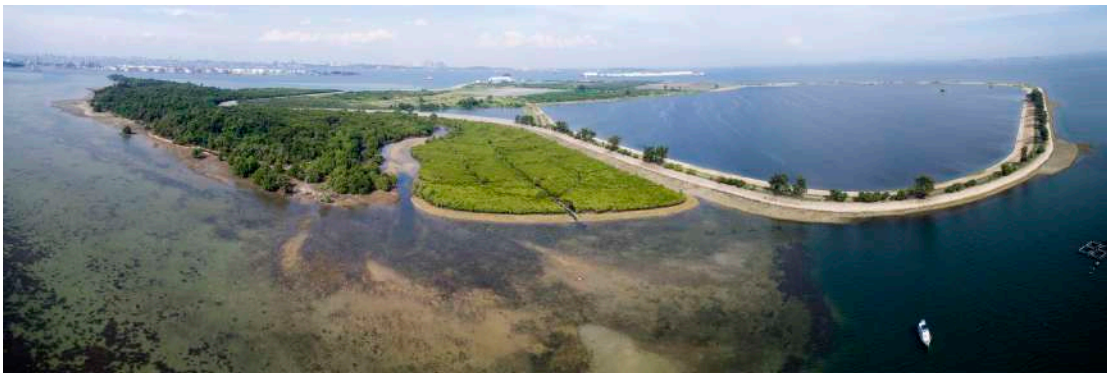
When implemented, these efforts together, can provide timely and important ecological information pertinent to conservation of marine resources.

5. Protect remaining natural marine habitats from unnecessary biodiversity loss.
The CMBS afforded much understanding of our marine areas. Although marine habitats in Singapore are fragmented and small, these sites are each unique, and host high diversity. Information on native marine insects for example, indicates unique assemblages, with very little overlap in species, at different localities within coastal areas of Singapore. Protection of habitat types therefore, cannot be reduced to a single exemplary site; and must be extended to be as exhaustive as possible.

Ideally, all existing natural areas are to be accorded protection from further development to conserve these pockets of refugia for marine organisms. In addition, these ecosystems provide humans with ecosystem goods and services at present not quantified in Singapore. We identify three broad areas for immediate conservation priority (A-C) and propose two broad areas for elevated protection status (D-E).

Proposed Areas for Immediate Conservation Priority

A. Intertidal and subtidal marine areas of Pulau Semakau and adjacent Pulau Hantu, and Pulau Jong to be designated **Marine Reserve.** Pulau Semakau and its associated patch reefs comprise many ecosystems: coral reefs, mangrove areas, intertidal sandflats, seagrass meadows, and coral reefs. The subtidal area of Pulau Jong is larger than the terrestrial area. Pulau Hantu is a popular dive site has seen increasing interest in the past decade due to biodiversity awareness. If protection is accorded to these three islands, zonation plans for use can be implemented to manage tourism impacts.



Pulau Semakau from above. More popularly known as 'trash island' due to the landfill area created between two islands—Pulau Semakau and Pulau Sakeng. The island comprises varied natural ecosystems such as coral reefs and mangrove areas that house significant biodiversity. Drone photograph by Heng Pei Yan with permission from NParks.

B. Intertidal and subtidal marine areas of Pulau Satumu and the adjacent Pulau Biola to be designated **Marine Reserve**. Both sites comprise the highest percentage of coral cover and have a high diversity of corals and marine organisms. Considered source reefs for the region, the sites can contribute to regional genetic diversity. Their protection is urgent as there are signs ship grounding have destroyed portions of these reefs.

C. Intertidal and subtidal marine areas of Pulau Ubin to be designated **Marine Reserve**. The proposed area would include Tanjung Chek Jawa, the largest known intertidal area in northern Singapore. Considered one of the richest in Singapore, Chek Jawa comprises many adjacent ecosystems: coastal hill forest, mangrove areas, rocky shores, seagrass meadows, coral communities, and sandy areas. Chek Jawa remains an icon of celebration and hope for many Singaporeans since its reprieve from reclamation in 2001. Much of the remaining coastal areas around Pulau Ubin are mangrove areas. Protecting these can be impactful due to the relatively large interconnected areas. Already, a community-driven project, Restore Ubin Mangroves (R.U.M.) Initiative, is in place to rehabilitate mangrove areas previously converted to fish and shrimp farms. These areas also offer hope for the recovery of the small-clawed otter population.

Proposed Areas for Elevated Protection Status

D. Lazarus, St. John's, and Kusu Islands are established sites for coral nurseries as their shoreline offers ideal sheltered areas for growth of corals. Designating these islands as **No-fishing Areas** can bolster their rehabilitation.

E. **Expansion of boundary lines** for Sungei Buloh Wetland Reserve to extend protection to adjacent mudflats. The health of mudflats and adjacent mangrove systems are interdependent. In the conservation plans for many countries, they are considered one contiguous ecosystem. This extension of reserve boundaries to accord similar protection to mudflats, an ecosystem not currently protected is logical, especially because the mudflat is utilised by mangrove inhabitants as foraging grounds.

6. Include topics on natural environment into school syllabus and promote science communication.

Only through education can we achieve a scenario where the general populace supports sustainability of available resources, and efforts to conserve these resources. Other than increasing science communication through public engagement, basic concepts in natural history can be inculcated in school. Topics on biodiversity, and the natural environment can be included in the syllabus at the primary, secondary, and pre-university levels.

THE SINGAPORE BLUE PLAN 2018 AND BEYOND

Successful stewardship of coastal and marine areas of Singapore is only possible through collaborative efforts between the community and the Government. Coastal and marine areas in Singapore host multiple users, ranging from industrial to recreational sectors. On any given day, thousands of users are present in coastal areas and marine systems. Their shared uses can, at times, present challenges, with conflicting outcomes. The community recognizes the commitment displayed by the Government to find a parsimonious balance between infrastructure development and conservation of biodiversity and habitats.

The Singapore Blue Plan 2018, like its predecessors, envisages a Singapore that commemorates and celebrates her coastal and marine heritage. The Blue Plan, and its contributors, are apolitical. The Blue Plan further advances key themes on which the community and the Government can work together. Coastal and marine areas of Singapore will benefit greatly from the continued, and future, collaborative efforts between the community, stakeholders, and government agencies. The community remains committed to continue dialogue with relevant agencies to realise these recommendations with the intent for the successful and sustainable conservation of coastal and marine areas of Singapore

END OF THE BLUE PLAN 2018

PART II

SCIENTIFIC SUPPORT FOR THE BLUE PLAN 2018

CHAPTER ONE

ECOSYSTEMS, HABITAT CONNECTIVITY & SUSTAINABLE DEVELOPMENT

1.1. INTRODUCTION

An ecosystem refers to the inter-connected network of biological organisms interacting in, and with, their physical environment. In coastal ecosystems, the physical environment can be structured by key organisms, such as mangroves, seagrass and coral reefs. The healthy functioning of these key organisms is not only crucial to the diverse flora and fauna living in the habitats, it is also vital for the ecosystems services provided to people.

Ecosystem services are the benefits that ecosystems provide to human populations and are borne out of the processes that keep an ecosystem functioning. Through processes such as photosynthesis, growth, energy (trophic) transfer and nutrient production, marine ecosystems provide services that regulate the environment. These services include carbon sequestration, mitigation of greenhouse gas emissions, coastal protection and nutrient cycling. Furthermore, useful goods such as food, timber and pharmaceuticals can be harvested from marine ecosystems. The connection people have with nature, be it for recreation, education or spiritual purposes, constitutes the array of cultural services provided by marine ecosystems. Hence, services provided by marine ecosystems are wide-ranging and can be far-reaching.

Economic expansion in Singapore has fuelled on-going coastal development in the form of land reclamation and shoreline modification (Fig. 1.1). Intensive land reclamation has increased Singapore's land mass from 578 km^2 in 1819 to 718.3 km^2 in 2015 (Singapore Department of Statistics 2015). Despite this, rich biodiversity still persists in our remaining natural habitats. Over the past decade, our scientific community have been uncovering the incredible biodiversity of our marine habitats and investigating phenomena that drives the resilience of our marine ecosystems. There is also increasing appreciation of hydrodynamics and habitat connectivity within the region in shaping marine ecosystems in Singapore. Additionally, potential impacts stemming from the urbanization of inland freshwater systems on downstream mangroves ecosystems are getting recognized.

In this chapter, we present the current state of knowledge on various marine and associated ecosystems in Singapore and the region, and the ecosystem processes that contribute to the healthy functioning of these ecosystems. Large-scale processes that connect marine habitats in Singapore and the region, and their importance for our marine ecosystems, will be described.

Figure 1.1. Satellite images showing changes to the coastline of Singapore from 17 October 1973 (left) and from 19 April 2017 (https://earthshots.usgs.gov/eathshots/Singapore#)

1.2. ECOSYSTEMS

1.2.1. Coral Reefs

Corals are soft-bodied invertebrates that produce calcium carbonate skeletons. Collectively, they form large structures known as coral reefs. Reefs are often referred to as 'rainforests of the sea' as they are a major source of habitat and food for one quarter of all marine species. Most coral reefs can be found in shallow coastal areas where there is high light penetration and good water exchange. Every year, coral reefs provide about US$375 billion worth of ecosystem goods and services, including food production, recreation and disturbance regulation (Costanza et al. 1997).

Coral reefs fringe 24 of Singapore's 46 offshore islands and there are also 51 patch reefs south of the main island (Tun 2012). The current estimate of reef area stands at 13 km^2 (12 km^2 Intertidal and 1 km^2 subtidal) (Tun 2012). The intertidal zone is dominated by dessication-resistant corals that are mainly boulder-shaped, while subtidal regions support a wider variety of corals spanning diverse growth forms (e.g. plating, branching) (see Tan et al. 2016). A small percentage (1%) of coral communities can also be found on artificial granite substrates (Tun 2012). Although reefs occupy only 2.4% of Singapore's territorial waters (Tun 2012), about half of Southeast Asia's hard coral species and more than 100 species of reef fish have been recorded (Low and Lim 2012).

Almost 95% of Southeast Asian coral reefs are threatened by unsustainable fishing practices, pollution and coastal development (Burke et al. 2011). In Singapore, large tracts of reef were buried by intensive coastal development and land reclamation since the 1960s (Chou 2006) and replaced by seawalls (Lai et al. 2015). The remaining reefs are smothered by the high sediment load that is generated from these activities. The turbid waters also hinder photosynthesis, affecting coral growth and reproduction. Singapore's reefs are also at risk of damage from busy traffic in its port waters. Waves generated by passing vessels can potentially dislodge corals from the reef (Ellis and Schmieman 2005), causing abrasion of soft tissues, skeletal damage and mortality. Occasional ship grounding incidents shear off chunks of the reef framework and destabilise the reef's structural integrity, preventing effective coral larval settlement and growth (Rinkevich 2005). Oil spills from ship collisions have occurred more frequently than expected (Chew 2017). Apart from smothering corals in the shallows, the chemicals in the oil and dispersants can stress and kill corals (Tun 2012).

Efforts to characterise and establish reef species diversity on corals reefs has led to the publication of species checklists (e.g. Huang et al. 2009; Tan and Goh 2016) and documentation of physico-chemical parameters (e.g. Tun 2012) relevant to coral reef health. Mass coral spawning events occur annually (see. Guest et al. 2005; Toh et al. 2016), and new reef species such as hermit crabs and anemones are still being discovered (Tan and Goh 2016). Using molecular techniques, it is now known that Singapore's coral reefs have high genetic diversity and that some reefs are important in helping to produce coral larvae that maintains the coral cover in others (Tay et al. 2015).

Effects of anthropogenic influence on Singapore's coral reefs were assessed, with emphasis on land use change (e.g. Tun 2012), sedimentation (e.g. Dikou and van Woesik 2006), nutrient inputs (e.g. Browne et al. 2015) and elevated sea surface temperature (e.g. Kimura et al. 2014). Singapore's total reef area is only 30% of what it was in 1953 ($31km^2$ Intertidal and $9km^2$ subtidal) (Tun 2012). Further decline of Singapore's reefs is also expected with reclamation of the southern coasts to support future development (Ministry of National Development, 2013). Coral cover in reefs beyond 6m depth have also greatly reduced due to the high sedimentation (Guest et al. 2016), limiting the available habitat for other reef organisms. The coral community now comprises more sediment-tolerant species (Chou 1996). Global threats such as elevated sea surface temperature have also impacted Singapore's coral reefs. Sea warming has led to an increased frequency of coral mass bleaching events (Donner et al. 2005). Widespread coral mortality was recorded in 1998 (25%), while in 2010 the mortality rate was approximately 10% (Tun 2012). In both instances, the coral species present on the reef was severely altered and corals that survived showed reduced reproductive output in the years after. Analyses of the mass bleaching event that occurred in 2016 are currently underway.

1.2.2. Seagrass Meadows

Seagrasses are marine flowering plants that grow in shallow coastal waters. Seagrasses, and the associated algae that grows on seagrass leaves, photosynthesize under sufficient light. The energy captured during photosynthesis then feeds the food web formed by the herbivores and predators that congregate in seagrass meadows (Valentine and Heck 1999; Fong et al. 2018). During photosynthesis, seagrasses release oxygen and organic carbon to the water column and sediments (Moriarty et al*.* 1986; Brodersen et al. 2015), and regulate the amount of nutrients in the environment (Romero et al. 2006). This action contributes to the carbon and nutrient availability within the ecosystem. Seagrasses leaves form a canopy that slows water flow and increases the deposition of suspended particles; this in turn enhances light penetration for photosynthesis. Seagrasses' underground rhizomes and roots stabilize the sediment and potentially reduce erosion (Christianen et al. 2013). Thus, a relatively low-energy and undisturbed environment will facilitate the development and survival of seagrass beds.

Seagrasses are distributed all along the coastline of Singapore Island, with a higher density of documented seagrass beds at the offshore Southern Islands (McKenzie et al. 2016). Seagrass beds to the north of Singapore Island tend to be around river mouths and associated with mangrove stands, a result of large river catchments in the Johor region of the Malay Peninsula draining into the northern straits between Singapore and Malaysia. Seagrass beds found among the Southern Islands grow in proximity to coral reefs, with considerably less freshwater influence and subjected to substantially more flushing in the Singapore Straits. Twelve seagrass species were confirmed from across 41 localities in Singapore (McKenzie et al., 2016). Singapore's three largest seagrass meadows are located offshore, and they are Chek Jawa Wetlands, situated on the eastern tip of Pulau Ubin (6.5 ha), Pulau Semakau (13.7 ha) and Cyrene Reef (14 ha) (Yaakub et al. 2013). These three locations also host the highest number of seagrass species.

In the past 10 years, studies on the environmental drivers, connectivity and seasonal dynamics of local meadows have been emerged. Previously, only survey data from NUS (Loo et al. 1996) and citizen science monitoring (TeamSeaGrass) were collected. As of 2014, the projected extent of seagrass meadows in Singapore waters is approximately 201 ha (Yaakub et al. 2014a), although this number needs to be verified in light of declines in major meadows such as Pulau Semakau (McKenzie et al., 2016). Furthermore, seagrass has been observed to colonise reclaimed areas, such as at East Coast Park and Tanah Merah (Fig. 1.2; Yaakub et al. 2014a).

Figure 1.2. Seagrass colonising reclaimed intertidal area near mouth of canal at Tanah Merah (Photograph from Ow Yan Xiang)

Experimental work by local researchers demonstrated that long term exposure to turbid conditions in seagrasses will lower their ability to recover from future stress (Yaakub et al. 2014b) or even override any benefits that can be gained from climate change (rising sea surface temperature and ocean acidification) (Ow et al. 2015; Ow et al. 2016). Our research suggests that the resilience and recovery potential of local seagrass beds might be lowered with continued coastal development without appropriate mitigation strategies. Loss of seagrass meadows and their ecosystem services, such as carbon sequestration (Fourqurean et al. 2012), coastal protection (Christianen et al. 2013) and nurseries for fishes (Nordlund et al. 2017), might inevitably affect adjacent marine ecosystems.

Currently, studies are being conducted to determine the genetic connectivity of Singapore meadows with those in the region (Lai, pers. comm.). The findings will tell us how much genetic material is exchanged amongst the meadows, and how dependent local seagrass beds are on regional meadows for replenishment of our seagrass stock, and vice versa.

Based on land-use projections of the 2008 Singapore Urban Redevelopment Authority's Master Plan, 2.65 km^2 of sand/mudflats will likely be reclaimed, which will translate to major losses for seagrasses (Lai et al. 2015). This will include approximately 1 km^2 of sandflats from eastern coast of Pulau Ubin, i.e. Chek Jawa, which currently encompasses one of the largest seagrass meadows in Singapore (Yaakub et al. 2013). If development plans according to the 2011 Concept Plan are realised, the largest meadow on Pulau Semakau would be destroyed, along with smaller beds that have established on reclaimed land along Tanah Merah and East Coast.

1.2.3. Mangrove Areas

Mangroves forests occur in the intertidal zones across the tropics and subtropics. Mangrove plants – specially adapted to survive in the harsh intertidal environment – form the structure of the ecosystem. Singapore harbours 35 true mangrove species (Yang et al. 2011), which is about 70% of the species in South East Asia (Giesen and Pacific 2006) and 50% of the global species (FAO 2007). Currently, mangroves occupy about 1% of the total land area in Singapore (Yang et al. 2011). Of the 35 true mangrove species, eight are Critically Endangered and another eight are Endangered (Table 1.1). The clearing of mangrove forests for various land use purposes (Hsiang 2000; Hilton and Manning 1995) resulted in only 483.14 ha mangroves left by 1992 (Hilton and Manning 1995). Through reforestation and natural regrowth at the undisturbed mangroves at Sungei Buloh (designated a Wetland Reserve in 2002), the military islands, and Pulau Ubin, mangrove areas increased to 624 ha in 2002 (Lai et al. 2015) and then to 734.9 ha by 2012 (Yang et al. 2011). Today, the offshore islands contain >55% of all mangrove forest and most of the back mangrove forest communities in Singapore (Figure 1.3; Yang et al. 2011). Mangrove species new to Singapore continue to be uncovered, namely *Kandelia candel*, the globally rare *Bruguiera hainesii,* and the re-discovered *Bruguiera sexangula* (Yang et al. 2011). Dispersal from mangroves in the neighbouring countries has probably helped sustain the local diversity. In contrast, many aerial plants common to undisturbed mangrove forests are lost, including 42 mangrove-related orchids (Turner and Yong 1999). Species diversity is important for the stability of the ecosystem - each different species could overlap in ecological functions and provide redundancy to cope with changes in the environment (Tilman 1997; Petchey and Gaston 2002).

Local researchers have been working to give us a better understanding of the ecosystem services provided by mangrove forests. Phang et al. (2015) showed that mangroves in Chek Jawa stored up to 500 tonnes of carbon per hectare. When this number was upscaled nationally, Singapore’s mangroves was estimated to be capable of storing 450,000 tonnes of carbon, equivalent to the annual emissions of 621,000 Singaporeans (Friess et al. 2016). Mangroves are efficient at storing carbon in their soils, as waterlogged conditions reduce the decomposition of soil organic matter. When mangroves are cleared, the soil is oxidized and carbon dioxide is released into the atmosphere (Lovelock et al. 2011). The contribution of mangrove forests to climate change mitigation is recognised internationally as national governments pledged toward mangrove conservation through the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). A long-term climatological study at Mandai mangrove found that mangroves can cool down local temperatures by almost 3° C (Ong 2015). Such a temperature reduction could have important implications for urban liveability and the costs of air conditioning. To our knowledge, this is one of the first studies on the role of mangroves in influencing microclimates and has implications for architecture and land use planning in Singapore.

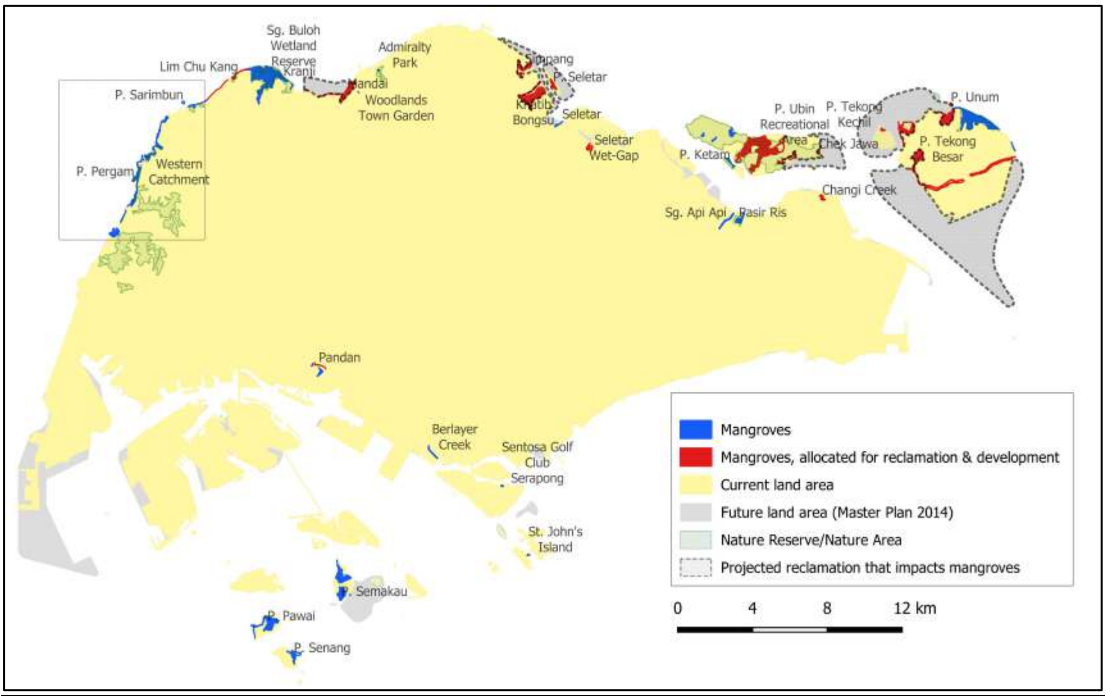


Figure 1.3. Location of mangroves in Singapore (modified from Yee et al. 2010). Both the Master Plan 2014 and MND's Land Use Plan released in the Concept Plan 2011 are used to determine whether mangrove areas are allocated for reclamation and/development. Maps of "Current land area" and "Land area based on Master Plan 2014" are from Data.gov.sg. Only Nature Areas near to the coast are shown here.

Mangroves can protect coastal communities during tides and storms by acting as a buffer to incoming wave energy. The tangled aboveground roots of many mangrove trees create friction, which reduces wave energy and height. Lee (2017) showed that several mangroves along the north coast of Singapore provide this service, with the width of the mangrove forest being one of the most important factors affecting its ability to protect the shoreline. Slowing water speeds also increases the settling of material over the mangrove surface. This allows mangroves to build up their land over time, and potentially keep pace with sea level rise (Krauss et al. 2014). This ecosystem service has been studied at Mandai mangrove, which traps 2.7-6.6 kg m^2 of sediment (Willemsen et al. 2016). By trapping sediments, mangroves can also trap associated pollutants. This is particularly important in Singapore, because many of such pollutants are found in high concentrations in our coastal zone (Bayen et al. 2005, 2016). Pollutant trapping was modelled in Sungei Buloh Wetland Reserve, which is a sink for pollutants during certain periods of the tidal cycle (Jahid Hasan et al. 2015). Results suggests that Sungei Buloh Wetland Reserve – and other mangroves in Singapore – can assist in water pollution control by taking pollutants out of circulation and storing them in mangrove sediments.

Mangroves are an important habitat for juvenile fish, as the mangrove roots provide protection against predators. Mangroves in northeast Singapore support a unique set of fish species that are not found in adjacent habitats (Benzeev et al. 2017). In particular, mangroves can show a higher species diversity compared to surrounding coastal habitats (Jaafar et al. 2004).

Table 1.1. List of all 35 true mangrove species recorded from Singapore (Yang et al. 2011), their conservation status following Chong et al. (2009) and the number of species in brackets. The definition for the five categories of conservation status in Singapore follows Davison et al. (2008).

Critically Endangered (7 species)	**Endangered (7 species)**	**Vulnerable (5 species)**	**Common (14 species)**
Avicennia marina	*Aegiceras corniculatum*	*Acanthus ebracteatus*	*Acanthus ilicifolius*
Bruguiera hainesii	*Brownlowia tersa*	*Acanthus volubilis*	*Acrostichum aureum*
Bruguiera sexangula	*Bruguiera parviflora*	*Ceriops tagal*	*Acrostichum speciosum*
Dolichandrone spathacea	*Ceriops zippeliana*	*Nypa fruticans*	*Avicennia alba*
Kandelia candel	*Heritiera littoralis*	*Rhizophora stylosa*	*Avicennia officinalis*
Pemphis acidula	*Lumnitzera littorea*		*Avicennia rumphiana*
Sonneratia caseolaris	*Lumnitzera racemosa*		*Bruguiera cylindrica*
			Bruguiera gymnorhiza
			Excoecaria agallocha
Nationally Extinct (1 specie)			*Rhizophora apiculata*
Brownlowia argentata			*Rhizophora murconata*
			Scyphiphora hydrophyllacea
			Sonneratia alba
			Xylocarpus granatum

Cultural ecosystem services (from recreation to spiritual value) are hard to measure and value, but they are important in the context of Singapore. Richards and Friess (2015) categorized social media photographs into different cultural ecosystem services and modelled their distribution. They showed that Chek Jawa can contain multiple cultural ecosystem services in different locations. Thiagarajah et al. (2015) showed how the connection between Singaporeans and mangroves has changed over time as Singapore became more urbanized. Historically, we valued mangroves for their abstract values such as spiritual and cultural heritage, but as Singapore urbanized and we became more detached from nature we began to value them for their tangible values such as social recreation.

Mangroves are sensitive to changes in local hydrodynamics and sediment supply. The damming of Sungei Kranji for the Kranji Reservoir in the early 1970s has reduced sediment load and increased flushing of freshwater, and likely caused the net 25% loss of mangroves in Kranji (Bird et al. 2004). Undammed but canalized rivers such as upstream of Sungei Khatib Bongsu, would likely carry less sediment to the mangroves. Land reclamation at mangroves' forefront, e.g. Pasir Ris and Pandan Mangroves, has altered flooding frequency and water salinity, and threatens the survival of *Rhizophora stylosa* at Pasir Ris (Yang et al. 2011). In addition, ship-wakes from high boat traffic (Bird et al. 2004) could be eroding mangrove sediments at Mandai, Pulau Tekong and Pulau Ubin.

According to the Master Plan 2014 (URA Master Plan 2014) and Land Use Map in the Concept Plan 2011 (MND Land Use Plan), about 42.3% of the mangroves could be lost to reclamation and development (Figure 1.3, Lai et al. 2015). Of upmost concern are the potential loss at Pulau Tekong, Pulau Ubin and Mandai Mangrove. Pulau Tekong and Pulau Ubin contain the two largest patches of mature mangroves in Singapore, while Mandai mangroves is the second largest on mainland. Land reclamation is already underway to merge Pulau Tekong Kechil, Pulau Unum and Pulau Tekong Besar at the northwest, while future reclamation on the southeast of Tekong is planned. At least 85-ha of mangroves would be directly impacted. Although it was announced that the mangroves will be conserved (Yeo 2016), it is unclear how that could be achieved when the wetland would be drained. The 147-ha Pulau Ubin mangroves is a locally rare large riverine mangrove system accessible by the public and contain the rare *Bruguiera hainesii.* The 20-ha Mandai Mangrove is ecologically linked (sediment, nutrients and seedlings sources) to Sungei Buloh Wetland Reserve, Lim Chu Kang and Western Catchment Nature Areas.

Moreover, the extensive Mandai mudflat is an important feeding ground for migratory birds that roost at Sungei Buloh Wetland Reserve (Tan 1995; Sodhi et al. 1997). Mandai Mangrove has also been the site of decades of scientific research, which has greatly improved our knowledge of mangroves in Singapore and the region (Friess et al. 2012). The 26-ha Khatib Bongsu mangrove was proposed for conversion into the Seletar-Serangoon Reservoir (Ministry of the Environment and Water Resources 2018) in 2008, but the project has yet to commence and plans for it was also omitted in PUB's 2017 "Our Water, Our Future" publication, which described strategies to meet Singapore's 2060 water demand.

1.2.4. Associated Freshwater Habitats

Fresh waters connect terrestrial and marine ecosystems. Consequently, freshwater ecosystems play an important role in processing and transporting resources, which largely comprise organic matter (e.g., detritus) (Hedgesa et al. 1997; Raymond and Bauer 2001). As the level and composition of organic matter (e.g. relative proportion of fine and course organic matter) exported by freshwaters are regulated by associated community assemblages (Pringle et al. 1999) and their interactions (i.e., food webs) (Trzcinski et al. 2016), disruptions can alter finely balanced resource pools in downstream marine ecosystems (e.g., mangroves and estuaries).

In the past two centuries, much of Singapore's natural fresh waters were lost or modified for human development and habitation. Forest streams and freshwater swamps gave way to expanding agricultural and urban centers (Corlett 1992; Ng and Lim 1992; Sodhi et al. 2004), while rivers were dammed or canalized in efforts to manage freshwater resources for water provisioning, as well as flood and disease vector control (Yeo and Lim 2011; Liew et al. 2018a). While fresh waters in Singapore used to comprise primarily of forest streams and relatively small rivers with freshwater swamps (Corlett 1992), today's natural inland waters are found almost exclusively within the confines of nature reserves, while reservoirs and canals dominate Singapore's mostly urban waterscape.

The large-scale loss of natural inland waters due to urbanization of freshwater habitats threatens the rich freshwater biodiversity (Corlett 1992). The disappearances of native fishes from urbanized waterways were noted from as early as 1934 (Alfred 1966). An estimated 60 percent of fishes and 70 percent of crustaceans are now extinct; suffering the brunt of the impact were species with restricted natural distributions (Giam et al. 2011). The endemic Singapore freshwater crab, *Johora singaporensis*, is one representative species that is critically endangered (Cumberlidge et al. 2009; Ng et al. 2015).

Invasive alien species are taking over urban freshwaters (Liew et al. 2016a; Liew et al. 2018a) with manifold increases in alien species occurrence/establishment since the 1960s when one of the earliest species checklists detailing introduced taxa was published (Alfred 1966). As conversion of natural rivers to reservoirs or canals often involve drastic changes in environmental conditions, alien species, which are often better adapted to the more open, urban environment, tend to outcompete most native species for resources such as food and shelter (Ng et al. 1993; Liew et al. 2016b). Unsurprisingly, almost all alien species in Singapore's inland waters can be found in canals (Kwik and Yeo 2015) and reservoirs (Ng and Tan 2010). If left unchecked, alien species can spread into natural fresh waters and impact the native freshwater diversity there directly (i.e., through predation and competition) or indirectly (i.e., via habitat modification).

Pollution from the development of surrounding watersheds also threatens freshwater ecosystems. Run-off from urban watersheds contains high levels of sediments and nutrients (Smith et al. 1999; Leavitt et al. 2006) that reduces water clarity and promotes phytoplankton blooms (i.e., eutrophication) (Havens et al 2003). Eutrophication and sedimentation can also disrupt the balance of primary productivity in freshwater food webs (Bagousse-Pinguet et al. 2012). For example, phytoplankton blooms and reduction in water quality can suppress the production of periphyton or benthic algae (Ferragut and Bicudo 2010; Borduqui and Ferragut 2012), which are important food sources for many freshwater organisms. Changes at the bottom of the food web are known to trigger bottom-up cascades that affect species at higher trophic levels (e.g., fishes) (Liew et al. 2018b).

Mangroves are also reliant on fresh waters as a means to modulate salinity and accrue sediment (Kirwan and Megonical 2013; Winterwerp et al. 2013). Coastal barrages, which dam all of Singapore's major rivers, are therefore considered one most critical threat to the persistence of these rapidly shrinking coastal ecosystems (Chen 2005; Thampanya et al. 2006). By acting as a barrier to mixing, dams significantly alter environmental conditions on both the fresh water and marine sides of the barrage.

1.3. CONNECTIVITY OF MARINE HABITATS

The various marine ecosystems distributed across the Singapore domain, are connected by a "super highway" – the sea. Animals and plants travel to different marine habitats, both actively (swimming) and/or passively (driven by hydrodynamics), to seek space, food and shelter. Besides living organisms, hydrodynamics also affects the transport of material such as sediments, carbon and nutrients among different habitats and to the open sea, regulating resource availability for all marine ecosystems.

1.3.1. Hydrodynamics

Hydrodynamics affect the transport and fate of almost everything in the water. Dispersal and migration of marine organisms are dependent on the flow of water. Water movement determines where and when dissolved and suspended material (e.g. nutrients, pollutants, sediments) will be transported away, thus affecting water quality and in turn the availability of resources to marine ecosystems. More importantly, hydrodynamics at the local scale determines the type of habitat that can develop at different sites, for example coral reefs prefer well-flushed locations while mangroves need areas with lower wave energy for sediment deposition and retention.

Singapore is a small island and well sheltered by Malaysia Peninsula and small Indonesian islands. However, coastal hydrodynamic action is rather dynamic and differs greatly along the coastline. For example, if you look out to the sea from the coastal boardwalks of Sungei Buloh Wetland Reserve, there is little wave action except for an occasional ship-wake generated waves. However, if you are sitting on one of the breakwaters along East Coast Park, you will observe wind-generated waves breaking with traces of white-capping. Moreover, the highest tidal water level in these two locations are different and the difference can be more than half a metre. Other significant coastal phenomena that affects local hydrodynamics include seasonal monsoon induced surge (Kurniawan et al. 2015; Tay et al. 2016) and extreme events of typhoon-induced waves and surges (Tay et al. 2012).

Swells, and wind- and ship-wake generated waves occur in a matter of seconds. The wave fetch around Singapore is generally short, and the directions of maximum fetch rarely coincide with those of the strongest winds (Chia et al. 1988). This means wave height and energy around Singapore are rarely very high. Open-water waves up to a metre in height may be generated by the Sumatran squalls during the southwest monsoon and by swell from the South China Sea. However due to the relatively shallow waters and obstruction by small offshore reefs, most of the energy from these waves are dissipated before they reach the coast of the main island (Chew 1974; Wong 1985). A recent study on the wave generated by moving fast ferries and large container ships showed that in water depths typical to Singapore's coastal waters, ship-wake generated waves (particularly from fast ferries) can have heights greater than 50 cm and can be destructive to the local coast (Shue 2017).

The tidal cycle takes place over hours. The tide in the Singapore Strait is generated mainly from North Indian Ocean and South China Sea, in which the tidal characteristics of both water bodies are different from each other. The Indian Ocean is dominated by semi-diurnal tides while South China Sea is dominated by both diurnal and semi-diurnal tides (Chen et al. 2005). Tidal waves from the Indian Ocean and South China Sea meet and interact approximately at the western part of the Singapore Strait which creates a complicated tidal dynamics along the strait (Chan et al. 2006). This also results in a higher tidal range in the west compared to the east within the strait (Chen et al. 2005) – 3.2 m and 2.7 m in the west and east respectively during spring tide, and 40 percent of spring tidal range across the strait during neap tide. This results in a tidal flow (i.e. flow of water due to flooding and ebbing) that is approximately 50% greater during spring tide compared to neap tide.

Storm surges in the Singapore Straits, which result in additional flow and water level above the tidal and seasonal norms, have been shown to be more correlated to storm surges that develop in the South China Sea rather than the Andaman Sea (Tay et al. 2016). The local short term surge events are usually induced by surface wind and atmospheric pressure fields in the South China Sea (Kurniawan et al. 2015). These short-term surge events can generate an increase in water levels of up to 0.5 m in Singapore Strait which can last for days. Modelling results suggest that the short-term surge events can result in an average change in magnitude of ± 0.2 m/s to the flow velocity across the strait (Kurniawan et al. 2015).

Like the local weather climate, Singapore's coastal hydrodynamics reflect the effect of the seasonal monsoons. The seasonal effect is especially prominent in the through-flow (volume flux transport) in the Singapore Strait (Tay et al. 2016). Figure 1.4 presents the cumulative volume flux induced by tide alone and combined tide and seasonal forcing, with negative values indicating net westward flux. The combined tide and seasonal forcing induced a net westward flux that is almost 10 times greater than tide alone in one year. With the seasonal forcing, there is westward flux progression during Northeast monsoon (November to February) as shown by the negative gradients, and eastward flux progression during Southwest monsoon (May to August), indicated by the positive gradients. March, April, September and October are the months with relatively small net flux transport towards either directions in Singapore Strait.

Singapore's coastal hydrodynamics are also affected by local salinity and temperature variation. Salinity and temperature play a major role in the chemical and biological processes of the marine environment. In this tropical region, the annual averaged rainfall is about 2161 mm (from 1960 to 2015) (www.singstat.gov.sg). Considering the large watershed area of Johor State in the north of Singapore across the Johor Strait, relatively large volumes of freshwater river discharge are expected. The largest Malaysian river discharging into Johor Strait is Sungei Johor, which discharges about 2.4 km^3 of freshwater per year (Milliman & Farnsworth 2011). This induces a significant difference in salinity between Johor Strait and Singapore Strait, with the latter being more saline.

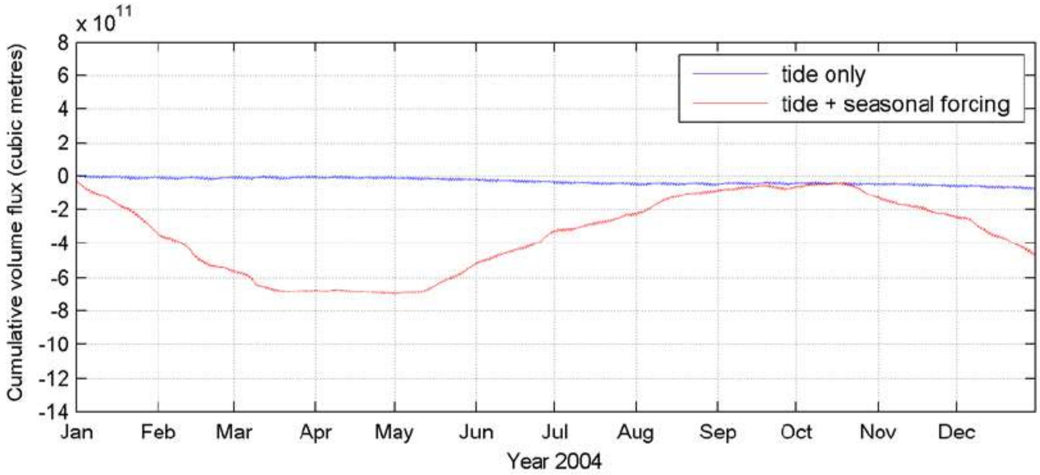


Figure 1.4. Throughflow in Singapore Strait in terms of cumulative volume flux with negative values indicating net westward transport (negative cumulative volume flux)

1.3.2. Movement of Plants and Animals

Habitats are said to be "connected" when there is substantial exchange of organisms and inorganic material among them. In marine systems, the dispersal and migration of organisms is a mechanism underlying habitat connectivity (Cowen et al. 2007).

Dispersal typically involves agents which are moved relatively passively by the ambient hydrodynamics. These 'passengers' include plants (e.g. mangrove and seagrass fruits, seeds, propagules etc.) and the larvae of many marine invertebrates (e.g. corals, sea stars, crustaceans). Dispersal is crucial for maintaining populations by ensuring a regular supply of larvae/propagules, and ensuring genetic diversity (Hasting and Botsford 2006). Both factors are imperative for marine populations to tolerate and recover (hallmarks of resilience) against disturbances and environmental change (Hughes and Stachowicz 2004; Hasting and Botsford 2006).

For many bottom-dwelling species, such as stony corals, snails, crustaceans, worms, and small reef fish, the adults are either not mobile or have limited range. Thus, these species are reliant on their planktonic larval stages for dispersal. These planktonic larvae are often tiny and unable to actively swim against currents and are hence passively transported by ocean currents. More often than not however, they are able to actively influence their dispersal through other means, such as via vertical migration (Sundelöf and Jonsson 2011), natal homing (Gerlach et al. 2007), or other targeted migratory behaviour (e.g. Hinojosa et al. 2016). On reaching their 'destination', the ability of the larvae to settle and grow is controlled to a certain extent by their internal clock (Selkoe and Toonen 2011), mortality rates (Ellien et al. 2004), habitat availability (Sanciangco et al. 2013), and the environment in which they are released (e.g. Cetina-Herdia et al. 2015). In short, the complex interaction of the biology of these planktonic larvae with the environment (hydrodynamics, water quality) determine their fate as they move across habitats (Ayre et al. 2009).

Studies on the larval connectivity of several invertebrate species in Singapore have shown that our marine habitats within the Singapore Straits are well-connected. A study on knobbly sea stars (*Protoreaster nodosus*) showed a very high level of genetic diversity in this locally-endangered species (Tay et al. 2016). Notably, the study found that local populations of the knobbly sea star still share the same genetic pool with populations further away across the Coral Triangle in Indonesia (Tay et al. 2016), and that there could still be ongoing larval exchange across these populations. Predictive modelling studies based on broadcast-spawning coral species and the fluted giant clam (*Tridacna squamosa*) larvae in the Singapore Strait revealed that there is connectivity with the region south of Singapore (i.e. Bintan and Batam), with the reefs there potentially seeding our own (Tay et al. 2012; Neo et al. 2013; Hui et al. 2016). Research utilising biophysical modelling and genetic work have suggested the potential for high levels of coral larval exchange within Singapore's Southern Islands (Tay et al. 2012, 2015, 2016). Based on Tay et al.'s (2012) research, the cluster of reefs around Sisters' Islands were subsequently designated as the first Marine Park in Singapore, securing one of the potentially stronger sources of larvae within Singapore waters.

Barriers to dispersal can exist within Singapore waters. An ongoing collaborative project between NParks, NUS, and TMSI (Project title: Environmental Management in the 21st century: Molecular Tools for Labour- & Cost- Effective Rapid Species Detection & Population Genomics) is investigating the population genomics across eight marine species with different life histories across different habitats in Singapore waters. Preliminary findings suggest that species which have a planktonic larval dispersive stage were found to have less restricted distributions across Singapore, whereas species which are direct developers were found to have restricted dispersal even across just ~9km of water.

Connectivity of coastal plants in Singapore has been relatively under-studied. Much of Singapore's mangrove forests and seagrass meadows have been reduced to small fragmented patches (Yaakub et al. 2014; Lai et al. 2015) and we know little about how these fragmented patches are connected. Across the Indo-Pacific, which includes the entire Thai-Malay Peninsula, connectivity of the mangrove forests is high, and are likely to be largely driven by oceanic circulation patterns (Wee et al. 2014, 2015). Presently, a collaborative research project between NParks, NUS and DHI (Project title: Assessing the resilience of seagrass meadows in Singapore and its potential for restoration) is underway to determine the connectivity among Singapore's seagrass meadows. Regional studies on seagrass fruit dispersal have already shown that floating fruits in some species, like *Thalassia hemprichii* and *Enhalus acoroides* can travel for tens of kilometres (Lacap et al. 2014; Wu et al. 2016). If the exchange of genetic material is crucial to the sustainment and recovery of these fragmented habitats, then identifying the source locations is a vital step to protecting these ecosystems.

Larger and more active animals migrate across habitats in search of food and shelter. Regional studies have shown that many important food fish species undergo ontogenetic migration, with individuals spending part of their life spans as juveniles in nursery grounds (e.g. seagrass meadow, mangrove) before migrating to an adjacent habitat in adulthood (e.g. coral reef, open water) (Unsworth 2008). Coral reef fishes, such as rabbitfish (Siganidae), snappers (Lutjanidae) and goatfish (Mullidae) move between seagrass and reef habitats in accordance to their life cycles (Grober-Dunsmore et al. 2007). Destruction of one habitat can often lead to a breakdown of this movement and can even cause local species extinctions in extreme cases (Mumby et al. 2004). This was documented in the Carribbean, when mangrove-dependent parrotfish (*Scarus guacamaia*) went extinct locally after mangrove forests were removed (Mumby et al. 2004). Active migration can likewise take place in species such as dugongs and turtles which move between habitats daily to forage or seasonally to breed. Tracts of excavated seagrass, which resemble feeding trails of dugongs (*Dugong dugon*) are often observed in seagrass meadows in Chek Jawa and Cyrene Reef (Yaakub and Tan pers. comms., 2016). Recent reports of the critically endangered hawksbill turtles (*Eretmochelys imbricata*) (IUCN, 2017) laying eggs on beaches on the mainland and the Southern Islands also demonstrate the importance of these habitats as nesting grounds (Koh 2017; Tan 2017). Apart from anecdotal records, information about the migration patterns of such mobile fauna locally is lacking.

1.3.3. Movement of Nutrients, Carbon and Other Inorganic Material

Nutrients (e.g. nitrogen, phosphate, phosphorous) and carbon move across ecosystems in the form of organic particulate matter. The exchange of nutrients and carbon is critical to the functioning of marine ecosystems (Nagelkerken 2009). Mangroves are important sources or sinks of carbon and nutrients for the inland forests, seagrass beds, coral reefs and the ocean. For example, mangroves contribute 21-70% of the organic carbon in seagrass sediment (Bouillon et al. 2004; Chen et al. 2017) and more than 10% of the ocean's dissolved organic carbon (Dittmar et al. 2006). The high productivity of seagrass meadows is an important source of organic material and nutrients for nearby coastal ecosystems (e.g. coral reefs, sand banks) when exported as living or dead leaves (Lai et al. 2013; Gillis et al. 2014). Furthermore, the presence of one ecosystem may be beneficial to another, especially in the face of climate change. For example, seagrass meadows could potentially buffer adjacent corals reefs from the effects of ocean acidification (Manzello et al. 2012; Unsworth et al. 2012) and reduce the abundance of pathogens harmful to humans and corals (Lamb et al. 2017). More in-depth studies are required to unravel this buffering capacity among ecosystems.

Connectivity of habitats in our marine ecosystems implies that impacts on one habitat can often spill over to other habitats. Such spill-over effects can cover large areas and take time to manifest; they can thus be difficult to predict. Conserving one habitat might be ineffective if surrounding habitats that are sources or sinks of larvae, sediments or nutrients are degraded. The installation of artificial structures in coastal areas, such as dykes and groynes, might disrupt the natural connectivity networks (Caldwell and Gergel 2013), given the strong dependence of habitat connectivity on local-scale hydrodynamics. Maintaining or creating suitable intermediate 'stepping stone' patches may help to extend the dispersal range of a target species (Hellberg et al. 2002). In tandem, it is also crucial that coastal modifications are designed to prevent the retention of passive agents like propagules or larvae (Di Nitto et al. 2013), particularly when they are built near sensitive "source" sites. Another approach would be to enhance artificial coastal structures to allow native fauna to colonise. Coastal structures, such as seawalls, around Singapore have seen the recruitment of coral communities on them. A well-documented example is found on the sub-tidal seawalls along Pulau Semakau (Goh 2007).

To safeguard the continuity and sustainment of our marine ecosystems and their processes, efforts to protect marine communities here from pollution, immediate habitat loss and degradation is paramount. Habitat degradation prevents larvae, fruits, seeds and propagules from settling and growing into reproductively-contributing adults that can seed future reefs, meadows and forests (Caldwell and Gergel 2013; Bishop et al. 2017). For this, we need concerted research and management efforts to ensure good water quality and habitat hospitability for these ecosystem-building organisms to thrive in.

1.4. URBANIZATION AND SUSTAINABLE DEVELOPMENT

Rapid economic development in Singapore was fueled by her thriving entrepôt trade activities. The driver of Singapore's progress shifted from a production based export-led industry (driven mainly by foreign direct investment (FDI)), to a service-centric economy. Alongside machineries as physical capital, land and labor are the other two environmental and human resources that have contributed towards production and national income (Tan 2016a).

Studies have found direct correlation of trade activities, and development of the region, to environmental degradation (Grimmond 2007; Frankel 2008; McCarthy et al. 2010). In Singapore, urbanization and coastal development involved conversion of natural habitats for key infrastructure development.

In an attempt to address sustainable development, Asia and the Pacific nations have crafted Sustainable Development Goals (SDGs) for implementation in 2016 that addresses economic, social and environmental dimensions of the region. For development to be truly sustainable growth must be inclusive and demands equal attention to the tri-nexus of economy, society and the environment. Unfortunately, this is not always feasible. In order to continue growing, nations have given priority to economic integration and strengthening institutional framework. Emphasis is often skew towards economic performance with a lack of attention to the environment. It has been acknowledged (but often ignored) that, a higher level of income from economic progress is likely to increase the utilization of the environment as a capital (Tan 2016a) with trade and economic development further degrading the environment (Tan 2016b; Tan 2018).

Further explanation on why environmental protection is overlooked with preference offered to economic development can be evaluated from two lenses of economic and regulation respectively. Economic means that costs and benefits (perceived) guide decision-making, and overrides potential damages made to the environment. For instance, this is the approach taken to assess cost-effectiveness of alternative energy sources in Singapore (Hamilton-Hart 2006). The second explanation is regulatory which concerns the application of Environmental Impact Assessment (EIA) – EIA is one way that enables empowerment to the community and engages the public pertaining to environment protection. Studies have found EIA to be a useful tool in administering environmental policies (Perry and Teng 1999). It has been argued that its use in Singapore is limited as it inconveniences the promotion of physical development (Chua 2005) and economic growth but has shown to demonstrate progress of late (Tan 2017).

Environmental conservation should be in tune with economic pragmatism because an economy remains a subset of the ecosystem and operates within an environmental domain permitted by the ecosystem. Economic pragmatism would not be attainable if the environment is not securely protected, that is when environmental challenges are being filtered through an economic rationality lens. Environmental degradation from Singapore's economic development has resulted in coral demise, red tides and decline of the mangrove population. There is an urgent need for greater environmental security to ensure that the ecosystem continues to service economic development.

1.4.1. Environmental Goods and Services and Market Failure

Public goods display non-excludable (not be effectively excluded from use of the good) and non-rivalrous (use of the good by one individual does not reduce availability to another) characteristics. Further to this definition is the lack of boundaries that fails to identify property rights attach to the good. One explanation to why the boundaries are not shaped clearly is that there is no definitive market for transaction that is, market has failed. When markets fail, there is no agreed way to price a good. And it is such dilemmatic domain which the ecosystem is subject to.

Although environmental goods and services may not be transacted via a market, the value of environmental goods and services should be included. The non-existence of a market and price implies that no procedure is in place to measure the costs of environmental damage and the benefits of preserving an environmental asset. There are many different ways to value and measure different aspects of the ecosystem such as, the air shed, forests, mangroves, ocean, the reefs, and water. Unfortunately, the different methods of valuation do not correlate with each other.

Measurement values the consumption of the environmental asset where high prices reflect the scarcity of these assets. It is demeaning to think that attaching a price to an environmental resource, environmental damage can be "bought" with the cost of the damage embedded in the purchase. This belief is not valid as accumulated degradation made to the environment remains deep in the ecosystem. A consumption pricing approach fails to account for the environmental damage and the use value of the environment. It is the use value that should be accountable; after all once an asset is removed from its habitat, it is no longer useful.

1.4.2. Approaches (Selected) to Valuation

There is no single agreed approach to value environmental degradation and utilization. The environment can be valued as a consumption good using contingent valuation and travel cost method; the concept of opportunity costs can also be used to value environmental goods and services in the form of sacrificed income.

Ultimately, the ecosystem must be recognized as a form of capital as it offers a service to the economy. Economic progress consumes ecosystem resources to produce higher income levels. The act of ecosystem consumption generates greenhouse gases (GHG) emissions that should be accounted for. GHG emissions valuation can be operationalize via a resource model which acknowledges inputs of environment, labor, and physical as capitals for national income generation (Tan 2016a).

Valuation studies on natural ecosystems are underway in studies such as the Natural Capital Singapore project (www.naturalcapital.sg). Over the duration of this project, 2018 to 2020, scientists from Singapore-ETH centre and NUS, in collaboration with researchers from NTU, SMART, and NParks endeavours to estimate ecosystem services and value for all terrestrial, coastal, and marine ecosystems in Singapore.

1.4.3. Policies for Sustainable Development

1. Environmental policies to address the source sink function of the ecosystem are,

   i. The environment should be measured as a capital (Tan 2016a) and internalize in national income (Tan 2015). This would favour a presentation of true economic performance for policy makers to concoct appropriate policy cocktails.

   ii. There are other policy aspects which can be improved such as, integrating trade and regional development policies into environmental policies, and engaging the public to combat climate change.

      - Inclusive Trade Policies –
        As trade agreements mature, a step-up from Free Trade Agreement (FTA) is the Comprehensive Economic Partnership (CEP), which extends economic integration beyond trade to tap on other sectors of the economy such as investment, financial aid and technological cooperation. CEP serves to deepen a mutually beneficial economic partnership and consolidation for all trade partners. Therefore, it is recommended that bilateral environmental agreements be considered in conjunction with CEPs for the future.
        This ensures that trade will be just as beneficial to the ecosystem as it is to the economy.

      - Empower the Community and Engaging the Public –
        An ideal scenario for (all) economic development would be to adequately study environmental impact, embrace robust mitigation measures (to address opposition against developments) through the Environmental

Impact Assessment (EIA). This serves to minimize the environmental impacts from development.

When the public is contributing towards future environmental policies, it deems to have bestowed a sense of national ownership and environmental stewardship.

iii. As urbanization continues, carbon pricing signals a cost and carbon taxes tells of acceptable forms of behaviour. The key is to re-invest the tax revenues reaped from both carbon pricing and taxes towards environmental maintenance as a source and sink function (Thampapillai et al. 2010). For instance, tax revenues can be channelled to environmental conservation in the form of coastal, nature and marine preservation.

2. Selected SDGs by United Nations General Assembly relevant to Singapore

Studies of small island states have been carried out by Nurse et al. (2001) and political economy reforms of islands were investigated by Duncan (2011). Singapore is no different to the other island states, neither is it immune to extreme events. The impacts of extreme events are systemic and they affect all aspects of the Singapore society; moreover, the island-state is more vulnerable to these shocks than is currently acknowledged (Tan and Lai 2016). The environment should be measured as a capital (Tan 2016a) and internalize in national income (Tan 2015). Sustainable development points to the well-being of economy, society and the environment and ensures that they are considered for public policy formulation. For an island-state to attain the goals of sustainable development, the reaction to extreme events and the management of the event aftermath are critical to a policy taker in climate change adaptation.

#8: Decent Work and Economic Growth – Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

#11: Sustainable Cities and Communities – Make cities and human settlements inclusive, safe, resilient, and sustainable.

#12: Responsible Consumption and Production – Ensure sustainable consumption and production patterns.

#13: Climate Action – Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

#14: Life Below Water – Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

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CHAPTER TWO
MARINE ORGANISMS

2.1. HISTORICAL ACCOUNTS OF MARINE BIODIVERSITY

The establishment of Singapore as a port in 1819 ushered trade activities that intensified over the next century. To maintain and ease trade routes, the colonial government prioritized the establishment of clear channels for ship passage to the port along the southern coast of the island. This resulted in the destruction of coral reefs as well as iconic landmarks such as the "Dragon's Teeth Gate" (*Long Ya Men*), which was obliterated in 1848.

Little marine research occurred during the colonial era. Species considered unique were reported as discoveries by those interested in natural history. An example of this was an the Blue-spotted ribbontail ray that was described as *Trygon ornatus* from Singapore (now known as *Taeniura lymma*; Fig. 2.1).

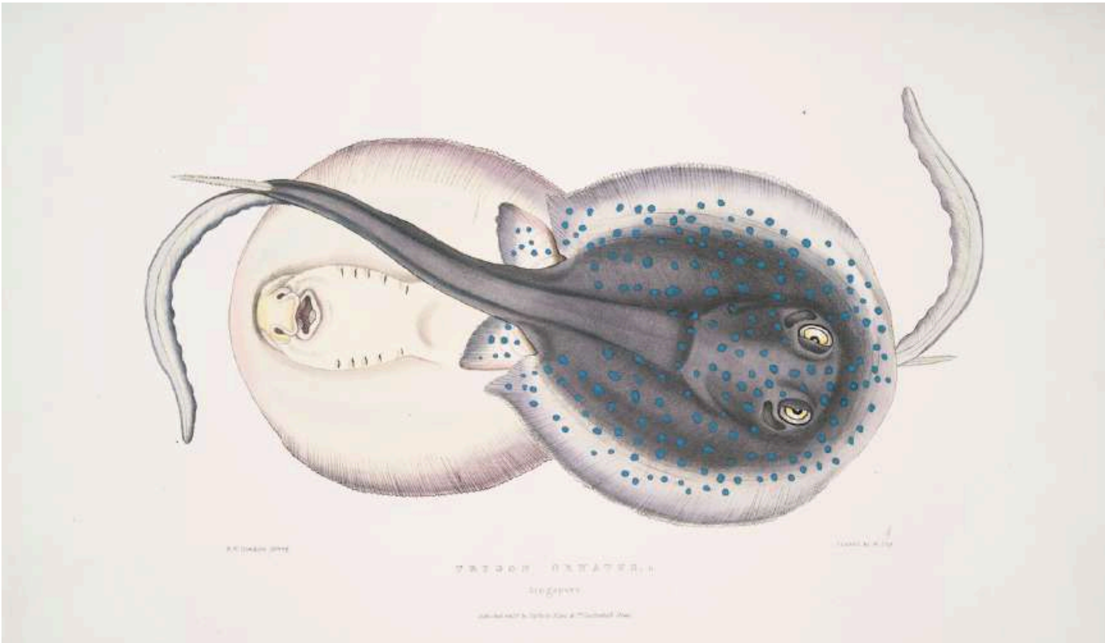

Figure 2.1. A painting of *Trygon ornatus* that appeared in a well-regarded list of Asian wildlife in the 1830s (Hardwicke and Gray 1830-34).

In the early 20th century, scientists at the Raffles Museum collected, categorized and conducted research on a variety of marine fauna, particularly mollusks and corals. The marine habitat of Singapore, however, remained largely unexplored and unprotected, as much of this research was the result of expeditions to Christmas Island or Malaya. These specimens were stored at the Raffles Museum (Barnard 2014; Tan 2015).

In contrast, there were efforts to preserve much of land-based resources of Singapore during the colonial era. Following massive deforestation of the island in the mid-19th century, in which 92 per cent of our original forest cover was felled, the colonial government

– through the Singapore Botanic Gardens – established forest reserves throughout the island (Barnard 2016). These forest reserves helped conserve valuable timber and, more importantly, provide an area in which water could be stored for the use of the growing population. This resulted in the development of our reservoir system, and the surrounding Central Catchment Area. Additional forest reserves scattered throughout the island, including Bukit Timah Hill, reflect the focus that the colonial authorities placed on preserving these non-marine natural resources.

Many of these colonial era forest reserves now form our current Nature Reserves, to which the government has added new sites such as Sungei Buloh Wetland Reserve and Labrador Nature Reserve. In 2015 the government created Sisters' Islands Marine Park, which expanded the area of management of Singapore's natural biodiversity to the waters surrounding the island.

2.2. PRESENT DAY EFFORTS

Species are fundamental building blocks to any biological system. Establishing their identities are important for further scientific endeavours, as well as management and conservation efforts. Efforts to elucidate marine biodiversity in Singapore has intensified in the past several decades. Surveys such as the ASEAN-Australian Marine Science Project: Living Coastal Resources, and the Comprehensive Marine Biodiversity Survey (hereafter as CMBS), contributed significantly to our knowledge of native biodiversity (see Chapter 1). In this chapter, work that has been performed on marine biodiversity is summarised and presented. The list is not exhaustive; these organisms showcase efforts that have been concentrated in Singapore over the past decade.

2.3. MARINE ORGANISMS

2.3.1. Marine Biofilms

Marine biofilms, or microbial aggregations, consist primarily of bacteria but also include diatoms/microalgae, protozoa, viruses, and are found attached to every submerged surface. The specific composition of biofilm communities can be influenced by multiple factors including surface type, water quality and hydrodynamic flow (Dobretsov et al. 2010). Biofilms can greatly impact marine industries – they increase shipping costs (Schultz and Swain 2000), enhance corrosion (Videla and Herrera 2005) and degrade performance e.g. in desalination. Biofilms also induce settlement in invertebrates and other microorganisms, and thus are a double edged sword – they can exacerbate the negative effects of fouling but can also play an important role in conservation and aquaculture (Mieszkin et al. 2013; Hadfield 2011). Recently, studies have discussed the ability of marine biofilms upon ship hulls and in ballast tanks/water to promote dissemination of invasive and pathogenic organisms (Ruiz et al. 2000) – a concern especially in light of the fact that environmental biofilms are reservoirs for antibiotic resistance (Balcázar et al. 2015).

Research on marine microbial diversity in Singapore has been limited to date, and on biofilms even more so. Previous studies on the water column showed that bacterial communities in Singapore waters closely resemble less urbanized port cities (Tan et al. 2016). However, the biofilm community is even more diverse from that of the water column and comprises mainly of unknown genera (unpublished data; see Fig. 2.2). Existing studies on marine biofilms have investigated the communities that form on toxic, biocidal surfaces (Fabrega et al. 2011; Chen et al. 2013) and the ability of biofilm communities to induce settlement in tubeworms (Chan et al. 2014). No local studies have been published regarding invasive microorganisms or the ability of specific biofilms to enhance establishment of invasive species. Ballast water of ships arriving from the Middle East and China were found to contain the bacteria responsible for cholera (*Vibrio cholera*), as well as fecal indicator organisms, indicating that ballast treatment was either unsuccessful or not implemented (Ng et al. 2015, 2017).

2.3.2. Plankton

Plankton forms an important food source and they contribute to nutrient cycling. Plankton consists of a diverse collection of microorganisms found floating within the aquatic environment consisting of organisms such as protozoans, diatoms, small crustaceans, egg and larval stages of larger animals. Plankton can be broadly classified into two categories: phytoplankton (microalgae) and zooplankton. Phytoplankton are primary producers (i.e. carry out photosynthesis) and they form the base of food webs in aquatic environments. (Figure 2.3). Zooplankton feeds on phytoplankton and in turn, is consumed by larger aquatic organisms such as fish. In this way, zooplankton play a key role in the transfer of energy from phytoplankton to higher trophic aquatic organisms. In addition, zooplankton can also control the phytoplankton population via their consumption rate.

The knowledge of marine plankton in Singapore is sparse. Early research studies were limited and largely focussed on describing the trends in the marine plankton population over time (Tham 1953, 1973b; Wickstead 1958; Thia-Eng 1973). In recent years, scientists have started to document the composition of marine plankton species found in Singapore (Pham et al. 2011; Schmoker et al. 2013).

Recent research has sought to understand how the plankton population is affected by the surrounding environment due to varying factors such as nutrients and light availability (Gin et al. 2000, 2001, 2006). High amounts of suspended sediments in the water column, which can be characteristic of Singapore's waters, can potentially affect the growth and reproduction of phytoplankton (Cloern 1987; Arst et al. 2008; Nayar et al. 2005, but see Berner and Sukenik 1998; Dubinsky and Stambler 2009). This might in turn affect the feeding efficiency (Tester and Turner 1989; Butler 1995; Sew et al. 2018), nutrition (Arendt et al. 2011), growth (Paffenhofer 1972; Tester and Turner 1989) and reproduction rates in zooplankton (Kang 2012). These effects might cascade through the marine food web.

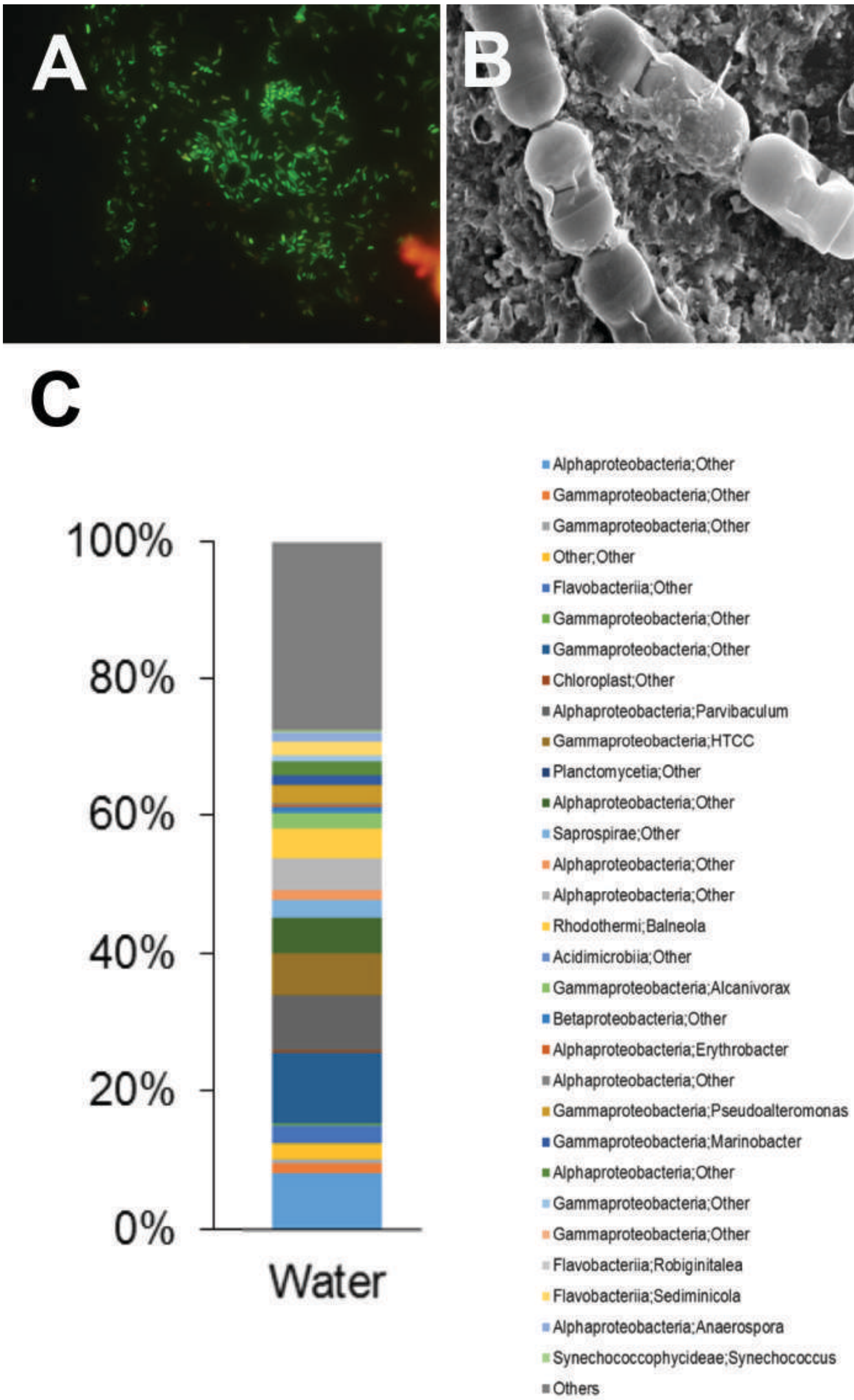

Figure 2.2. Micro-organisms in our local waters. A and B: microscopic techniques to facilitate the identification of some bacteria. Fluorescence and scanning electron microscopy, respectively; C: bacteria genera that are typically found in our waters. Figurs by: Zainul Z.

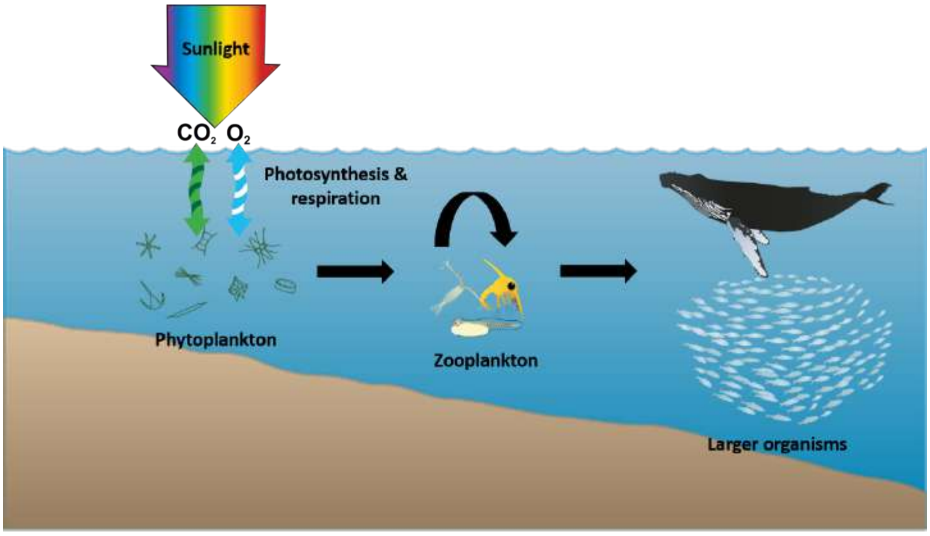

Figure 2.3. Simplified marine food web. Primary production carried out by phytoplankton through photosynthesis which is eventually eaten by zooplankton. Zooplankton either feed on other zooplankton or are eaten by larger organisms.

Occurrences of harmful algal blooms (HABs) within the Johor Straits had caused massive fish kills which resulted in considerable economic losses (Quek and Lim 2010; Lee 2014; Neo 2015). Algal blooms are often characterised by unregulated phytoplankton growth. The impacts of HABs has created an interest toward understanding the possible causes of these harmful blooms (Leong et al. 2012; Khew 2016, 2017). It has also brought about the need for measures to mitigate the impact of these blooms (Leong et al. 2012; Khew 2016, 2017). Algal blooms often occur due to changes in the marine environment such as the introduction of excessive light and/or nutrients. At high densities of phytoplankton, oxygen levels in the water can be depleted and certain phytoplankton may produce toxins, such as the neurotoxin domoic acid, both of which can be detrimental to marine organisms. These toxins can bioaccumulate in the food chain and consumption of affected marine organisms can also be harmful to human life (Leong et al. 2015).

2.3.3. Macroalgae

There are 342 species of marine macroalgae found in Singapore that are categorized according to pigment majority: 103 green (Chlorophyta), 90 brown (Ochrophyta), 125 red (Rhodophyta) and 24 blue green macroalgae (Cyanophyta) (Pham et al. 2011). The microscopic blue green algae (Cyanobacteria) become conspicuous as they form large colonies at bloom conditions and occupy sizeable areas on the reef. At present, Singapore contributes 25% of the overall marine macroalgae biodiversity in the coral triangle region (Phang et al. 2016).

Algae are important in the maintenance of the health of marine ecosystems. They set the stage for primary production as inorganic carbon and light energy are converted into forms usable by consumers. The ubiquitous turf algae with high turnover rates are mainly responsible for productivity and contribute largely to nitrogen fixation and nutrient retention (Gattuso et al. 1998; Heil et al. 2004). Crustose and calcareous algae strengthen the coral reef framework by adding into its calcium carbonate budget (Chisholm 2000). This functional group is also the preferred substrate for settlement of coral larvae (Harrington et al. 2004). Leathery, terete and foliose groups create habitats for other species and provide structural complexity to the reef ecosystem.

There is high variation in macroalgae abundance and diversity in the waters surrounding Singapore across all marine habitats. In the north and northwest (Kranji, Mandai, Lim Chu Kang) are macroalgae associated with mangroves where roots are often found reinforced by *Bostrychia* sp. (West 1992). Other common macroalgae species found in these areas include *Dictyota* sp. and *Boodleopsis* sp. (Lee et al. 2015). Towards the south and southeast are macroalgae found in various marine habitat types. Seagrass beds and intertidal reef flats with sandy and rocky substrates are southeast attributes where *Caulerpa* sp., *Halimeda* sp. and *Jania* sp. are common (Lee et al. 2015). To the south are where most algae studies have been conducted, the earliest records of which was by Purchon and Eunoch (1954) at the intertidal rocky shore of Pulau Satumu. Depending on the season, intertidal reef flats are often found covered in *Sargassum* sp., *Bryopsis* sp. or *Chaetomorpha* sp. Macroalgae diversity increases at the subtidal zones where turf algae dominate wave-exposed reefs like those at Pulau Satumu while *Sargassum* sp. dominate in sheltered reefs like those at Pulau Hantu. Among the reefs in the southern islands, St. John's have abundant and diverse community of macroalgae. Out in the more open sea are floating navigational aids or buoys where macroalgae can also be found. Ten new species were added to the list of macroalgae in Singapore after the buoys were studied by Lee et al. (2009), which showed that diverse macroalgae community are found in such artificial structures.

Seasonality among species and groups differ and there are those that are ephemeral with no regular bloom period. Essentially, macroalgae life histories coincide with other members of the reef such that it benefits the system as a whole. High biomass formers bloom during the northeast monsoon season that gradually die off so that by the time inter-monsoon season arrives, population is reduced enough to diminish impediments when corals (and other reef organisms) spawn. Southwest monsoon season is then overtaken by turf while other groups regain momentum towards new growth and maturation.

2.3.4. Porifera (Sponges)

Some 250 sponges species have been recorded on man-made structures, inter-tidal flat, coral reef and the deeper benthic assemblages in Singapore waters over the last two decades (Hooper et al. 2000; Lim and Tan 2008; De Voogd and Cleary 2009; Lim et al. 2009a, 2009b; Lim et al. 2012; see Fig. 2.4). Distribution of sponge species in Singapore waters is largely dependent on the following factors: 1) depth (inter-tidal or sub-tidal); 2) substratum type (mud, sand, gravel, rock and made-made); and 3) salinity. A number of new species were discovered from Singapore waters recently: *Tethycometes radicosa* (Lim and Tan 2008); *Suberites diversicolor* (Becking and Lim 2009); *Forcepia* (*Forcepia*) *vansoesti* (Lim et al. 2012); *Anamixilla singaporensis* (Van Soest and De Voogd 2015); *Clathrina sororcula* (Van Soest and De Voogd 2015); *Theonella laena* (Lim and Tan 2016).

The Neptune's Cup sponge was discovered from Singapore in 1820 (Hardwicke 1820) and it captured the world's imagination with its large and peculiar wine glass form. It was highly sought after by private collectors and the museums in Europe, and was probably the most famous export from Singapore two centuries ago. This sponge disappeared for over a century probably due to over harvesting and very few knew of it until a recent re-discovery of live individuals in Singapore waters in 2012 (see Lim et al. 2012). There is another group of little known and forgotten sponges which are the bath sponges. The earliest Singapore sponge fauna studies (Dragnewitsch 1905; Willimott 1939) mentioned the existence of bath sponges from our waters. It's interesting to note that the local fishermen knew the existence of bath sponges and there was an undeveloped bath sponge-fishing industry in the early 1900s that provided sponges for cleaning of paint work on cars and train carriages, and even as toilet (bath) sponges (Willimott 1939). However, the Fisheries Department of Singapore determined that the local bath sponges were only as good as the lowest quality of Bahamas and Cuban sponges with the help of experts in London (Willimott 1939). The last known report of the sponge industry was in 1948 in a newspaper article on the only person exporting bath sponges collected by local fishermen that were not very abundant. This was the last account of bath sponge industry that did not take off and one that few people knew.

The CMBS contributed significant knowledge of little-known benthic sponge fauna at areas below 20 m depth that are not accessible by scuba diving. The deepest of Singapore waters is off St. John's Island extending beyond 200 m (see Hill 1968) was surveyed and a few interesting sponges were collected (unpublished results). The most notable discoveries were patches of sponge beds comprising of the *Xestospongia testudinaria* (Barrel Sponge) found between Pulau Sudong, Pulau Hantu and Pulau Semakau at beyond 20 m depths and the Lithistid sponges (Rock sponge) found near the port limit where depths go beyond 50 m. These patches of sponge beds at deep waters are ecologically important habitats similar to the shallow-water coral reefs, providing habitat and shelter for other organisms such as fishes, ascidians, molluscs, corals, bryozoans, and hydroids.

2.3.5. Cnidaria (Corals, Anemones, Jellyfishes)

Inventories on cnidarians from Singapore are varied: Studies of well-known groups such as hard corals had begun since the 1960s (Chuang 1961) and there are recent efforts to document other cnidarians (e.g. Fautin et al. 2009; Tan et al. 2016; see Fig. 2.5).

There are approximately 140 to 160 species of hard corals present (see Loo and Chou 1995; Huang et al. 2009) although there have been dramatic declines of coral cover and shifts to sediment and coral rubble at the deeper reef slope (Guest et al. 2016). About 31 species of soft corals are known. However the state of their population and health remain unknown (Goh and Chou 1994, 1996; Benayahu and Chou 2010; Benayahu and Ofwegen 2011; Seah et al. 2015). Singapore has more sea anemone species than the entire west coast of North America (Fautin 2013, 2016). More than 50 morphotypes were collected during the CMBS (Tan et al. 2016), of which one was new to science—and named *Synpeachia temasek* (Yap et al. 2014). Preliminary surveys tube anemone reveals six species present in Singapore.

Little is known of jellyfishes in Singapore. Historical records spanning 132 years report at least 30 jellyfish species present in Singapore; however these are typically from unconfirmed sightings (Yap and Ong 2012). Identity of eight jellyfish species are confirmed, of which five have never been recorded from Singapore (Yap and Ong 2012).

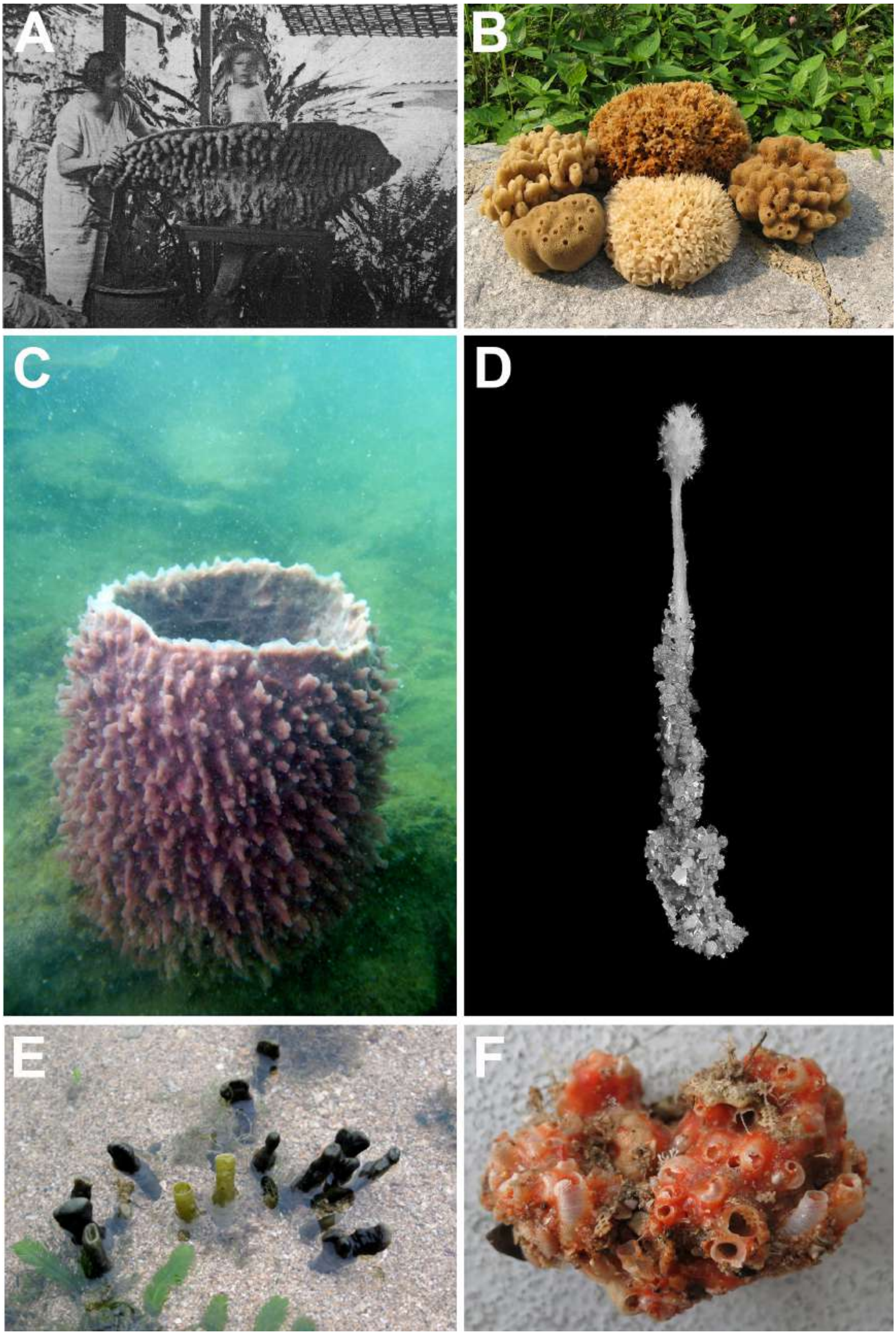

Figure 2.4. Sponges of Singapore and nearby waters. A: a child bathing in a dried specimen of Neptune's cup sponge in Indonesia. This sponge was once common along the shores of Singapore. Photo: van Heurn FC; B: bath sponges of excellent quality collected from Singapore waters; C: *Xestospongia testudinaria*, also commonly known as the "Barrel sponge". It is the most common

sponge in Singapore waters; D: *Tethycometes radicosa*, the first new sponge species discovered from Singapore waters after over a century; E: *Coelocarteria singaporensis*, one of the few sponges discovered from Singapore in the 19th century and the first sponge to be named after Singapore; F: *Theonella laena*, a new sponge species discovered recently in the deeper waters of Singapore near the port limit. Photographs B– F by: Swee Cheng Lim.

2.3.6. Polycladida (Free-living Marine Flatworms)

The order Polycladida, consisting of mostly free-living marine flatworms, is very understudied and relatively unknown in Singapore. The oldest scientific literature on Singapore polyclads were published more than a hundred years ago, in which Collingwood (1876) and Laidlaw (1903) described eight species (see Fig. 2.6).

In recent years, through CMBS, four papers on polyclad species of Singapore were published (Chim et al. 2015; Bolaños et al. 2016; Ong et al. 2018; Ong and Tong in press) with one in progress (Ong and Tong in press). Thirty-eight species of Acotyleans (flatworms without suckers) and 81 species of Cotyleans (flatworms with suckers) were discovered (Bolaños et al. 2016; Ong et al. 2018; Ong and Tong in press). Among these, at least 10 are species new to science. Work on this group is ongoing.

Polyclad flatworms are found within coral reefs, rocky shores, mudflats and seagrass patches (Ong et al. 2018). Although diets of polyclads are not well-studied, it has been reported that they feed on ascidians, gastropods, bivalves, and corals. It is thereby reasonable to associate polyclads with these different habitats for food and/or shelter. Hence, any harm to these ecosystems will consequently alter the community structure of the flatworm populations.

2.3.7. Mollusca (Snails, Bivalves, Cephalopods)

In Singapore, some 1,200 species of molluscs comprising over 800 gastropods and 300 bivalves have thus far been recorded (Tan and Woo 2010). Many historical records remain unsubstantiated and are believed to be misidentifications or based on mislocalised material because of Singapore’s long history as an entrepôt. The verification of historical records and documentation of the current malacofauna diversity is an ongoing work. In the past decade alone numerous new records were reported (e.g., Chan 2017; Tan and Clements 2008; Tan and Low 2013; Tan et al. 2016, 2017; Toh 2013, 2017). Remarkably the new records include two previously undocumented molluscan classes (see Ang and Tan 2013).

Cephalopod molluscs includes the octopus, cuttlefish, squid and nautilus. In Singapore, their habitat include coral rubbles, mudflats, seagrass, seawalls, and sandy bottoms. Members range from several centimetres to meters long. Little is known about cephalopod species in our waters. At present, 31 cephalopod species from seven families have been reported in Singapore (Tan and Yeo 2010; Norman et al. 2016). Of note, pieces of nautilus shells have been spotted on several occasions in Singapore. Although no live nautilus was ever encountered, a complete *Nautilus pompilius* shell was also found. No cephalopod species are listed among the endangered animals of Singapore. It is thus apparent that our knowledge of the molluscan diversity of Singapore is far from complete.

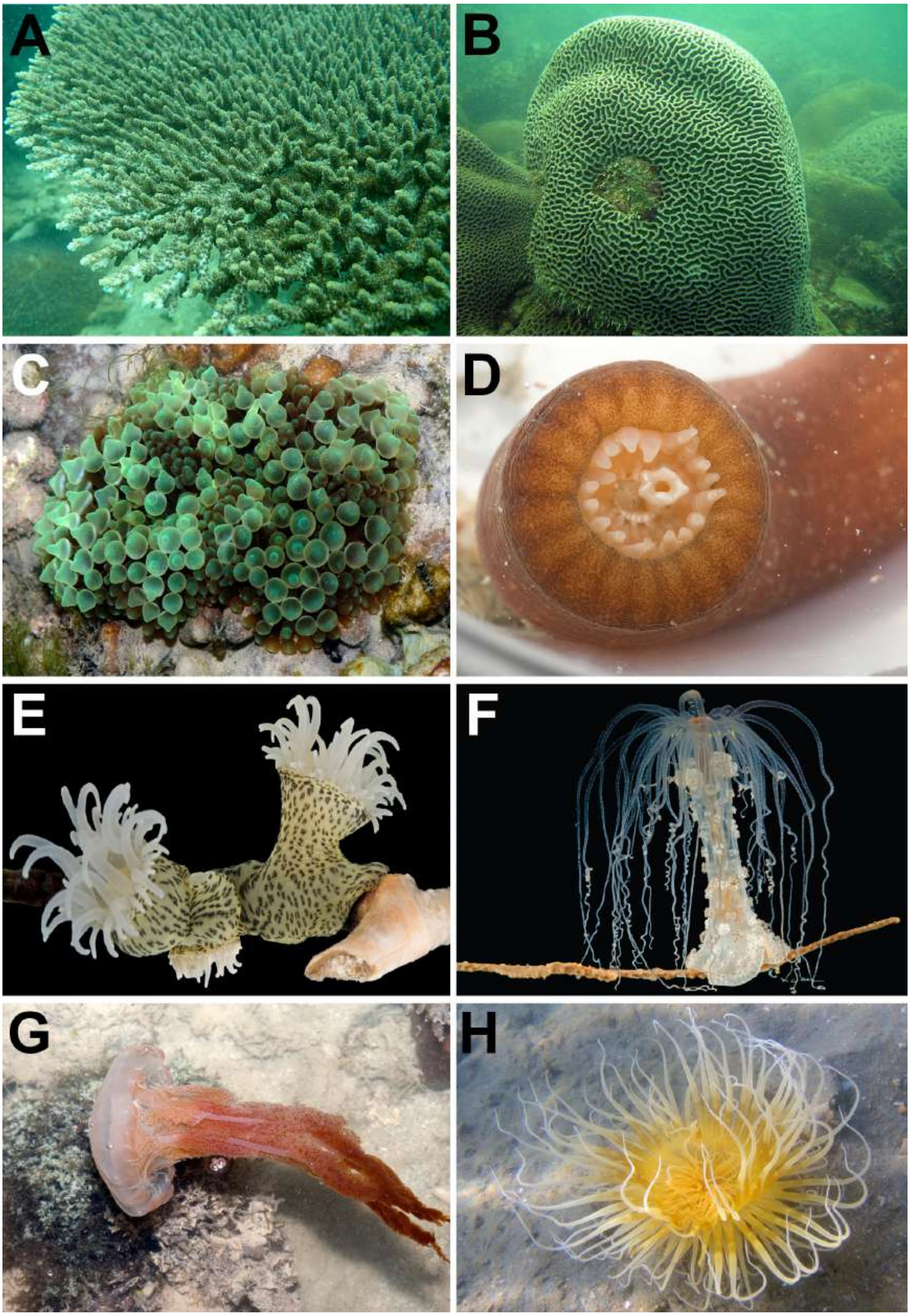

Figure 2.5. An array of cnidarians of Singapore. A: *Acropora hyacinthus* – one of the many hard coral species found locally. Photograph by: Danwei Huang; B: work is ongoing to resolve the chaotic taxonomy of corals belonging to the genus *Platygyra.* Photograph by Danwei Huang; C: the variable appearance of *Entacmaea quadricolor* has led it 'discovered' as 50 different species throughout history. It has since been synonymised and recognised as an important symbiotic host to other marine life. Photograph by Ria Tan; D: *Synpeachia temasek* a new species to science, was first encountered

from the beaches of Changi. Photograph by Ria Tan; E: one of the many anemones collected during CMBS of which its identity is still being determined. Photograph by Rene Ong; F: an Aliciidae anemone. Like many others collected, work is underway to establish an identity to it. Photograph by Rene Ong; G: *Chysaora chinensis* often appears in our waters between March to August and is capable of delivering very painful stings. Little work is done here to understand its seasonality. Photograph by Ria Tan; H: one of the many undetermined ceriantholid species found in our waters. Photograph by Ria Tan.

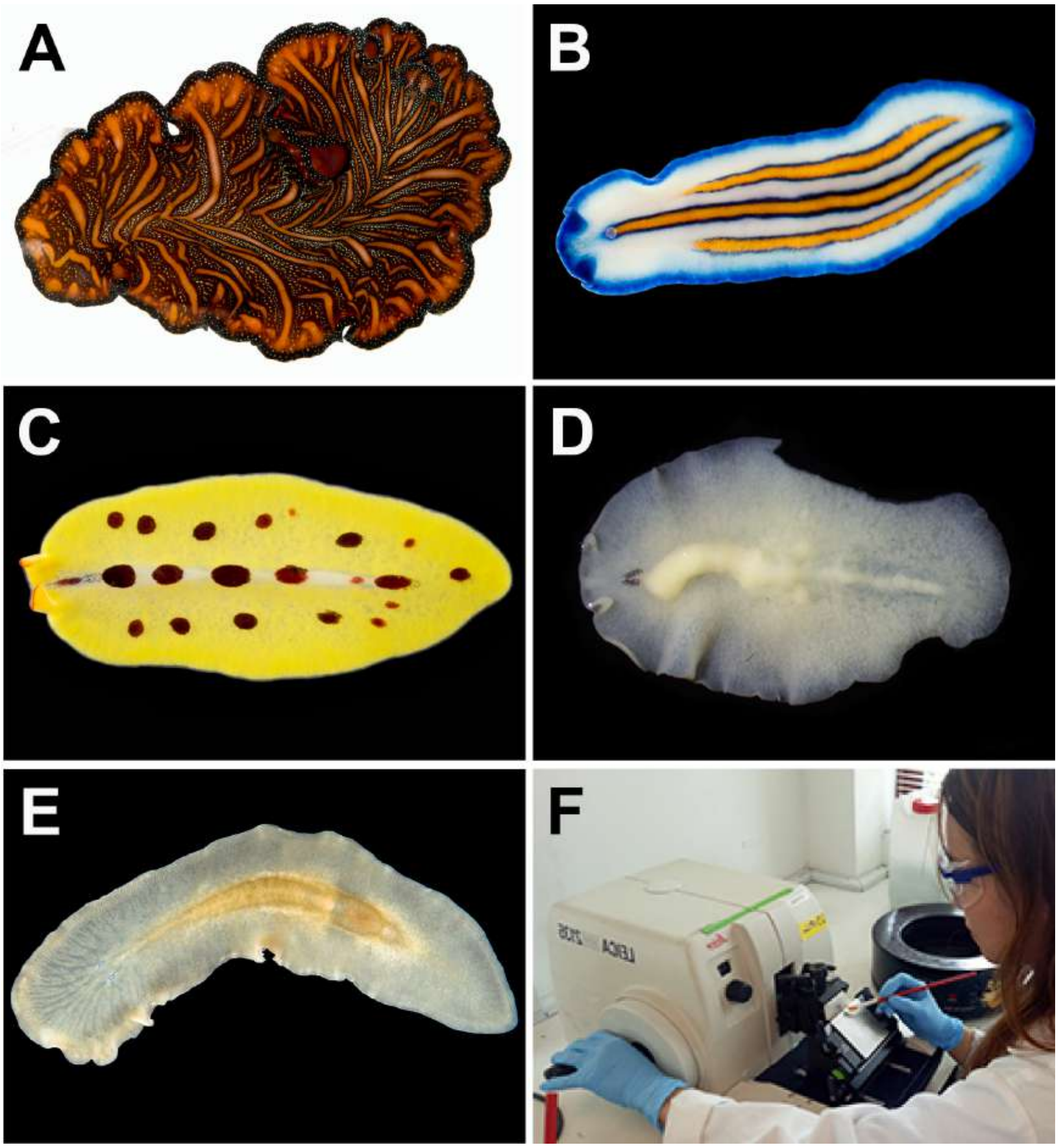

Figure 2.6. Flatworms collected from Singapore, and work to determine its indentity. A: *Pseudobiceros bedfordi*, first described in Singapore by Laidlaw (1903); B: *Pseudoceros* sp., a possible new species to science. Work involving molecular methods are underway to determine its identity; C: *Eurylepta* sp., another possible new species to be described; D: an example of a preserved flatworm which has lost its coloration, thereby hindering efforts to identify it; E: an acotylea flatworm of which the study of its musculature through histology is necessary to determine its species; F: using a rotary microtome to section a flatworm in a wax block for histological work. Photographs by Rene Ong.

2.3.7.1. Mollusca: Giant Clams

Giant clams are distributed amongst the shallow tropical coral reefs of the Indo-Pacific. Known for their large body size and colourful mantles, giant clams serve numerous ecological roles in the coral reef ecosystems: as food, as shelters, and as reef-builders and shapers. Less than 60 years ago, giant clams could be readily observed from the shores at low tide in Singapore—something that is not possible today. Five giant clam species once lived in Singapore's coral reefs; but two are now locally extinct (*Hippopus hippopus* and *Tridacna gigas*) while the three others remain critically endangered (*T. crocea*, *T. maxima* and *T. squamosa*) (Neo and Todd 2012). During the early 19th century, giant clams were regularly harvested for domestic consumption and shell trade, and possibly for lime production. These factors were early drivers of the decline in clam numbers. *Tridacna gigas* was the first species to disappear and likely overexploited due to its large size, while *H. hippopus* was last recorded in 1963. Recent surveys have confirmed the absence of both *T. gigas* and *H. hippopus*, while *T. crocea*, *T. maxima* and *T. squamosa* are only present in low numbers.

While local exploitation is no longer a major threat, major coastal development projects beginning in the 1960s have led to the degradation of reef habitats and their associated fauna. Many of the fringing and patch reefs in Singapore have been buried to provide new land, and earlier known reefs with giant clams have been reclaimed entirely. Even though local populations of giant clams have markedly declined over the past few decades, it is still heartening to see extant individuals thriving on the reefs despite being under pressure from multiple anthropogenic stressors. In addition, recently established rehabilitation programmes are exploring ways of increasing stock numbers using mariculture techniques.

The remaining few species of clams are unlikely to recover to become large and healthy population without intervention (Guest et al. 2008). Giant clam mariculture efforts began in 1998, where early studies examined the effects of elevated nutrients and sediments on reproduction and larval survival. Subsequent studies began looking at the autecology of giant clams, mainly their larval biology, behavioural ecology, and shell morphology (Huang et al. 2007). In 2011, with the support and funds from the National Parks Board, researchers from the Department of Biological Sciences (NUS) established a fully operational giant clam hatchery at the St John's Island National Marine Laboratory, Tropical Marine Science Institute. In Phase I of the restocking programme, researchers focused on the breeding and out-planting of cultured *Tridacna squamosa*—a native extant species in Singapore. Since the launch of the programme, cohorts of juvenile *T. squamosa* have been successfully cultured and are currently in the growing-out phase before the final phase of transplantation. With a renewed interest in a previously extirpated species, the Phase II restocking programme looked at the possibilities of reintroducing the true giant clam, *Tridacna gigas*—a species that can grow up to 1 m long and weigh more than 200 kg! The ultimate goal of these programmes is to replenish local coral reefs with cultured giant clams that will eventually produce self-sustaining populations. These rehabilitation programmes have also helped raise awareness of the plight of the giant clams in Singapore, and with dedication and some luck, these megafaunas may yet have a chance to thrive again.

2.3.8. Polychaetae (Marine Bristleworms)

Early records of polychaete worms from Singapore begun in the late 1800s, followed by gaps in the 1900s, picking up again only in the past thirty years. Even so, efforts in the past decades were sporadic and relied on untrained local expertise. The first polychaete checklist for Singapore was published by Tan and Chou in 1993 with 28 families comprising of 64 species. The ASEAN-Australian Marine Science Project: Living Coastal Resources conducted between 1987 and 1997 added two new species and one new record (Tan and Chou 1994, 1996, 1998). Updates from Chan (2009) and efforts resulting from CMBS (one new species, and fifteen new records recovered), the current status of polychate worms in Singapore stands at 28 families comprising 90 species (Lee and Glasby 2015a, 2015b; Lee and Ong 2015; Glasby et al. 2016; see Fig. 2.7). The diversity is considered low, when compared other South East Asia or South China Sea areas, reflecting the insufficient taxonomic knowledge for these organisms (Glasby et al. 2016).

Of the species recorded thus far in Singapore, seven were originally described locally — *Onuphis punggolensis* (Tan and Chou 1998), *Neanthes wilsonchanii* (Lee and Glasby 2015b), *Tylonereis heterochaeta* (Tan and Chou 1993), *Perinereis singaporiensis* (Grube 1878), *Perinereis viridis* (Glasby and Hsieh 2006), *Syllis solida* (Grube 1878), *Lysidice collaris* (Grube 1870) through synonymy (Hartman 1948).

Based on information from the CMBS and a benthic survey at St John's Island in 2016, several polychaete species appear in both the intertidal and subtidal zones. Differences in distribution is likely associated to habitat types (e.g., hard substrates or silty bottom or macroalgae). Free-living species of Nereididae, especially *Neanthes glandicincta*, dominated the silty habitats along the northern coast of Singapore, while burrowing Eunicidae were most abundant in reef areas in the Singapore Strait. On the intertidal shores at the Southern Islands, giant reef worms from the family Eunicidae build large structures by agglutinating rubbles together. Some of these structures could extend well beyond 1 m and are able to withstand strong forces from incoming waves, thus providing a relatively stable habitat for other small marine creatures and algae to grow. The role of the giant reef worm as reef builders and eco-engineers may serve to be essential for strengthening the integrity of the intertidal reefs at the Southern Island.

One of the biggest threat to the local polychaete population in Singapore is the intense coastal development activities. Land reclamation kills off entire benthic communities, including polychaetes, by burial. Settlement of fine sediment in the water column could also smother filter-feeders or affect their life cycle. Some areas where earlier polychaete records were documented, are now lost to land reclamation, ie. Kampong Mata Ikan and Pulau Ayer Chawan (Monro 1931; Vohra 1972). Cessation of coastal development and addressing existing gaps in taxonomy knowledge will aid in the conservation of polychaetes, an important component of the benthic community.

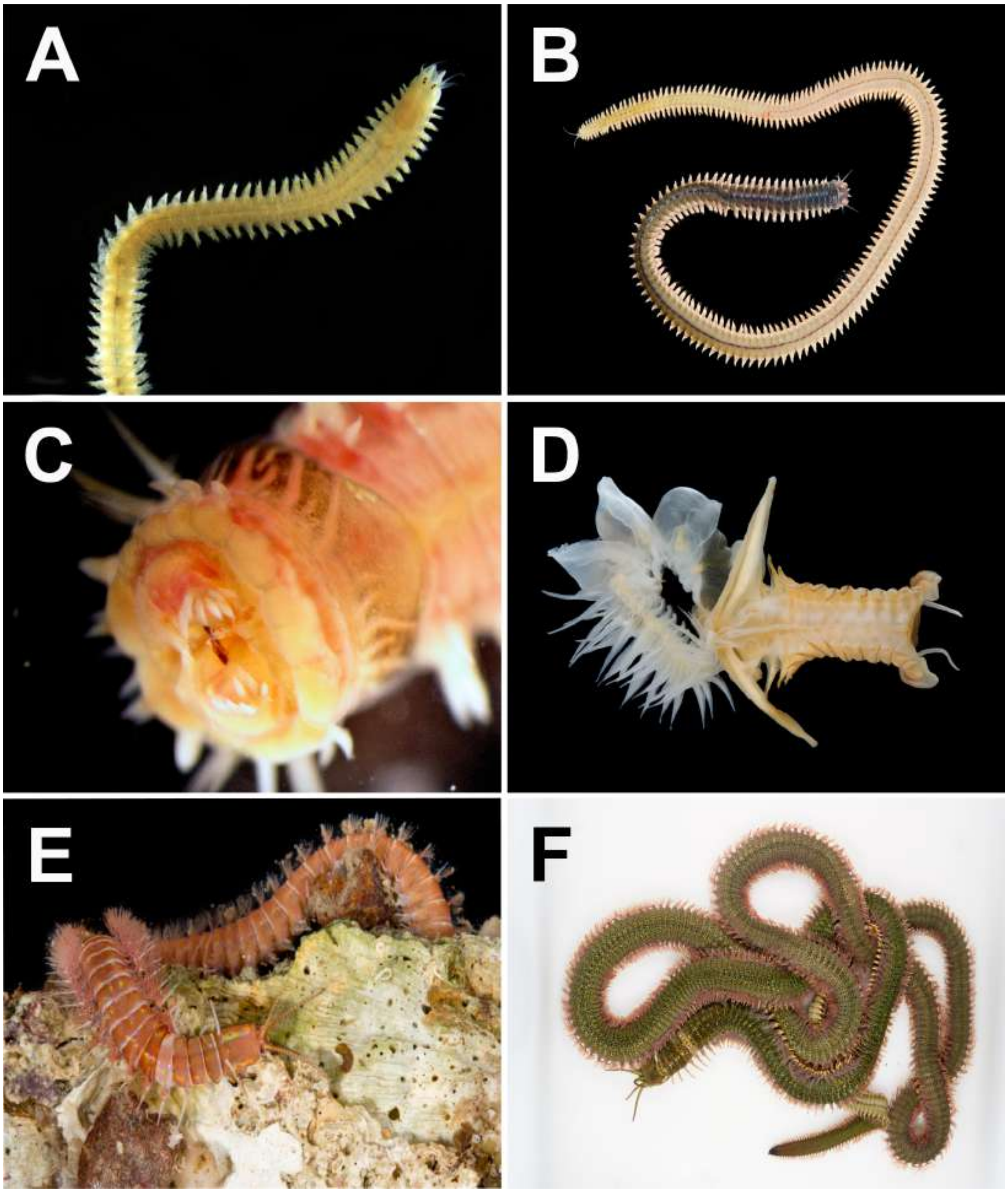

Figure 2.7. Some described and undetermined polychaetes species of Singapore. A: These vibrant colors of *Neathes wilsonchani* will fade with time in preserved specimens, hindering easy identification of the animal; B: obtaining a complete individual of *Perinereis singaporiensis* seen here for accurate identification is not an easy task – the animal fragments easily when handled; C: a close-up of a polychaete's proboscis. The arrangement of structures in the proboscis help workers to determine its identity; D, E and F: undetermined polychaetes collected from Singapore. Work is underway to put an identities to them. Photographs by Rene Ong.

2.3.9. Crustacea (Crabs, Shrimps, Allies)

The recent Comprehensive Marine Biodiversity Surveys (2010-2015) have recorded numerous groups of crustaceans collected from our waters viz. Stomatopoda (Ahyong 2016), Isopoda (Bruce et al. 2016) as well as various groups of the Decapoda, for example, caridean shrimps (Anker and De Grave 2016), squat lobsters (Lin and Osawa 2016), porcellin crabs (Osawa and Ng 2016). The brachuyran crabs, however, are not been well represented, with only a single publication on the coral rubble mimic crab (Ng and Komatsu 2016) and a CMBS poster of 30 leucosiid crabs collected from Singapore.

The brachyuran crabs within mangrove areas in Singapore are better studied compared to the other habitats. Based on the museum collections accumulated over six decades, as well as published journal articles by crab taxonomists over a span of 60 years, Tan and Ng (1994) compiled a checklist of mangrove crabs, reporting the presence of 76 species of mangrove crabs. Since new records (e.g. Ng and Sivasothi 1999b; Lee and Ng 2012), and new species of mangrove crabs have been described from Singapore (e.g. *Haberma nanum* Ng and Schubart 2002).

Most of the work on crustaceans within Singapore centres around the unpublished thesis by Ow-Yang (1963). Although his identification key was published by Lovett (1981), who used his records and figures for crabs of Malaya and Singapore, much of Ow-Yang's data, remains unpublished (see however Chen and Ng 2004 on *Doclea*). This work needs to be updated due to the substantial changes to brachyuran systematics and key collections of Singapore crabs, over the last 50 years. Figure 2.8 showcases several species of crustaceans found in Singapore.

2.3.10. Echinodermata: Crinoidea (Feather Stars)

Crinoids are from the phylum Echinodermata, to which sea stars and brittle stars belong. There are two forms of crinoids, stalked and unstalked. Here, we focus on the unstalked crinoids, also known as feather stars, since stalked crinoids are not present in Singapore waters.

Approximately 550 feather star species are known globally, with 263 species found in Southeast Asian waters alone. Approximately 39 species of crinoids have been recorded in Singapore since the 19th century (Messing and Tay 2016; Fig. 2.9). In recent years (2012-2016), 26 nominal species have been documented. One species, *Cenometra bella*, was a new record discovered in 2013 during the CMBS. Only two species are included in the Singapore Red Data Book, *Stephanometra oxyacantha* and *Himerometra robustipinna* (Davison et al. 2008). The former, *S. oxyacantha*, now synonymised as *S. indica*, is listed as 'vulnerable' while *H. robustipinna* is listed as 'data deficient'. While *S. indica* has been rarely recovered in recent surveys, *H. robustipinna* is one of the more familiar species from both intertidal and subtidal habitats (Tay and Low 2016). Crinoids in general are more commonly encountered in subtidal areas; however, a particular 200m stretch of sandy and rocky beach on Lazarus Island is known to have high densities of crinoids, with up to 150 individuals at its peak. Majority of the crinoids there belong to the species *Himerometra robustipinna*, easily identified by its bright red colouration.

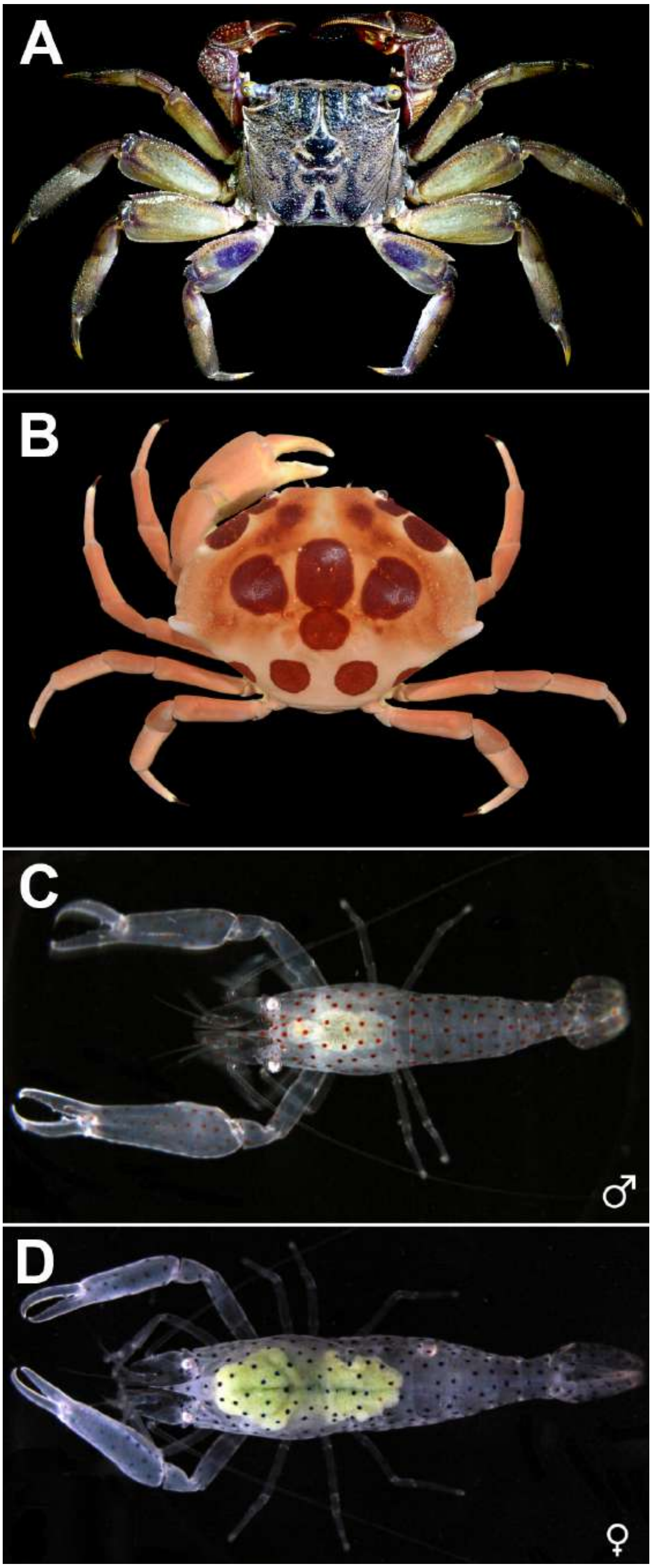
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Figure 2.8 Some crustaceans reported from Singapore. A: a male *Episesarma singaporense*. Photograph by Lee Bee Yan; B: a female *Carpilius maculatus*. Photograph by José C .Mendoza; C and D: a pair of *Anchistus miersi* shrimps collected from the fluted giant clam, *Tridacna squamosa*. Photographs by Neo Mei Lin.

Through CMBS, we were able to ascertain the crinoid population in Singapore. About 1500 individuals belonging to 26 morphospecies were recorded in more than 30% of the subtidal locations surveyed through dredging or trawling (Tay and Low 2016). Crinoids were found at depths ranging from 7.0–130.5 m. The highest density of crinoids recorded was 0.4 individuals m^{-2}, at a site east of the Singapore Strait. Sites off Jurong Island also had very high densities of crinoids (Fig. 2.10). As many as 12 different species of crinoids could be found within one site. In summary, crinoids in Singapore are unexpectedly well-documented, although the majority of reports focused on species identification and population distribution. The information gap on the ecology of crinoids in Singapore can be improved with further studies of these organisms.

2.3.11. Echinodermata: Holothuroidea (Sea Cucumbers)

Prior to CMBS surveys, little information existed on the biology and taxonomy of sea cucumbers in Singapore, despite their abundance, large sizes, ecological, and economic importance. This faunal group of Singapore was poorly represented in the museum collections, and large part of the collections were unidentified. During the five-year CMBS project, about 50 species of sea cucumbers were reported. This included numerous new records, eight potential new species, and two new species. Based on results from CMBS and records in various field guides (Ong and Wong 2015), we estimated 70 species of sea cucumbers to occur in Singapore (Ong et al. 2016). The documented richness of holothuroid fauna in Singapore at 50 known species (Ong and Wong 2015; Ong et. al. 2016) is comparable to diversity at islands of comparable size for example Guam (65 spceies; Michonneau et al. 2013), Yap (37 species; Kim et al. 2014), Spermonde Archipelago (56 species; Massin 1999) and part of the eastern coast of Thailand (31 species; Mucharin et al. 2005).

While the species diversity of holothuroid species in Singapore is comparable to other areas in the Indo-West Pacific, differences exist at higher taxonomic levels. Most of the sea cucumbers sold for food in Asian markets belong to the order Aspidochirotida and Dendrochirotida, with a few species of the order Molpadida. Four taxonomy orders of sea cucumbers are found in Singapore—Aspidochirotida, Dendrochirotida, Molpadida and Apodida. In Singapore the most abundant orders are the Aspidochirotida and Dendrochirotida. Aspidochirotida are more commonly found on reef flat in Singapore Straits whereas Dendrochirotida dominate habitats in the Johor Strait and seabeds in Singapore Straits (Ong et al. 2016). The higher occurence of Dendrochirotids could be due to conditions created by coastal eutrophication which had increased by 30 to 60 fold over the last 50 years (Gin et al. 2000). To the best of our knowledge, there has been no evidence of large-scale collecting for food; but sea cucumber populations are likely to be impacted by reclamation activities.

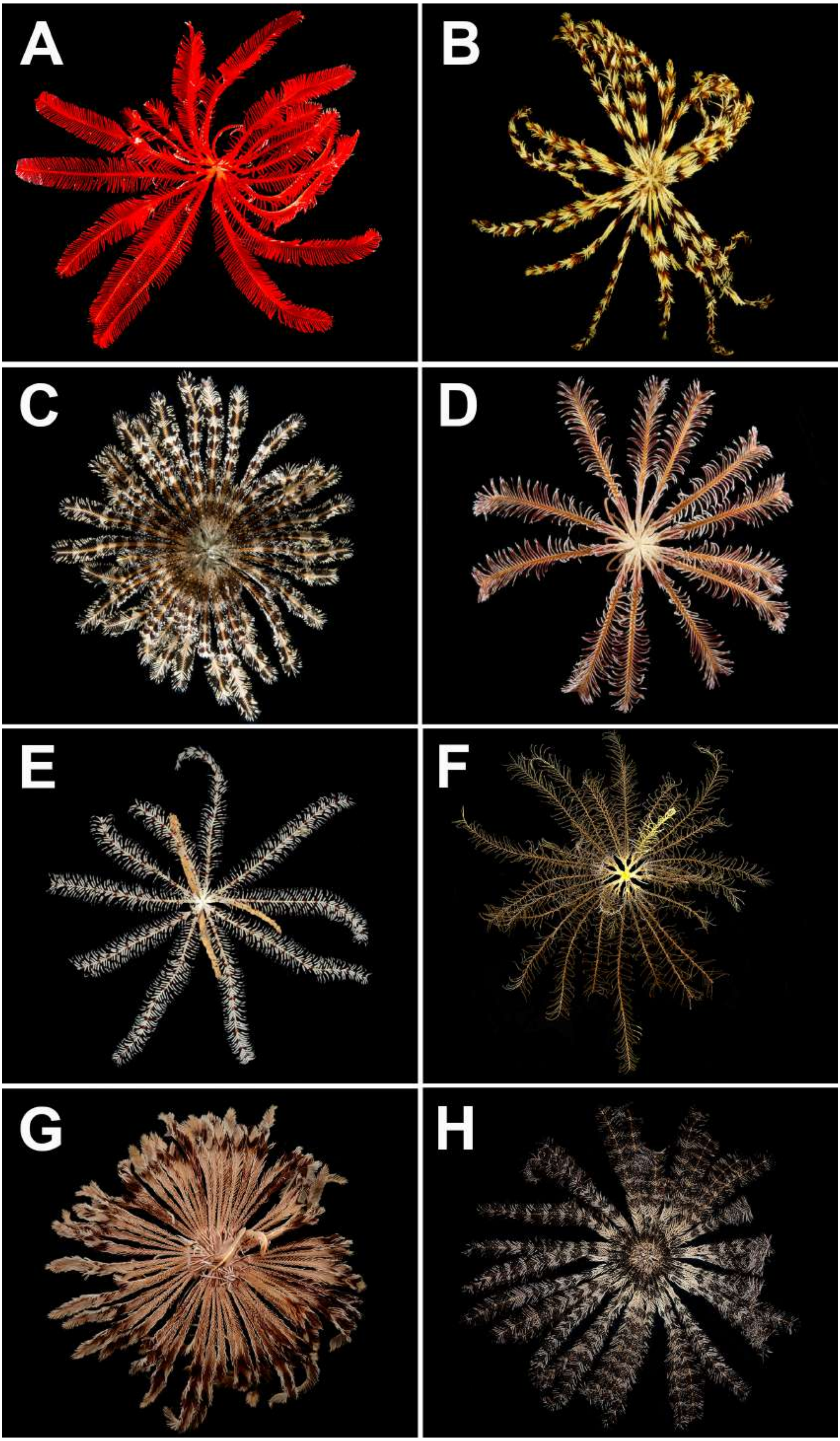
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Figure 2.9. Some crinoids encountered in Singapore. A: *Himerometra robustinpinna* one of the most conspicuous and recognizable crinoids found in Singapore; B: *Cenometra bella* a new record for Singapore, only this single specimen was encountered during our field surveys; C: *Dichrometra brachypecha*, determining the identity of this species is tedious as challenges still pervades at a higher taxonomic level (e.g. genus); D: *Heterometra crenulata*, exhibits variable morphological characters, hindering accurate identification; E: *Oligometra serripinna* is a charismatic 10-arm crinoid; F: *Phanogenia typica* has distinct tiny hooks on its pinnules that cause it feel sticky when touched; G: *Pontiometra andersoni*, arms of this species abscises when stressed; H: *Stephanometra indica* is another crinoid species with known taxonomic challenges that makes identification difficult. Photographs courtesy of Comprehensive Marine Biodiversity Surrvey Team.

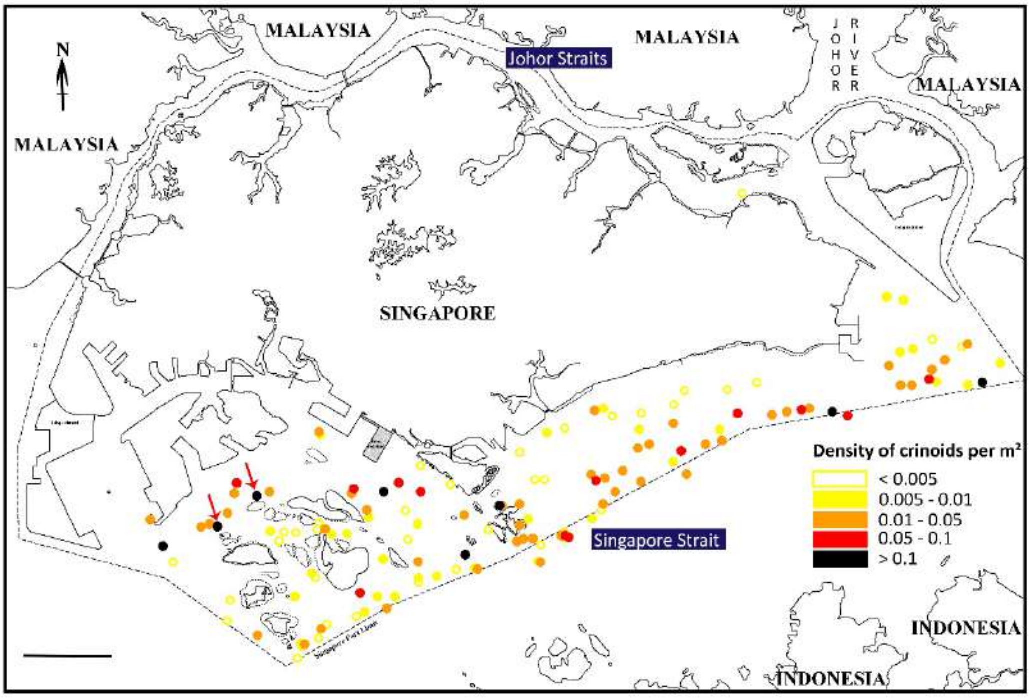

Figure 2.10. Population distribution and density of crinoids from dredging surveys (2012 – 2014). Arrows indicate sites with the highest species densities of 11 – 12 species per site. Scale bar = 5 km. Map taken from Tay and Low, 2016.

2.3.12. Marine Insects

Insects are not the first group of animals that one will associate with marine ecosystems, but there is a surprisingly rich representation of these six-legged organisms in coastal and marine environments. Often overlooked due to their minute size and cryptic behaviour, our local knowledge stems from targeted scientific studies by experts in the entomological field. Marine insects are high in diversity and abundance, with important roles in coastal ecosystems such as mangroves and rocky shores. Many marine insects have larvae adapted to the coastal substrates, feeding on micro-organisms and in turn are consumed by other marine predators. Many known adults are themselves predatory or scavengers integral to the food web of their respective ecosystems (Fig. 2.11).

Figure 2.11. *Hermatobates* sp. on a hard coral. Photograph by Tran Anh Duc

Insect fauna of our marine and coastal environments are typically not well understood and remains an understudied area. One of the better studied groups of insects in Singapore are the water bugs (Heteroptera: Gerromorpha & Nepomorpha) due to a long history of local expertise working with overseas collaborators. Although mostly known for their presence in freshwater ecosystems, there are substantial numbers that have adapted to marine coastal and even open water surfaces. These insects represent an interesting evolutionary frontier by modifying their freshwater-adapted features to cope with tidal fluctuations of coastal habitats and other challenges. Most marine-adapted water bugs skim on the water surface or are able to hide in pockets of air in burrows and crevices during high tide and emerge only to feed at low tide (Tran et al. 2015). Due to the unique conditions faced by insects in surviving a marine environment, species generally tend to be highly restricted to their specific habitats.

The mangrove insect project by NParks and NUS (2012-2014) found 150 mangrove-specific species of long-legged dolichopodid flies, of which 60 are new species, with 50 species endemic to Singapore mangroves (Fig. 2.12). Extensive sampling show limited distributions of particular species, such as *Ngirhaphium caeruleum* only found in Semakau mangroves (Grootaert and Puniamoorthy 2014). Up to 33.7% of dolichopodid species are unique to a specific mangrove area (e.g., Sungei Buloh, Pulau Semakau), highlighting the need to protect several sites to preserve Singapore's mangrove fauna.

Figure 2.12. *Ngirhaphium caeruleum* Long-legged fly (Dolichopodidae) is endemic to mangrove areas of Pulau Semakau. Photograph by Hwang Wei Song.

Singapore mangroves has been described as one of the richest in biodiversity in the world despite its miniscule size and patchy distribution (Grootaert et al. 2014). From a scientific viewpoint, it is a highly attractive puzzle to investigate further as it represents a biogeographic and evolutionary novelty. The first record of an intertidal velvet water bugs was from Singapore mangroves – *Hebrus nereis* and *Hebrus mangrovensis* from Kranji and Mandai mangroves. At the same time, coastal mangroves are considered to be the most threatened habitats, especially so for water bugs. Two species of water treaders (Mesoveliidae) *Nereivelia murphyi* and *Nereivelia polhemorum*, both described from Sungei Buloh and Mandai mangroves are now extremely rare and should be considered highly endangered (Yang and Murphy 2011). *Nereivelia murphyi* is only known from mangrove swamps in Southern Thailand and Singapore, while *Nereivelia polhemorum* is only known from Sungai Buloh and Mandai mangroves. A water measurer bug *Hydrometra orientalis* is also found in Singapore mangroves, living along brackish pools between mud lobster mounds.

Beyond mangroves, coastal rocky shores and coral rubble flats contain a significant diversity of marine insects not found elsewhere. An exclusively marine coral treader bug *Hermatobates singaporensis* was originally found in Singapore offshore islands (Polhemus and Polhemus 2012). A number of intertidal shore bugs are only found on rocky intertidal shores (e.g., *Salduncula murphyi* [Saldidae], *Corallocoris marksae* [Omaniidae]), and an unidentified intertidal beetle (*Laius* sp. [Malachiidae]) has been recorded from St John’s and Lazarus islands rocky shores.

2.3.13. Ascidiacea (Tunicates)

Fifty species of ascidians was recently reported occurring in Singapore (Lee et al. 2016). Ascidians are found on both artificial and natural substrates, ranging from benthic, subtidal to intertidal. The report resulted from several efforts at documenting ascidian diversity in Singapore. The first is a three-year long survey, from 2009-2011, of surfaces on navigational buoys, jetties and pontoons funded by the Coastal and Marine Branch of the National Parks Board of Singapore. The second is the CMBS of the Straits of Singapore in 2013. These two large-scale surveys recovered hundreds of specimens. Estimates based on morphotypes indicate another 50 – 80 species awaiting identification. This is a conservative estimate as ongoing efforts, and photography surveys, indicate that more species are to be discovered within the territorial waters of Singapore. Further, some ascidian species may have been mistaken as sponges and may not have been collected.

Studies conducted elsewhere indicated that non-indigenous ascidian species tended to recruit and thrive in artificial coastal environments (e.g. ports, harbours) while native species were generally confined to natural locations (Glasby et al. 2007; Tyrell and Byers 2007; Marine et al. 2010). Our preliminary study suggest otherwise (Lee et al. 2013).

Four hundred species was reported to occur in the South China Sea and maritime Southeast Asia (Lee et al. 2016); Malaysia with 22 species, Vietnam with 18 species, Indonesia with 229 species, and Philippines with 183 species. High diversity reported from Indonesia and Philippines are results from major expeditions such as the Challenger, the Dutch Siboga, and the Albatross Philippine in the1800s. Newly published records since have been scarce.

Ascidian diversity is still poorly known in Singapore and Southeast Asia. There are no studies in the region to assess the impact of environmental threats on ascidian diversity. Recent efforts in documenting ascidian diversity are sparse. Taxonomists focusing on ascidians are typically based in the west (Gretchen Lambert, USA; Francoise Monniot, France) and are retired or near retiring (Rosana Rocha, Brazil). In 2012, the Australian Patricia Kott who is an authority in ascidian taxonomy passed away. There is thus an urgent need to train new researchers to continue these efforts. At present, there are no known ascidian experts in Southeast Asia. In Singapore, since funding was discontinued since 2011, work stemming from ascidians that were collected was placed on hold.

The ideal scenario for Singapore into the next decade is to elucidate most of the ascidian diversity occurring here. This can be achieved through the invitation of taxa experts to identify and train local and regional scientists. Community programme such as Bioblitz by NParks offer a framework under which members of the public can aid in documenting these organisms.

2.3.14. Fishes

Marine fishes in Singapore inhabit a wide variety of coastal habitats, such as tidal canals, mangrove creeks and pools, mudflats, sandy shore, rocky shore, seagrass beds and coral reef. The fish fauna of Singapore has been documented since the mid-19th Century during the British colonial era, in a handful of publications by European and American naturalists (see Ng et al. 2011). Notable ones include Cantor (1849), Peters (1868), Steindachner (1870), Karoli (1882), Duncker (1904), Fowler (1931) and Herre (1937). Among them, the Dutch surgeon, Dr. Pieter Bleeker, was the most prolific. He published three articles specifically on Singapore's fish fauna (e.g. Bleeker 1861), and another 14 in which new fish species were named after specimens obtained in Singapore. Most of these publications were cited in the list of Malayan fish fauna by Fowler (1938), which lists over 640 species of marine fish from Singapore. Although presently outdated, Fowler's compilation, which also includes Peninsular Malaysia, remains the most comprehensive review of the fish fauna in Singapore.

Subsequent publications on Singapore's marine fish fauna are either general in coverage (e.g. Tham 1973b; Lim and Low 1998), or restricted to smaller areas (e.g. Tham 1950; Kwik et al. 2012; Ng et al. 2015; Toh et al. 2016), habitats (e.g. Chua 1973; Khoo and Tay, 1990; Low and Chou 1994) or taxonomic groups (e.g. Ng 2012; Larson et al. 2016). Although Singapore's marine fish fauna appears to be well studied, new records, and even new species are still being discovered today (e.g. Larson 2001; Low et al. 2009; Jaafar & Ng 2012; Low 2013; Lim et al. 2014). It is obvious that there is still much to discover.

To update Fowler's (1938) catalogue is not simply a matter of adding names extracted indiscriminately from publications and the internet. Research has to be undertaken to trace as many published records as possible, and efforts have to be made to determine synonyms and misidentifications. It implies that voucher specimens, if available in museums, should be examined to have their identities confirmed. The fauna would be over-represented if synonyms and misidentifications are not considered, because a single species can be represented by two or more names.

Research assessment of wild fishes in local waters is limited. Visual census both *in situ* and of fishermens' catches and collections are the usual methods of recording diversity. As a result, many small and cryptic species have almost certainly escaped notice. Most of these fauna can only be found with the use of ichthyocides and collecting that involves some damage to their habitat. It is also difficult to monitor the large pelagic species, such as billfishes and devil rays that may on occasion, enter Singapore's territorial waters from adjacent areas.

Species which are outside their known geographic or latitudinal ranges, or when their natural habitat did not exist in Singapore, should be treated as having a doubtful occurrence. Particularly relevant are species represented by material only obtained from the market. Their apparent absence in Singapore in recent times does not mean that they have become locally extirpated as would have been presumed without knowledge of the provenance of the original material on which their records were based. For these reasons, it is not possible to be certain of the actual number of fish species present in Singapore. From numerous scattered publications, it is estimated that around 950 species of marine fishes are presently known from Singapore. Among which, at least 710 species are of confirmed occurrence.

The marine fish fauna of Singapore is affected by a number of human related *a*ctivities such as land reclamation; water pollution; housing, industrial and port development; damming of inland drainages to create freshwater reservoirs (see Tan et al. 2010; Ng and Tan 2013); as well as excessive and uncontrolled commercial fishing (see Chou 2011). Alien species, through deliberate introduction or escapees from aquaculture trade, or unintentionally introduced through shipping activities (Jaafar et al. 2012) may have a role in affecting fish diversity. In the Singapore Red Data Book (Lim et al. 2008), seahorses and anemonefishes are featured as the only marine fishes vulnerable to excessive anthropogenic exploitation. It is not known if the species commercially exploited for food are threatened with local extinction.

Unlike freshwater fishes, marine fish are not geographically restricted to Singapore territorial waters, and it is difficult to determine their status or abundance. The presence of most species is directly related to the health of their respective habitats, being rare or absent when these are degraded or depleted. As long as these habitats are allowed to recover, it is possible for recruitment from surrounding areas to occur without human intervention. However, there is no past and present data on fish stocks in Singapore waters.

2.3.15. Amphibia (Frogs, Toads)

Only one amphibian species truly inhabits coastal and estuarine ecosystems in Singapore—the crab-eating frog, *Fejervarya cancrivora*. This medium-sized species attains snout-vent length of 8 cm. The species name '*cancrivora*' means 'to devour crabs'. Apart from crabs, the diet of this frog includes other invertebrates and smaller frogs. Only lone males call and its vocalization has been described as approximating a loud machinegun. The species is distributed throughout Southeast Asia. In Singapore the species has been recorded within intact and disturbed forests as well as recreational parks. Coastal locality records include Sungei Buloh Wetland Reserve, Pasir Ris Park, East Coast Park, Pulau Semakau, Pulau Ubin and Pulau Tekong. Moving forward, further amphibian surveys of outlying islands may yet yield interesting results.

The species has an osmoregulatory mechanism both in their larval and adult stage, thus able to tolerate a degree of salinity. Gordon and Tucker (1965) found that tadpoles were able to tolerate brackish water (32% seawater) and excreted salts via an extra-renal pathway. However, the stages of early embryonic development and completion of metamorphosis require lower salinities.

Annual harvests for food of this frog species reach 3-4 tonnes, reportedly found mainly from rice fields (Kusrini and Alford 2006). In Singapore, newly-metamorphosed adults are sold as live food in pet stores. In 2012, Gilbert et al. found several such individuals positive for the deadly chytrid fungus.

2.3.16. Reptilia: Lizards

Two species of lizards are commonly encountered in the mangroves and coastal habitats of Singapore: the Asian water monitor lizard and the maritime gecko.

The Asian water monitor lizard, *Varanus salvator* reaches 3 m in total length. They scavenge, and are known to feed on fish, frogs, crustaceans, and small invertebrates. They are also adept climbers, and smaller individuals are known to raid bird nests for food. The species is widespread throughout Asia and thought to be a species complex. In Singapore, they are seen basking in parks and aquatic areas. They are also sighted swimming in canals and have on more one than occasion, caused alarm when misidentified as crocodiles. They are listed as 'Least Concern' on the IUCN Red List and currently appear to be thriving throughout Singapore. However, they often appear as road kills near to their habitats. Locations in Singapore in which it has been reported are Admiralty Park, Labrador Nature Reserve, Khatib Bongsu, Lim Chu Kang, Lorong Halus, Pasir Ris Park, Pulau Semakau, Pulau Tekong, Pulau Ubin, Sentosa, Sembawang Park, St John's Island, Sungei Buloh Wetland Reserve and West Coast Park (Fig. 2.13).

The maritime gecko *Lepidodactylus lugubris* is an all-female native species of gecko (snout-vent length 5cm, total length 10cm) found in coastal and estuarine habitats. They feed on small insects and flower nectar. They have a slender body with a pair of elongated black spots on the nape, with dark mottling that resembles a series of chevrons on their dorsum.

Although native to Southwest Pacific, this species was introduced to the Caribbean, as well as Central and South America, possibly through the nursery plant trade. It is described as one of the most successful reptile invaders, with reports of bold foraging behaviour that allows them to successfully establish and displace native species (Short and Petren 2008). They are also commonly found in the pet trade, where they are described as exhibiting active social hierarchies. The maritime gecko can be found on rocks, trees and anthropogenic structures such as park benches and hand railings at Labrador Nature Reserve, Lim Chu Kang, Pasir Ris Park, Pulau Tekong, Pulau Ubin, Sentosa, St John's Island, and Sungei Buloh Wetland Reserve.

Figure 2.13. *Varanus salvator* at Sungei Buloh Wetland Reserve. Photograph by Abraham Matthew.

2.3.17. Reptilia: Crocodiles

The estuarine crocodile, *Crocodylus porosus* is found in mangrove areas and brackish waters. It is the largest predator in those habitats. In 1996 the IUCN listed *Crocodylus porosus* as regionally extinct, but was recently considered 'uncommon' and listed as "Critically Endangered" in the second edition of the Singapore Red Data Book (Davison et al. 2008).

The species reaches 7 m in total length but individuals found in Singapore are usually 3 – 4m. Adults scavenge on carrion, and feed on fishes, birds, and mammals. Juveniles hunt smaller prey items such as frogs, snakes, fishes and crabs.

Crocodylus porosus can tolerate marine conditions, thus able to colonise islands aiding in its wide distribution across Tropical Asia, Australia, and islands in the Pacific. In Singapore, they are frequently encountered at Sungei Buloh Wetland Reserve, one of the largest remaining mangrove areas in the country (Fig. 2.14). They have also been reported at Kranji Reservoir, the Seletar Reservoirs; this may be due to females seeking waterbodies unaffected by tidal movements to lay eggs. The species has also been found in the north of Pulau Tekong. In 2017 there were crocodile sightings along the northeastern coast of Singapore, at Changi Beach Park, East Coast Park and Pasir Ris Park. It is unclear if these were sightings of the same one individual, or multiple individuals.

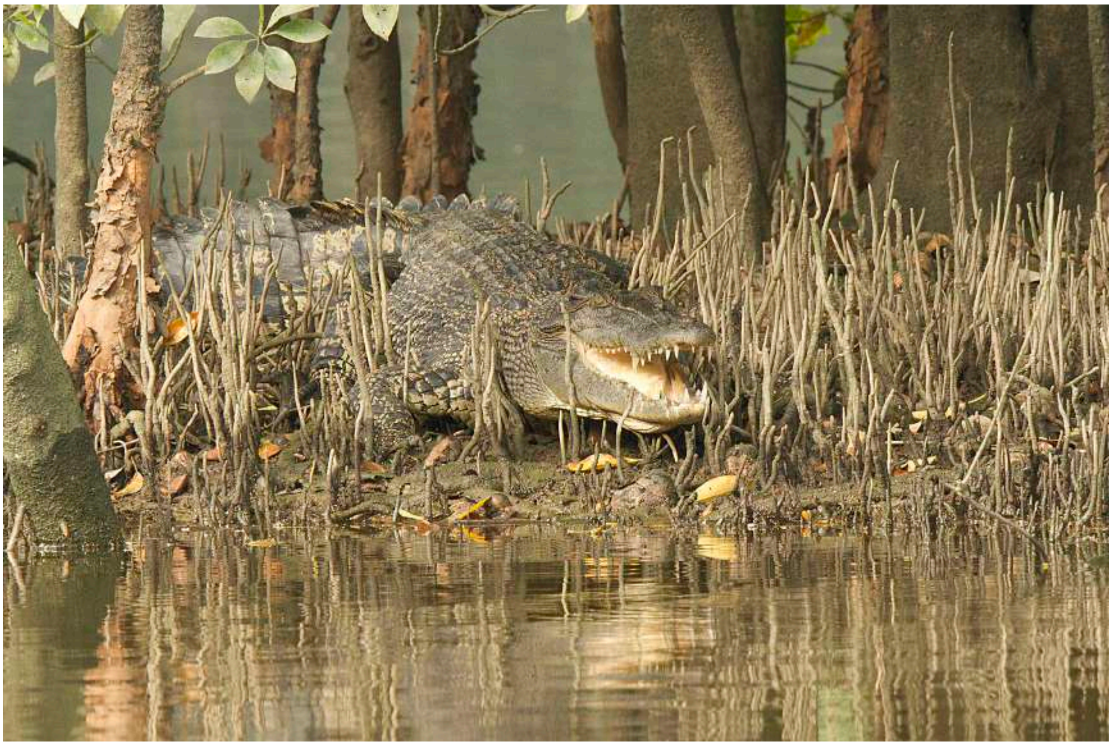

Figure 2.14. *Crocodylus porosus* at Sungei Buloh Wetland Reserve. Photograph by Abraham Matthew.

Prior to urbanization, the species was found all over Singapore, with some islands even referring to crocodiles. These are Pulau Buaya ("Crocodile Island' in Malay) and Alligator Island (today's Pulau Pawai). The earliest site-specific encounter is recorded circa 1820 and at least 380 public records of human-crocodile encounters have been noted since. During the 1800s, the species was victim to advantageous culling, where government incentives were given as bounty for their capture. Subsequently, the mid-1900s led to the increase of the reptile skin trade in Singapore and crocodiles were often shot on sight. Whilst the IUCN status suggests a lack of crocodiles in Singapore, there is no time frame in which crocodiles have not appeared.

A possible increase in sighting incidences may be due to land reclamation works along the coast of Johore state of Peninsular Malaysia, but this hypothesis has yet to be verified.

2.3.18. Reptilia: Snakes

Marine snakes of Singapore can be separated into two broad categories based on habitat type: mangrove snakes and sea snakes. Mangrove snakes are found primarily in mangroves but also occur in estuaries and mudflats. Sea snakes are associated with open-water environments such as coral reefs, and are fully adapted to a completely aquatic lifestyle.

The six species of snakes typically found in mangrove areas of Singapore belong to three families. Four of these species are from the family Homalopsidae, restricted to muddy substrate and estuaries, exhibit a wide range of diets (Voris and Murphy 2002). *Cerberus schneiderii* is a generalist feeding on fishes and crustaceans (Chim 2009). The other three species are crustacean specialists, usually associate with mud lobster mounds that serve as refuge areas for their prey (Karns et al. 2002). *Gerarda prevostiana* feeds on recently molted crabs with soft shells, while *Fordonia leucobalia* specializes on hard-shelled crabs (Jayne et al. 2002). *Cantoria violacea* likely feeds on *Alpheus* shrimp but little else is known of this elusive species.

Acrochordus granulatus from the family Acrochordidae, is a unique snake with a piscivorous diet. It is not necessarily restricted to the mangrove areas and has been recorded all over Singapore's shores, including at Sembawang Beach, Pulau Semakau and Tuas (Baker and Lim 2008). There is also a freshwater-dwelling population at Lower Seletar Reservoir, likely remnant from when Sungei Seletar was dammed to create the reservoir (Ng 2011).

Cryptelytrops purpureomaculatus from the family Viperidae, is a semi-arboreal pit viper regularly found resting on the raised roots of mangrove plants. They are one of the seven highly venomous terrestrial snakes in Singapore. Although they are not uncommon, their sedentary nature and cryptic colouration makes them elusive. Their diet mostly consists of small vertebrates, like lizards and birds, which they ambush (Baker and Lim 2008).

These six species are heavily reliant on mangal habitat that provides food and shelter. The loss of more than 99% of mangrove habitats in Singapore has severely impacted these snakes (Yang et al. 2011); their range is now limited to fragmented patches of mangroves totaling only 7.35 km^2 in area. Yet, very little is known of these species throughout their range and thus poses significant challenges to making informed conservation recommendations (McDonald-Madden et al. 2016).

Future research on mangrove snakes should include long-term monitoring, and focused surveys of lesser-known mangrove areas such as Admiralty Park, Changi Creek, and Sungei Khatib Bongsu, to identify resident populations. Carrying out radio telemetry studies will be beneficial in trying to understand how snakes move between mangrove areas, and also how these habitats are utilized but these taxa.

Fourteen species of sea snakes are reported in Singapore, all belonging to the family Elapidae (see Tab. 2.1). Only two species are more commonly encountered, and discussed below: *Laticauda colubrina* and *Aipsyurus eydouxii*.

Laticauda colubrina has been reported from Singapore's Southern shores (Southern Islands, Labrador Park, etc.) in areas dominated by rocky shores. Unlike other true sea snakes, this species can move both on land and in sea (Shine et al. 2003). They feed mostly on moray and conger eels, which they kill with potent venom. Post-feeding, they move ashore to digest their food. This species is also known to court, mate and lay eggs on land (Shetty and Shine 2002). This is unique amongst sea snakes, which otherwise give birth to live young. Before its reclamation, the reef adjacent to Pulau Sudong was reported to be a nesting ground for this species (Tan 2016b).

Table 2.1: A list of Mangrove and sea snakes that have been recorded thus far in Singapore. Conservation Status is with reference to Davison et al. (2008). LC - Least Concern, EN - Endangered, NA - Not Available

Family	**Species**	**Common Name**	**Conservation Status**
Acrochordidae	*Acrochordus granulatus*	Banded File Snake	NA
Homalopsidae	*Cerberus schneiderii*	Schneider's Bockadam	LC
	Fordonia leucobalia	Crab-eating Water Snake	EN
	Gerarda prevostiana	Gerard's Water Snake	EN
	Cantoria violacea	Cantor's Water Snake	EN
Viperidae	*Cryptelytrops purpureomaculatus*	Mangrove Pit Viper	EN
Elapidae	*Acalyptophis peronii*	Horned Sea Snake	NA
	Aipsyurus eydouxii	Marbled Sea Snake	NA
	Astrotia stokesii	Stokes' Sea Snake	NA
	Enhydrina schistose	Beaked Sea Snake	NA
	Hydrophis cyanocinctus	Blue-banded Sea Snake	NA
	Hydrophis gracilis	Slender Sea Snake	NA
	Hydrophis hardwickii	Spine-bellied Sea Snake	NA
	Hydrophis lapemoides	Persian Gulf Sea Snake	NA
	Hydrophis platurus	Pelagic Sea Snake	NA
	Hydrophis spiralis	Yellow Sea Snake	NA
	Kerilia jerdoni	Jerdon's Sea Snake	NA
	Kolpophis annandalei	Bighead Sea Snake	NA
	Lapemis curtus	Short Sea Snake	NA
	Laticauda colubrina	Yellow-lipped Sea Krait	EN

Aipsyurus eydouxii has so far only been recorded along the North-eastern shores of Singapore (Chek Jawa, Changi Beach, Beting Bronok) (Tan 2016a). These areas are at the mouth of the Johor River and are dominated by sandy shorelines and seagrass meadows. *Aipsyurus eydouxii* feeds mainly on fish eggs that are laid on the benthic substrate (Voris 1972). Little else is known of its ecology.

The main threat facing sea snakes is the global lack of knowledge on this group. Detection and identification in the field is difficult. In Singapore, sightings of sea snakes are rarely reported and local conservation statuses of most are unknown. Reclamation of shoreline impacts sea snakes directly by decreasing available habitat and potential nesting grounds.

Creating a portal that allows members of the public to report sightings will aid efforts to understand the diversity and distribution of sea snakes in Singapore. Enhancing sea walls to function as breeding sites for *Laticauda colubrina* can aid the conservation of this species.

2.3.19. Reptilia: Sea Turtles

Three species of sea turtles — Hawksbill (*Eretmochelys imbricata*), Green (*Chelonia mydas*), and Leatherback (*Dermochelys coriacea*) —have been reported in Singapore. The latter species was only reported once in 1883 (Diong 2006). Beyond the occasional reports of nesting and hatching events and dead adults washed ashore of Hawksbill and Green turtles, little is known of their local ecology. Despite only occasional sightings of sea turtles here, Singapore is important for the conservation of regional sea turtle populations; these animals undertake regional migrations that traverse political boundaries to move between nesting and foraging grounds.

A major threat to sea turtles in Singapore is the ubiquity of artificial lighting. Female turtles do not nest on well-lit beaches (Salmon 1995a). Hatchlings move towards inland lights rather than the ocean (Salmon 1995b), a phenomenon observed in Singapore (Basu 2007). Once at sea, hatchlings are also attracted towards lights from ships making them easy prey (Thums et al. 2016).

Marine debris is another major threat as sea turtles ingest these with, often, fatal consequences (Schuyler et al. 2014). Discarded fishing gear can also entangle sea turtles while damaging important habitats (Gilman et al. 2010).

Some of these threats can be easily mitigated. Cessation of lighting on sandy beaches allows females to lay eggs (Salmon et al. 1995a). Lights along the shoreline should be kept dim or shielded so that hatchling attempts to reach the water can be successful. Offshore light sources, such as from ships, can also be fitted with sea light-guards.

The recent launch of a sea turtle hatchery at the Sisters Islands Marine Park is an encouraging initiative in sea turtle conservation. Because beaches in Singapore are heavily utilised, they are not conducive environments for egg development, and may result in total mortality of nest clutches. Translocating nests to this protected hatchery increases chances for successful development. Activities such as these can also be an avenue for public outreach and education; important because members of the public are typically the first to encounter nesting females or emerging hatchlings.

Identifying important nesting beaches on mainland and offshore islands is key for sea turtle conservation in Singapore. Satellite tagging programs to tracks sea turtles provide insights on where local sea turtle populations forage and nest. Obtaining DNA samples from individuals encountered can provide information of the population at the genetic level. These endeavours require intensive manpower efforts, which is only possible with appropriate amount of funds and properly-trained personnel.

2.3.20. Birds

Estuarine, coastal and marine habitats in Singapore support a high diversity of bird species, ranging from year-round residents, to long-range migrants from the farthest reaches of the northern hemisphere. The rich diversity of aquatic and marine life in these habitats serve as an important food source for many bird species, especially migratory birds. In all, at least 82 bird species are associated with marine and estuarine habitats here (Wells 2006; Wang and Hails 2007) representing approximately 20% of total bird species diversity in Singapore. Of these, 12 species are recognised as internationally Near-threatened, 3 species are listed as Vulnerable to extinction, 3 species listed as Endangered (Great knot, Nordmann's greenshank, and Far Eastern curlew), and 2 species listed as Critically Endangered (Christmas frigatebird and Spoon-billed sandpiper) (IUCN, 2018).

In the tidal sand and mud flats of Singapore, the abundance of marine invertebrates such as crabs, molluscs and nematodes (Iwamatsu et al. 2007), and even microbial biofilms (Kuwae et al. 2008; Kuwae et al. 2012), serve as important sources of nutrition for shorebirds migrating along the East Asian-Australasian Flyway. Estuarine habitats such as Sungei Buloh Wetland Reserve, Pulau Ubin, and Pulau Tekong are key staging and refueling points for waders migrating between the northern and southern hemispheres during the months of September and March (Lim and Lim 2009). These tidal mudflats also occasionally host a variety of endangered migratory species such as the Chinese Egret (globally vulnerable to extinction) and the Great Knot (globally Endangered) (Wells 2006; Lim and Lim 2009).

Large shorebirds such as herons and egrets, as well as smaller birds such as kingfishers and terns, feed on the various fish species that can be found in coastal and estuarine waters. The nationally endangered Great-billed heron (Davison et al. 2008), for instance, can often be found foraging for fish in shallow waters off Chek Jawa, Sungei Buloh, and the Southern Islands. Coastal habitats also support colonies of breeding birds in Singapore (Lim and Lim 2009). The globally near-threatened Malaysian plover (IUCN 2018) and the Little Tern breed on sandy shores in Singapore (e.g. Tuas, Marina East, Pulau Semakau) (Cheah and Ng 2008; Lim and Lim 2009) while Black-naped Terns and Bridled Terns breed on rocky outcrops off the waters of Changi and at Pedra Branca, respectively (Deng et al. 2008; Singapore Bird Group 2014).

Further away from the shore, the busy open waters of the Straits of Singapore also plays host to a variety of migratory pelagic bird species. Recent studies have shown that the Straits of Singapore is a key migratory passage for the globally Near-threatened Swinhoe's storm petrel, with upwards of 500 individuals passing through the straits from their breeding grounds in the Korean peninsula to the Indian Ocean in the month of September (Poole et al. 2011, 2014), as well as the globally Vulnerable Aleutian tern (Poole et al. 2014). The relatively recent discoveries of Bulwer's Petrel, Pomarine Jaeger, and Long-tailed Jaeger migrating through the Straits of Singapore further suggests that more species remain to be discovered migrating through territorial waters of Singapore in the near future (Poole et al. 2014; Singapore Bird Group 2018).

2.3.21. Mammalia: Otters

Two species of otters have been reported in Sinapore— the smooth-coated otter *Lutrogale perspicillata*, and small-clawed otter *Aonyx cinereus*. The former is the dominant species occurring throughout the mainland and offshore islands; in mangrove, coastal, esturarine, reservoir, and urban habitats (Theng and Sivasothi 2016; Khoo 2017). Since the emergence of resident smooth-coated otters in Sungei Buloh Wetland Reserve in the late 1990s, the population has expanded across the island, to about 79 individuals (Theng and Sivasothi 2016). Increasing population size is likely a result of migration from neighbouring Southern Johor. In Singapore, recovering coastlines after decades of development, cleaning up of polluted rivers making way for healthy fish prey populations, and an effort to green artificial waterways, are likely factors to facilitate colonisation of otters (Public Utilities Board 2010, 2014; Theng and Sivasothi 2016; Theng et al. 2016).

With a healthy and breeding smooth-coated otter population, human-otter conflicts are on the rise (Khoo 2017). Management of these issues is under the purview of the Otter Working Group, a partnership between the National University of Singapore, National Parks Board, Wildlife Reserves Singapore, other government agencies, institutions, and representatives of the public, which have taken pre-emptive measures to prevent such scenarios. Measures include the erection of signages on appropriate behaviour in areas of otter presence, and establishing presence on the ground when a 'crisis' situation arises to guide actions and manage reactions from the public (e.g. territorial fights in urban areas, exploration onto busy roads). Long-term measures to aid otter conservation include community involvement and raising awareness about otter ecology, behaviour and population dynamics through social media, educational campaigns and talks. This could potentially aid in allaying fears of overpopulation, or otters being a dangerous animal/pest species.

There has been a shift in the community involvement in otter research over the past decade. Before 2012, research relied largely on record submissions from independent sources, most of which were from naturalists and institutions (Theng and Sivasothi 2016). As otters gained visibility in areas of high visitorship and on social media, the community saw the involvement of more members of the public that have formed closely-knit networks of enthusiasts who share information about the day-to-day movements of several otter groups (Khoo 2017). They have since been a strong pillar of support to local researchers, with whom up-to-date information about group structure, movements, behaviour and even ecology, are shared with. Coupled with the increased visibility of otters in the recent four years, the community has facilitated further research into species ecology (e.g. home range, population status, behaviour, genetics) that contribute to a better understanding of the species and of co-existence with wildlife in urban landscapes.

The highly visible population of otters in Singapore has drawn global attention in the form of both local and international documentaries (e.g. BBC Planet Earth II, Wild City Singapore), news (e.g. BBC News, The Straits Times) and social media (e.g. OtterWatch, The Dodo, Mothership), putting her on the map for hosting charismatic wildlife in a city. In riding on this story of conservation success, Singapore is well-positioned to play a larger role in otter conservation in the region with her financial resources and infrastructure. This manifested in the form of hosting the 13th International Otter Congress (by the IUCN Otter Specialist Group), provision of funding for small projects and the potential hosting of training workshops that aim to spark otter conservation work in other parts of Southeast Asia. These are efforts that should be continued to aid in reversing the grim declines in otter populations elsewhere in the region (Pacifici et al. 2013), driven primarily by loss of wetland habitat, wildlife trade and conflict with fishermen (de Silva et al. 2015).

In the next decade, local population recovery of small-clawed otters, which were once common prior to the 1960s (Sivasothi 1995), ought to be the focus of otter species conservation in Singapore. Such an effort already undertaken by the National Park Board's (Pulau Ubin) species recovery programme (National Parks 2016). This effort should be highly structured and best commissioned as a study, which should first aim to fully understand the limiting factors and threats to the species' establishment in Pulau Ubin that can then inform subsequent management actions needed to raise the probability of recovery success (NOAA Fisheries 2016).

2.3.22. Mammalia: Dugong

The dugong (*Dugong dugon*), also known as the 'sea cow', is a large herbivorous marine mammal listed as 'Critically Endangered' in the Singapore Red Data Book (Davison et al. 2008). Dugongs are elusive and rarely observed. Only three unconfirmed wild sightings of the dugong in Singapore were reported since 2000; all were along the Johor Straits. The most recent sighting, accompanied by low-resolution photographs, was in 2013 was at Tanjung Chek Jawa in Pulau Ubin. In 1998, a female dugong calf was rescued near Pulau Ubin, swimming close to her mother. The latter drowned after being entangled in a net (Chew 2009). The calf was rescued and adopted by Underwater World Singapore where she remained until her death in 2014.

Dugong parts and carcasses are also occasionally encountered along coastal areas of Singapore. Five entire adult carcasses have been washed since 1972. The two most-recent carcasses in 2002 and 2006 were dissected, and the bones retained at the Lee Kong Chian Natural History Museum. In addition, gut contents of the specimen from 2006 was visually analysed and weighed. On March 2011, members of the public on a guided walk by Nature Society Singapore found a dugong tusk in its bone casing on Changi beach.

A study conducted in Malaysia, along the Johor Straits, mapped the distribution and abundance of dugongs via polling of the fishing community; and found that the southern tip of the Straits is 'the most critical habitat for dugongs' (Hashim et al. 2017). However, little is known of dugongs in territorial waters of Singapore. Unconfirmed dugong feeding trails suggest that seagrass meadows in Singapore may be supporting a population of dugongs. Formal scientific study is underway to confirm if these trails can be attributed to dugong foraging bouts.

2.3.23. Mammalia: Cetaceans

The Indo-Pacific humpbacked dolphin, *Sousa chinensis*, is the most common cetacean within territorial waters of Singapore. Divers and users of Southern Islands of Singapore regularly report sightings of small pods, typically fewer than ten individuals. The ecology of this species within Singapore is unknown.

In 10th July 2015, the carcass of a sperm whale, *Physeter macrocephalus*, was found off Jurong Island. This marks the first record of this species reported from Singapore. The female specimen measured 10.6 m and autopsy confirms a potentially fatal wound to the caudal area. This injury is likely due to collision with a large vessel. Further examination of the gut reveals plastic wastes. The skeletal remains of whale are on exhibit at the Lee Kong Chian Natural History Museum, accompanied with an excellent info-display.

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CHAPTER THREE

ECOLOGICAL COMMUNITIES

3.1. INTRODUCTION

Singapore contains a wide range of coastal and shallow-water habitats which host numerous benthic and pelagic communities. Coral reefs fringing many islands south of the mainland are home to rich communities of corals, fish, invertebrates and algae, but other benthic habitats in the subtidal and intertidal environments such as the sedimented seafloor, seagrass meadows, mangroves and sandy shores also harbour unique sets of fauna.

3.2. SUBTIDAL BENTHIC COMMUNITIES

The subtidal benthic habitat is a complex ecosystem, comprising a great diversity of animals. Some of these animals burrow into the sediment, aerating the deeper layer of sediment in the process, which facilitates the degrading of pollutants by marine bacteria (Hutchings 1998; Rosenberg 2001). Some benthic polychaetes can also absorb heavy metals in the sediment and convert them to less toxic forms in their guts (Dean 2008). Organic materials such as phytoplankton detritus that settled down from the water column are consumed by deposit-feeders and filter-feeders which, in turn, are very important food sources for larger animals. Some of these larger animals occupy a high position in the food chain and are economically important species for humans. The benthic community thus serves critical links between the seabed and the water column. The benthic community is also an ideal tool for assessing environmental disturbances (Dean 2008) because of its attributes, including the high diversity of species, differential sensitivities of each species to disturbances, and high availability of sessile or slow-moving animals that are unable to escape from their local environment. Changes in the community structure as a response to pollutant stress could be used to determine the severity or type of disturbances; acute disturbances often cause the more sensitive species to die off while chronic disturbances drive slow and gradual declines in abundance and diversity (Pearson and Rosenberg 1978; Rosenberg 2001).

The waters in Singapore are very shallow and depths of more than 50 m are restricted to the boundary of our port limit along the Singapore Strait. The deepest point of Singapore's seabed, the Singapore Deeps, has a depth of about 200 m and is located at the southeast of Kusu Island (Hill 1968). A large part of the Singapore's marine subtidal seabed is made up of soft sediment and much lesser proportion of seabed is made up of coral rubble and gravel-sand around the deeper end of the Singapore Strait (Tropical Marine Science Institute 2015). The sandy substratum of the Singapore seabed as described by Hill (1973) have since changed to one of predominantly soft muddy sediment due to extensive coastal development, maintenance dredging of navigational channels and land reclamation (Tan et al. 2010). Clarity of our marine waters is impacted as a result, and visibility of water now averages less than 3 m (Toh et al. 2015).

Few studies have been done on the subtidal habitats of Singapore, partly due to the high cost of sample collection (e.g. specialised equipment, research vessel, diving skills, etc.), labour-intensive sorting of samples, and trained expertise required in identifying organisms. Many of the earlier subtidal benthic studies in Singapore were taxonomic, with the first large scale regional biodiversity project, ASEAN-Australia Living Coastal Resources (LCR) conducted from 1986 to 1994. The earliest ecological study on subtidal benthic community in Singapore was by Lee (1973), and since then, there have been very few studies conducted for the subtidal benthos as compared to other marine habitats in Singapore. Some earlier studies were simple surveys of occurrence and distribution of benthic fauna but the areas covered were limited (Lim and Koh 1990; Lim and Gan 1990; Khoo 1990; Chung and Goh 1990; Chuang et al. 1992; Sachidhanandam and Chou 1996). Others studied the change in benthic community with environmental changes over time (Chong and Chou 1992; Goh et al. 1994; et al. 2002; Chou et al. 2004; Lu 2005a, 2005b).

More recently, as part of the Comprehensive Marine Biodiversity Survey (CMBS), more than 350 surveys were conducted in virtually every subtidal seabed in the Johor and Singapore Strait, from depths of 5 to 200 m. More than 1,100 species and morphospecies have been recorded from the subtidal benthic habitats. This list includes new species of sponge (*Theonella laena*), kinorhynchs (*Centroderes impurus*, *Echinoderes annae* and *Leiocanthus nagini*), crabs (*Mariaplax galaxeaei* and *Tritodynamia serratipes*), squat lobster (*Galathea johnsoni*), isopods (*Odysseylana sakijang* and *Odysseylana temasek*) and copepods (*Enalcyonium kohsiangi* and *Pennatulicola robustclavus*) that were described in recent years (Anker and Ng 2014; Rahayu and Ng 2014; Sidabalok and Bruce 2015; Uyeno 2015; Lim and Tan 2016; Lin and Osawa 2016; Sørensen et al. 2016; see Figs. 3.1-2). Other notable findings include the rediscoveries of the neptune cup sponge *Cliona patera* and elbow crab *Daldorfia horrida* in Singapore after more than a century (Lim et al. 2012; Tan and Low 2013). At least 25 other locally threatened species were recorded, including the critically endangered snapping shrimp *Synalpheus stimpsonii* and crabs of the genus *Harrovia*, both which are closely associated to crinoids. The project has also identified hotspots of several rare animals, such as barrel sponge (*Xestospongia testudinaria*) gardens with high density of crinoids along the Sisters Fairway and at the southeast of Jurong Island, the long hydroid *Monoserius pennarius* along East Coast, protobranch bivalves at the southeast of Pulau Ubin and the basket star *Euryale aspera* at the southeast of Kusu Island (Tropical Marine Science Institute 2015). The elusive basket star was presumed to be rare according to the Singapore Red Data Book (Davison et al. 2008). These findings were published in the proceedings of two international workshops organised for the CMBS, one for the Johor Strait in October 2012 and another for the Singapore Strait in May 2013. Local capabilities of local scientists were raised during this project, which is a successful example of an inclusive exercise involving academics, government agencies, corporations and the general public.

Figure 3.1. *Tritodynamia serratipes*, one of more than 1,100 species recorded from the subtidal benthic habitats during the Comprehensive Marine Biodiversity Survey

Figure 3.2. *Galathea johnsoni*, one of more than 1,100 species recorded from the subtidal benthic habitats during the Comprehensive Marine Biodiversity Survey

A separate biodiversity assessment at a high wave energy area adjacent to Southern and Sisters Fairways was carried out in 2016. It was the first of its kind focusing on hard substrate benthos and using the photographic quadrat. Preliminary results revealed relatively high species biodiversity and patchy seabed even within a small area of 1.78 km^2. Some areas (up to 40 m depth) had very little silt, comprising of large particles or biogenic rubbles, while areas nearer the fairway (30 to 60 m depth) appeared to be heavily silted with fauna-encrusted sedimentary rocks. The area with sedimentary rocks recorded higher diversity of small invertebrates, suggesting that unevenly-shaped rocks may provide crucial microhabitats for small crustaceans, brittle stars, and polychaete worms. A total of at least 504 species/morphospecies of invertebrates were identified. Polychaetes turned out to be the most speciose and abundant fauna group, amongst which a high number were commensals associated with hydroids and crinoids and also rock burrowers. The survey also recorded interesting findings on the lancelets in Singapore including *Epigonichthys cultellus*, which is a new local record for Singapore, and *Branchiostoma belcheri*, which was thought to be locally extinct (Lee et al. 2016). Two species of conservation interest that were encountered included the vulnerable seastar species *Iconaster longimanus* (Davision et al. 2008) and the critically-endangered crabs of the genus *Harrovia*, which are closely associated with crinoids. Red sea fans or gorgonians are not very common in our waters but were also found in the deeper areas surveyed. This survey also found a population of barrel sponge (*Xestospongia testudinaria*) within the study area, as observed during the CMBS (Fig. 3.3).

Figure 3.3. *Xestospongia testudinaria* forms sponge gardens with high densities of associates including crinoids, hydroid *Monoserius pennarius*, protobranch bivalves, and basket star *Euryale aspera*. Photograph by Lim Swee Cheng.

Even though the CMBS project had extensive nautical coverage, most areas were surveyed only once. This is problematic for establishing an understanding of the benthic community due to the dynamic nature of the abiotic and biotic parameters that changes over time. The lack of local experts and funds also hinder the progress of taxonomic research as many specimens are still left unidentified. Logistical challenges such as the availability of suitable equipment, working in turbid waters, existing maritime restrictions also placed limitations on the sampling effort. For a survey of such massive scale, a longer study period will also enable the collection of qualitative and quantitative data useful for ecological analysis. It was also very challenging when using heavy instruments such as dredges and trawls along the Singapore Strait, due to the exceptionally high traffic of large and fast-moving vessels. The turbid water caused by high level of sediment movement also made surveys using SCUBA diving difficult. Our sampling instruments were often entangled and damaged by natural structures (e.g. rocky outcrops and large boulders) and large marine trash (e.g. rubber tyres), resulting in damaged equipment and lost time.

Benthic communities are threatened by intense coastal reclamation, development, and maintenance dredging of shipping lanes and terrestrial runoffs. These processes alter the hydrodynamics of the waters and increase sediment input into the sea. Increased sedimentation can result in smothering of benthic animals and dredging leads to the removal of the substratum and the animals associated with it (Hendrick et al. 2016; Miller et al. 2002; Newell et al. 1998). Land reclamation can also decimate entire communities by direct burial. These impacts have been described in Chong and Chou (1992) and Lu et al. (2002) following reclamation works in Sungei Punggol in the 1990s. Few published studies on the impact of disturbance (physical or biological) are available for our local benthic fauna. Earlier literature on the presence of heavy metals in Singapore marine sediment had indicated that high concentrations of heavy metals were present in the industrial areas around Jurong Island, East Johor Strait and Keppel Harbour (Orlic and Tang 1999; Tang et al. 1998; Chua et al. 1998). More recently published data by Coung et al. (2008) indicated a decrease in heavy metal concentration but is overall still higher in the Johor Strait (Zulkifi et al. 2010). Studies on the presence of Persistent Organic Pollutants (POPs) in Singapore marine sediment were also scarce and focused mainly in the Northeastern and Southwestern regions of Singapore (Obbard et al. 2007; Wurl and Obbard 2006, 2005; Basheer et al. 2003). Ecological studies on how the benthic community responded to those levels of environmental contaminants were however sorely absent.

The Singapore Red Data Book (Davison et al. 2008) has identified several species from subtidal benthic habitats that are threatened ("vulnerable" to "presumed nationally extinct") in local waters. These marine animals include the sea whip *Junceella gemmacea*, the clavagellid bivalve *Brechites penis*, several species of small crustaceans (i.e. *Porcellanella picta*, *Favus granulatus* and *Elamenopsis rotunda*) and many large echinoderms (i.e. *Iconaster longimanus*, *Anthenea aspera*, *Luidia maculata*, *Luidia penangensis*, *Chaetodiadema granulatum*, *Laganum depressum* and *Euryale aspera*). Localities where remaining populations of these species are found such as the subtidal habitats off Chek Jawa and the Southern Islands can perhaps be offered more protection. While conducting field work during the CMBS survey, large amount of trash was found along the Johor Strait especially close to the Woodlands Causeway, causing smothering of the sediment and creating a zone of anoxic sediment. Illegal dumps in the form of rubber tyres were also found during dredging and trawling surveys around the Singapore Strait.

To curb further losses of benthic communities, these habitats need to be included in environmental monitoring programmes both locally and around the world. A complete inventory of all subtidal benthic fauna, with focus on understudied taxa can aid in a more thorough understanding of our marine environment. A long-term research programme will enable timely collection of faunal and habitat information, providing a better grasp on the health of our benthos. This could further enable us to generate local benthic biological indicators and sediment quality indices to more accurately detect the effects of any anthropogenic pollution effects on our benthos and its connected marine ecosystem. It could also be an early warning system for any transboundary issue and potential dead zones in local waters.

A volunteer programme could be developed to provide much needed manpower in the field and laboratory and at the same time create interest in this field of research with the general public. Including more training in marine zoology and taxonomy as part of Singapore's academic journey can also allow us to increase local capability in this area. Studying the benthic community (including sandy shore, mudflats, mangrove, etc.) is after all, the only way where biologist will see most marine phyla.

3.3. MANGROVE AND SANDY SHORE CRAB COMMUNITIES

Mangroves and sandy intertidal shores constitute some of the major habitats inhabited by crabs in Singapore and around the region. The conditions in these habitats are extremely harsh—with high winds, drastic daily changes in temperature and salinity, and physiologically dry. Despite so, brachyuran diversities of these shores are comparable to, if not more than, that of coral reefs (Tan and Ng 1994). The crab assemblages in these ecosystems play important ecological roles. For instance, mangrove crabs (e.g., ocypodid and sesarmid crabs) are known nutrient recyclers and bioturbators (see Robertson, 1986; Lim and Heng, 2007), while lagoonal and sandy-shore crabs (ocypodid and dotillid crabs) function mainly as bioturbators (see Bradshaw and Scoffin 1999; Lim 2006). Because of their functional significance in the ecosystems, studying their ecology permits the inference of health of the shoreline (see Yong and Lim 2009), which is of management relevance.

As detritivores, mangrove crabs break down organic matter in the mangroves and speed up nutrient cycling. In addition, they are an important food source for animals of higher trophic levels. For example, diet studies of the giant mudskipper (*Periophthalmodon schlosseri*) and the yellow-spotted mudskipper (*Periophthalmus walailakae*) reported a high dominance of mangrove crabs (approximately 90%) in their diets at the Lim Chu Kang mangroves (Su and Lim 2016). In turn, these mudskippers are potential prey items for larger and apex predators. As such, understanding mangrove crab assemblages can be useful in extrapolating on the health of a forest. In another study, it was observed that soldier crabs are capable of coping with human disturbance when sharing sandy shores allocated for recreational activities (see Chen et al. 2017). However, this ability to adapt is limited, suggesting that holistic coastal management is the key to a healthy sandy intertidal ecosystem, while allowing for recreational activities. Mangrove crab assemblages are being studied for their use as bioindicators to assess the ecosystem functionality of the mangroves. This study, among others, will unquestionably allow for more informed decisions when developing or restoring our coastlines.

Apart from direct coastal reclamation and development, oil spills are the most serious threats to intertidal crab communities. For instance, in January 2017, two tankers collided at the Pasir Gudang port in Malaysia, spilling over 300 tonnes of oil into the Straits of Johor. The oil affected the northeastern shores on mainland Singapore as well as intertidal shores on Pulau Ubin, threatening numerous fauna, including soldier crab (*Dotilla wichmanni*) populations along Changi Beach Park (Fig. 3.4). In a separate event, a major oil spill in 2010 extirpated populations of the horn-eyed ghost crabs (*Ocypode ceratophthalmus*) in East Coast Park (see Yong and Lim 2015). Governmental authorities implemented mitigation measures promptly after the events where the oil-stained sand was scraped off and disposed. These measures were likely effective in alleviating the impact of the oil spill on the sandy shore ecosystem. In the soldier crab populations, crab densities showed signs of recovery two months post-spill and juveniles (smaller-sized individuals) were also recorded (see Su et al. 2017). For the horn-eyed crab populations, crabs were observed approximately three months after the event although individuals occurred higher along the intertidal gradient, possibly to avoid the residual oil in the sand (see Lim and Yong 2015). Therefore, while sandy shore crab populations are highly sensitive to oil deposition on the shores, they show high rates of recovery making them excellent biomonitors of such events (see Gomez et al. 2000).

Figure 3.4. Soldier crab *Dotilla wichmanni* at northeastern Singapore and Pulau Ubin was affected by the 2017 Pasir Gudang oil spill. Photograph by Theresa Su.

To make informed management decisions for any ecosystem, the components of the habitat should be investigated so as to infer about its current state of health, possible sources and sinks, and hence extrapolate its future potential. It is possible to determine the health of the mangroves and sandy shores from the crab assemblages inhabiting in these ecosystems. However, comparisons of habitat responses after an intervention or event are only achievable when baseline data is available. Therefore, we should always encourage ecological research work at various time points that permits charting of population dynamics of these organisms and hence determine ecosystem health. To do so, strong communication and cooperation between research groups and relevant authorities should be fostered. This would provide the support for research in the various localities, especially in the collection of time-sensitive data (e.g., after an oil spill).

3.4. REEF CORAL COMMUNITIES: POPULATION HISTORY AND PHYLOGENY

Corals in Singapore thrive in a sediment-burdened environment as a result of coastal development and land reclamation. Large amounts of sediment (as high as 44 mg cm^{-2} day^{-1}; Low and Chou 1994) released into the marine environment have caused adverse impacts to corals by direct smothering and reducing light penetration to the benthos (Erftemeijer et al. 2012). This has contributed to a tremendous decline in coral cover since the 1960s (Chou and Tun 2012). Despite the degraded state and being subjected to high levels of disturbance, Singapore reefs still harbour nearly 200 stony coral species, roughly 25% of the world's total (Huang et al. 2009). Although the biology and ecology of these organisms have been widely studied in Singapore, little is known about their population histories and demography.

Not much is known about how coral reefs in Singapore came into being. During the late Pleistocene Epoch (about 20,000 years before present (BP)), waters around modern day Singapore was part of the exposed Sundaland, and seawater was only found to have reached around the current mean sea-level after the Postglacial Marine Transgression (PMT) during the mid-Holocene about 6,500 years BP (Hesp et al. 1998). It is possible that this was the time when coral reefs in Singapore started to establish. However, the larval source of these early coral populations is open to debate. A study on the flooding of Sundaland as the result of PMT in and around Singapore (Sathiamurthy and Voris 2006) showed that the larval source for the early settlers might come from three different directions: (1) northwest, i.e. The Straits of Malacca and the Andaman Sea, (2) southwest, i.e. the Java Sea and Makassar Straits, and (3) northeast, i.e. South China Sea, and the Gulf of Thailand. Identifying the larval source of the early coral populations and ultimately deducing the levels of population genetic structure of Singapore's reef to these adjacent populations will provide vital information for reef management and conservation, both locally and around the region.

Understanding local levels of population genetic structure is essential in the view of sustainable management and effective conservation of coral reefs in Singapore. Using several microsatellite markers, Tay et al. (2015) showed that, there is high level of connectivity among populations of the brain coral, *Platygyra sinensis*, in Singapore. There is an urgent need to test whether these patterns extend to other coral species, and whether genome-wide data will show similar or complementary trends. Moreover, assessing levels of genetic diversity from genomic data is essential to gauge the resilience of coral populations and improve best practices in restoration efforts, which is one of the few effective mitigative measures in coral reefs conservation (Baums 2008; Shearer et al. 2009; Barshis et al. 2013).

Genomic data may also be used to infer past and present effective population size and gene flow of Singapore's reef and the reefs around the region. Understanding effective population size and gene flow ultimately allows us to make better decisions for planning management and conservation strategies (Gasca-Pineda et al. 2013). We hope that we will be able to use genomic data to deduce population genetic structure, levels of genetic diversity, past and present effective population size and gene flow of stony corals in Singapore's reefs as well as selected reefs around the Indo-Malay Archipelago within the next few years.

At a broader and deeper level of the history of corals is the field of phylogenetics, which involves the tracing of species history through time and determining their evolutionary relationships with closely-related species. Evolutionarily, stony corals all belong to the same group – Scleractinia – which comprises over 1500 species, spread across the world, in shallow and deep waters (Huang and Roy 2015). Corals were traditionally classified based on their physical form (morphology), it is known that they can exhibit high levels of morphological variation among members of the same species, which could be due to genetic or environmental factors, among others (Todd 2008). Coupled with the lack of phylogenetically informative characters, the taxonomy and phylogeny of corals have stymied scientists for some time, prior to the advent of molecular genetics (Budd et al. 2010; Kitahara et al. 2016).

In the last two to three decades, the phylogeny of Scleractinia has been revolutionised by molecular data, which when combined with morphological data, provided us with much clearer insight into the evolution of corals. With the first few sets of molecular data, scientists realised that the phylogeny of coral is vastly different from that which is based on molecular data, as proposed by Wells (1956). With a handful of genes, the coral phylogeny all seemed to follow the same general pattern: there appears to be three distinct groups – "robust", "complex" and "basal" (Romano and Palumbi 1996; Huang 2012). Yet despite great leaps in our understanding of the phylogeny, the issue of patchy sequencing and uneven distribution of information is still hindering our understanding, and there remains much work to be done (Budd et al. 2010; Kitahara et al. 2016). For example, while members of the Robust group are better studied (Budd et al. 2012; Huang et al. 2014a, b), research into the "complex" groups have been lagging behind (Kitahara et al. 2016).

To compound the problem, very low research efforts focus on the sampling, taxonomy and phylogeny of Southeast Asian corals by regional universities and institutions. Regionally, we lie close to the Coral Triangle: a wonderfully diverse region, alone with which there are more than 600 species of hard corals, not to mention the associated fauna (Kassem and Madeja 2014; Huang et al. 2015). Given the incredible array of organisms living in a complex web of life right at our doorstep, the lack of research progress in this region should motivate the training of more systematists to help discover the stunning biodiversity and help guide conservation policies.

Today, we have a new but severely underutilised tool to help us better understand the phylogeny of corals better. We have entered the era of next generation sequencing (NGS), the era of big data. We can now generate vast amounts of sequences for a fraction of the cost of traditional sequencing. This new field is termed as phylogenomics – using genomic data (rather than single genes) to build a phylogeny. However, because this tool is still in its infancy stage as compared to the sequencing of humans, there remains much work to be done in building up the foundation for utilising this tool, which requires manpower and money. There have been efforts to kick-start it; a look into the literature will reveal several teams working on the new field: phylogenomics of corals and other related taxa (Kitahara 2017; Quattrini et al. 2017; Wang et al. 2017). Once again, these are headed by people from outside the region, and it would be good to increase our profile and efforts into the phylogenomics of corals over in Singapore.

But why is phylogeny important for conservation? Firstly, phylogenies give us insight into a biodiversity measure known as "phylogenetic diversity". While most of us are familiar with species richness—the measure of how many species there are in an area, and how many of each species, phylogenetic diversity (PD) is the esoteric cousin that is concerned with quantifying diversity based on the evolutionary relationships between members of a community (Faith 1992). Rather than simply using total species in an area as a measure for conservation, PD aims to protect the species that are evolutionarily and taxonomically most distinct from the other members, and also incorporates other data such as functional and evolutionary diversity into the matrix, and has been used for corals (Huang and Roy 2015; 3.5).

This gives a more complex but holistic picture for guiding conservation efforts, and looks beyond simply preserving total numbers of species (Huang and Roy 2015). Interestingly, it has been found that while the Coral Triangle has among the highest corals biodiversity, when projecting using potential loss of coral areas based on anthropogenic impacts, it was some species-poor areas that may have higher priority for conservation based on ED, with a much smaller loss of ED projected in the coral triangle (Huang and Roy 2015). We know little about the PD in our reefs, and with more robust phylogenetic trees, we can do more in our efforts to maximise the PD for conservation and demarcate areas effectively (Rodrigues and Gaston 2002; Winter et al. 2012).

Phylogenies, through providing data about our past, can give us insight into the future too. For instance, through certain techniques, we can determine how old corals are on a geologic scale, and by correlating with paleo-environmental data, we can test hypotheses see how different taxa will be affected in the impending climate change scenario (Kitahara et al. 2017). Corals that are susceptible to bleaching also tend to be close relatives, and we can better direct our resources by using robust phylogenies as a guide for conservation (Huang 2012). It is inevitable that with rising global carbon dioxide levels, there will be increased global sea surface temperatures and ocean acidification, which will have severe, adverse impacts on corals around the world (Huang 2012; Hughes et al. 2017). As Hughes et al. (2017) advocates, we need to expect different communities of corals in today's reefs, and ensure that the biological and ecological functions of corals are maintained in our uncertain future. Through phylogenetic knowledge, this would be a useful tool in guiding our policies in Singapore.

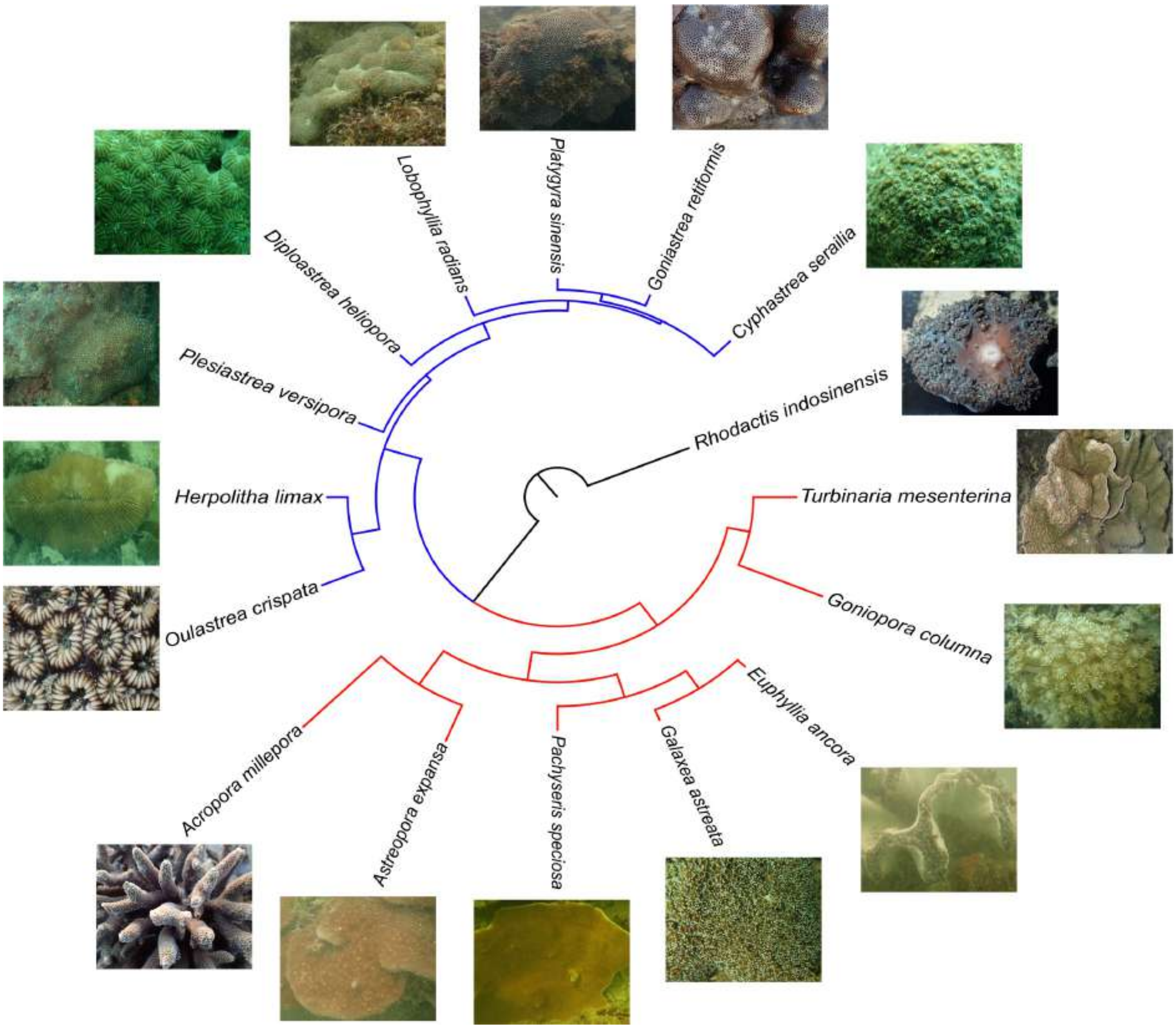

Figure 3.5. Phylogeny of 16 corals found in Singapore, with *Rhodactis indosinensis* (Cnidaria: Anthozoa: Corallimorphia) as outgroup. Blue and red lines represent members of the "Robust" and "Complex" clade respectively. This tree is reconstructed based mostly on DNA sequences recently sequenced for a NGS study by Reef Ecology Lab (NUS). (Photo credit: Neo Mei Lin, Oh Ren Min, Randolph Quek and Sudhanshi Jain).

Citizen science are usually field-based and the involvement of citizen scientists are often difficult in a laboratory setting, especially when it comes to molecular work. However, the diving community in Singapore can definitely be involved with future population and phylogenetic work by helping scientists collect relevant coral tissue samples. With little training on the collection methodology and targeted coral species identification, volunteer divers can help reduce scientist's workload in the field. This has been done elsewhere and has been proven to succeed. For example, the Underwater Research Group (URG) of New South Wales in Australia, a group of citizen scientists, have helped with the identification and collection of tissue samples from the weedy sea dragon for genetic studies (Turnbull 2015). A similar approach can be employed in Singapore with active involvement of the diving community in genetic studies. This will not only increase the awareness towards the importance of such work among the members of the public, but also bridge the gap between citizen scientists and marine biologists. This can only bring benefit to the conservation and the better management of coral reef particularly in Singapore.

Access to certain localities are still restricted, impeding our ability to have a holistic understanding of Singapore coral reef's ecosystem. For example, it is still very difficult to gain access to the live-firing areas to do monitoring surveys or collect tissue samples for genetics work. Channels that may provide opportunities access restricted areas could aid in further research being done on reef organisms found in these areas and in turn, assist in the overall conservation of Singapore's coral reef.

3.5. REEF FISH COMMUNITIES

Coral reefs are also home to the most diverse fish community in the world, consisting of more than 4000 species (Lieske and Myer 1994; Allen et al. 2008). Reef-building corals are essential components of the complex habitat frameworks that support a vast fish diversity of fishes (Chong-Seng et al. 2012). Some coral reef fishes play an important role in maintaining reef health conditions, for example, herbivorous fishes, a groups of fish species that feed on algae (e.g. parrotfish and rabbitfish), reduce competition between corals and algae as well as preventing a phase shift to algae-dominated degraded reefs (Hughes et al. 2007; Green and Bellwood 2009). However, coral reefs worldwide are under direct threats of local (e.g. overfishing, coastal development and pollution) and global stressors (e.g. ocean warming and acidification) (Burke et al. 2011; Roger et al. 2014). Although only 8% of coral reef fish species directly depend on live corals (Coker et al. 2014), most fish species would be negatively affected if losses of local coral cover and structural complexity occur (Prachett et al. 2011).

In Singapore, more than 100 coral reef fish species have been recorded in coral reefs off the southern islands (Low and Chou 1992; Taira et al. 2017). Declines in coral reef areas, primarily associated with intensive coastal urbanisation and more recently with mass bleaching events (Guest et al. 2016), pose a major threat to the associated reef fish communities. Despite no direct evidence that these disturbances have adversely affected reef fish communities in Singapore, some studies implied that the potential impacts of coastal development have already been in place (Low and Chou 1992; Bauman et al. 2017; Taira et al. 2017).

While bleaching impacts on scleractinian corals have been relatively well documented in Singapore (Guest et al. 2012; Chou et al. 2016), those on other zooxanthellate biota and the associated fish species are seldom studied. Fish species with host or feeding specialisation are among the most vulnerable to such extensive reef degradations (Hawkins et al. 2000). Potentially vulnerable fish species in Singapore include obligate coral-feeding butterflyfish (i.e. *Chaetodon octofasciatus*) and host specialists on zooxanthellae organisms (e.g. *Gobiodon histrio* on *Acropora* spp. and Amphiprioninae on sea anemones; Fig. 3.6).

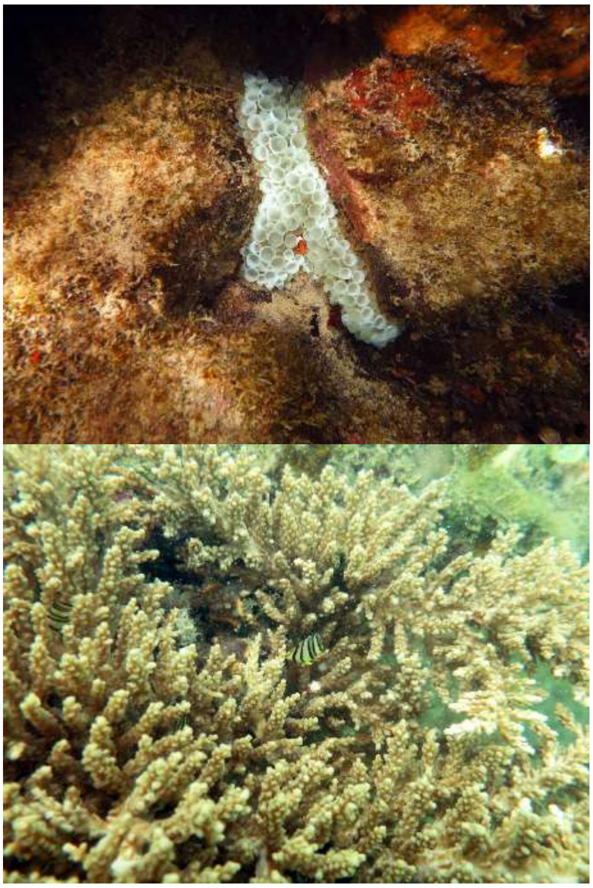

Figure 3.6. A tomato anemonefish (*Amphiprion frenatus*) in a bleached anemone host *Entacmaea quadricolor* (top) and an eight-banded butterflyfish (*Chaetodon octofasciatus*) swimming among *Acropora* corals (bottom).

Despite no commercial fishing, subsistence and recreational fishing activities, to a smaller extent, may contribute to the demographic distribution of commercially and ecologically fish species by removing large-size individuals from the population (Hawkins and Roberts 2004). Furthermore, "ghost fishing" - abandoned fishing traps and nets, has been observed at multiple reefs and caused unnecessary damage or death of fish trapped in them (e.g. Yeo 2014; Chim et al. 2015; see PII Chapter 5).

Various types of approaches have been implemented in Singapore to enhance reef-associated biodiversity, including fish (Ng et al. 2013). For instance, coral propagation and transplantation have also proven to effectively enhance coral cover (Bongioni et al. 2011; Afiq-Rosli et al. 2017; Toh et al. 2017). Deployment of physical structures such as artificial reefs, reef enhancement units (REUs) and underwater coral nursery tables can attract fishes for food and shelter (Low and Chou 1999; Taira et al. 2016; Ng et al. 2017). Manmade structures such as seawalls also support a variety of corals and the reef-associated fishes, but they need to be built with that in mind (Ng et al 2012; Toh et al. 2016; Taira et al. 2017). An increasing number of recent studies have investigated the topics related to conservation with attempts to understand how reef fish communities respond to human and environmental disturbances at various scales such as habitat connectivity, larval dispersal and response of coral reef fishes to human disturbances and climate change and effectiveness of Marine Protected Areas (MPAs) (Hixon et al 2011). However, such studies are highly limited in Singapore and this knowledge is of paramount importance for effective management of the remaining coral reef areas from local stressors and to build resilience to climate change impacts. The involvement of the public in conservation efforts will further promote Singapore's sustainable development. One such example in which public volunteers can participate include "Reef Friends", a coral reef monitoring project that contributed to new records of several fish species in Singapore (Low et al. 2009). Another example is "Project Driftnets Singapore (http://projectdriftnet.blogspot.sg/)" which aims to document the abandoned fish traps and nets across the coastlines of Singapore. In addition, regular local divers can also contribute to augmenting the Singapore's fish species list by documenting their observations in "Singapore Biodiversity Records".

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CHAPTER FOUR

ENVIRONMENTAL RECONSTRUCTION

4.1. RECONSTRUCTING LEAD LEVELS IN THE SINGAPORE STRAITS

Lead (Pb) is released to the environment mainly by emission of leaded gasoline and high temperature industrial activities (Nriagu 1989). Sources of lead into the marine environment include atmospheric deposition (Flegal 1986) and runoff from local industries (Komárek et al. 2008). Lead in natural archives such as long-lived corals provide a means to track long-term changes of Pb in the environment. Variation of lead and lead isotopes in coral skeleton vary closely with that of surrounding seawater (Kelly et al. 2009; Lee et al. 2014). During calcification, lead in seawater transported to the calcifying region can substitute for calcium into the carbonate structure (Shen and Boyle 1987). A major challenge, however, for successfully applying coral records as proxy for lead is external contamination. The concentration of lead in coral skeleton is extremely low such that even minute contamination from reagents, receptacles and laboratory environment could render results of analyses meaningless. Additionally, due to the particle-reactive nature of lead (Bacon et al. 1976), it is easily adsorbed onto the porous surface of coral skeleton (Shen and Boyle 1988) – another possible source for lead contamination (Reuer 1995) necessitating extensive cleaning of coral samples prior to analyses (e.g. Shen and Boyle 1988). Lead measured in corals from three sites around Singapore captured variability of lead in the Singapore Straits, including two periods that overlapped reclamation timelines of Bukom/Busing islands and Jurong Island (Figure 1; Chen et al. 2015).

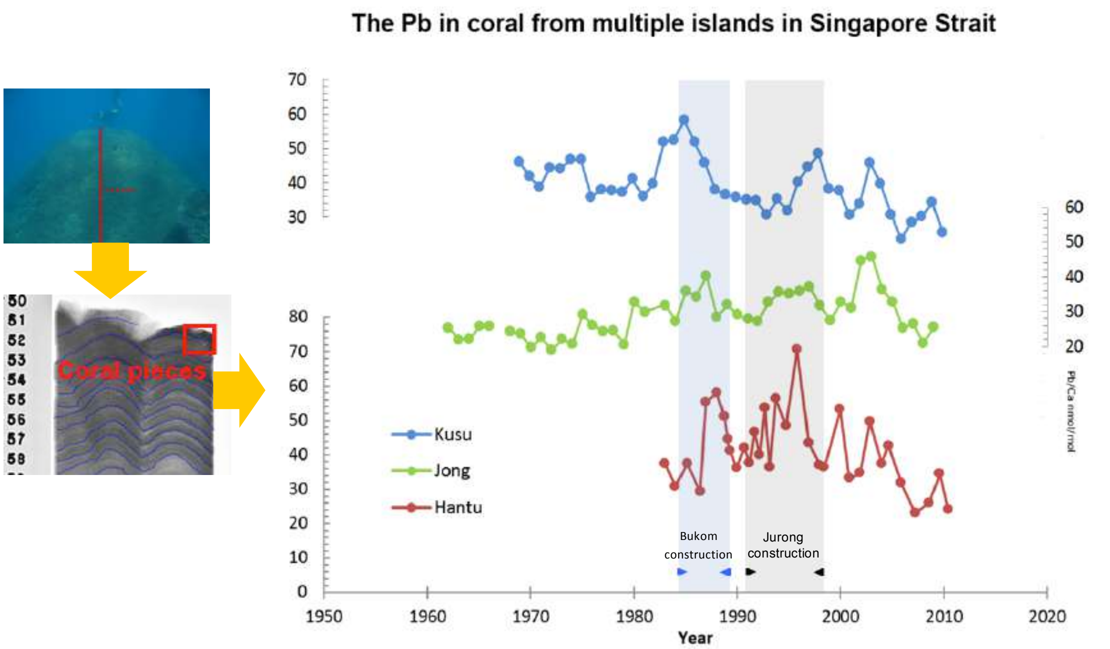

Figure 4.1. An illustration on the reconstructed Pb concentration in coral skeletons from multiple islands in the Singapore Straits. The blue shaded period was construction of Bukom/Busing island, and the grey shaded period was construction of Jurong island.

Multiple corals in the Singapore Strait coincidently show higher Pb/Ca values during the construction of Bukom/Busing islands and Jurong Island, especially from the corals in Pulau Hantu (Fig. 4.1).

4.2. PROXIES FOR RETROSPECTIVE TERRESTRIAL RUNOFFS

An elemental tracer broadly used as a proxy for changes to near-shore water quality driven by terrestrial/river runoff, coastal activities and proximal land use changes, is the ratio of barium to calcium (Ba/Ca) in coral skeleton (Alibert et al. 2003; Sinclair and McCulloch 2004; Fleitmann et al. 2007; Lewis et al. 2007; Carriquiry and Horta-Puga 2010; Maina et al. 2012; Moyer et al. 2012; Prouty et al. 2014). In coastal regions, flood events present the most robust relationship to coral Ba/Ca as they carry fresh sediment-laden water from rivers (Alibert et al. 2003; McCulloch et al. 2003; Sinclair and McCulloch 2004). Long-term trends as well as peaks in coral Ba/Ca have also been shown to closely match trends/peaks in skeletal luminescence (Alibert et al. 2003; Sinclair and McCulloch 2004; Grove et al. 2010; Lough et al. 2015), another coral record that correlates strongly with terrestrial riverine and freshwater inputs (Boto and Isdale 1985; Susic et al. 1991; Zicheng et al. 2002; Grove et al. 2010; Grove et al. 2012; Llewellyn et al. 2012, Tanzil et al. 2016). In Singapore, skeletal luminescence in long-lived massive *Porites* corals was found to be highly reproducible and track external sources of river-related freshwater runoff (Tanzil et al. 2016). Ongoing studies indicate that coral Ba/Ca ratios may be recording some variability in reef sediment-related flux, or closely related parameter/s, in Singapore reef waters. While proxy reconstructions are extremely useful, it should not be a replacement for on-site long-term environmental monitoring. For example, despite Ba/Ca being widely used as a tracer for terrestrial discharge, there is, however, still uncertainty surrounding its reproducibility and reliability (Saha et al. 2016). It is therefore crucial that direct comparisons between in-situ seawater measurements and coral proxies are made in order to ensure valid calibrations and reconstructions of any environment.

4.3. NUTRIENT CYCLING IN CORAL REEFS

Nitrogen isotope ($\delta^{15}N$) in coral provides useful information about changes in nutrient sources (Marion et al. 2005) and the efficiency of nutrient utilisation (e.g., Casciotti 2016; Cloern et al. 2002). It can therefore be used to better understand and reconstruct marine nutrient cycling. For example, changes in bulk $\delta^{15}N$ in corals obtained from the nearshore reefs in Bali recorded changes in chemical fertilizers used in Bali since the 1970s. More recently, coral skeletal-bound nitrogen isotope (as opposed to bulk) has been used to provide evidence for anthropogenic influence on marine nitrogen cycle (Ren et al. 2017). Skeletal bound $\delta^{15}N$ from a coral from the Dongsha Atoll, South China Sea, was used to show $\delta^{15}N$ anthropogenic nitrogen deposited through the atmosphere (Fig. 4.2), and skeletal bound nitrogen isotope from 8 locations around the world has also shown an almost 1:1 relationship world within ~2‰ precision with its nutrient source (Wang et al. 2016). There are, however, considerations that need to be taken when using $\delta^{15}N$, especially skeletal-bound $\delta^{15}N$, as a coral proxy. Analytical difficulties exist – the method for coral skeletal-bound nitrogen isotopes (CS-$\delta^{15}N$) has only been proposed recently (Wang et al. 2015; Wang et al. 2016). Furthermore, the N content in the coral skeleton is extremely low (~4nmol of N/mg of coral) and prone to contamination. Few reputable laboratories have thus far churned out and published reliable CS-δ^{15}N measurements (e.g. Erler et al. 2016; Ren et al. 2017). In Singapore, reconstruction of the marine nutrient cycling using coral skeletal nitrogen isotopes is underway, which would enhance our understanding of the linkages between terrestrial and marine environments. The reefs in Singapore are exposed to water from both South China Sea and Malacca Straits. Reversing monsoon currents allow for an intermittent record of riverine and oceanic waters (Pang and Tkalich 2003).

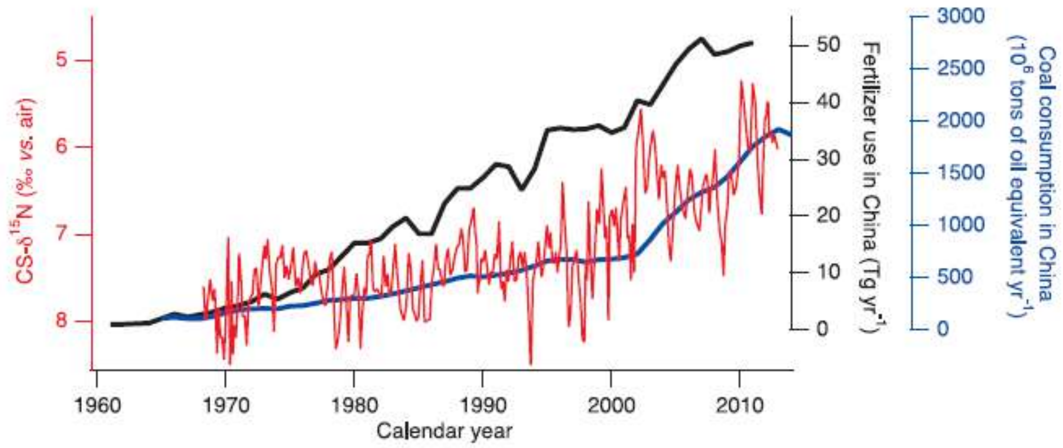

Figure 4.2. Comparison of the CS-δ^{15}N decline with two contributors to anthropogenic N emissions in China (Ren et al. 2016). Higher values of CS-δ^{15}N (red) are plotted downward.

4.4. METAL LIGANDS AS PROXY FOR RIVERINE ORGANIC MATTER

Trace metals are present in low concentrations in seawater, and only a fraction of which is bio-available. Metal bioavailability has great implications for metal bio-accumulation and/or bio-limitation of primary productivity. The presence of natural complexing ligands determines this biologically-active fraction (Sunda and Giullard 1976). A major source of natural metal complexing ligands (controlling metal speciation and bioavailability) in coastal seawater is riverine organic matter (Shank et al. 2004; Laglera and van den Berg 2009; Kim et al. 2015; Krachler et al. 2015; Yang et al. 2017). Using the coral records of metals and comparing them to riverine load proxies as detailed above, methods are currently being developed for reconstructing temporal bioavailability of metals in the Singapore Straits. Comparison of organic ligands measured in seawater vs. ligands in coral skeletons are being made to validate and assess the potential of this novel coral proxy. Reconstruction of long-term organic metal ligands will increase our understanding of metal bioavailability as they relate to riverine organic matter present in Singapore's marine environment.

4.5. REEF CORING: RECONSTRUCTING CORAL COMMUNITIES

Coral reef monitoring in the region and Singapore only begun in the 1980s with the ASEAN-Australia Living Coastal Resources project and continued with the later establishment of the Global Coral Reef Monitoring Network (Chou et al. 1994; Tun et al. 2008; Guest et al. 2016; Kimura et al. 2016). Even then, much of the historical reef research has focussed on coral reef and macroalgal cover, with even less work done on reef communities on the individual reefs. While species richness and diversity indices were investigated later on, the diverse forms of the different species are beginning to be known for their diverse functions and for their evolutionary history (Darling et al. 2012; Denis et al. 2017; Huang 2012; Madin et al. 2016). Coring into the coral reef matrix and retrieving samples sediments, coral skeletons, molluscs and gastropod shells can be used to potentially reconstruct past reef history (Perry et al. 2009; Morgan et al. 2016). These historical materials can be dated (e.g. using radiocarbon or uranium-thorium dating) to potentially reconstruct changes in reef community assemblage over time. As historical records of Singapore's past coral reefs are poor, reconstruction to such means could vastly improve our knowledge. Along with old photographs and written records, these would allow us to present a historical record of Singapore's reefs, identifying threats and impacts through time, and informing potential management decisions on conservation and restoration of reefs.

4.6. LONG TERM ENVIRONMENTAL VARIABILITY

Long-term monitoring provides an environmental baseline for understanding complex physical, chemical, biological and ecological responses to natural and human-induced environmental changes. Without long-term data sets, it will be impossible to capture natural variability occurring at longer time scales (inter-annual; decadal). Long-term environmental datasets should be collected using consistent field and laboratory methodologies (with documented quality control and quality assurance, laboratory analysis, and data archiving) and made available to scientists, agencies, resource managers, other stakeholders and the public. Long-term monitoring can ultimately help scientists and policy-makers better pre-empt changes to Singapore's sensitive marine ecosystems. Data from the long-term monitoring station can also serve in meeting Singapore's responsibilities under the international/national standards (e.g. WHO guidelines, environmental pollution standards/thresholds). Public open access long-term monitoring data will allow Singapore to actively contribute and be a part of international/global observation efforts.

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CHAPTER FIVE

THREATS TO THE MARINE ENVIRONMENT

5.1. NATURAL ECOSYSTEMS AND INCREASING POPULATION

Singapore is amongst the most densely populated countries in the world. With a land area of only ~720 km^2, Singapore hosts a population of ~5.6 million. The inevitable consequences of Singapore's acute land scarcity and high population density are the conversion of undisturbed natural areas for housing, infrastructure and industry. The pressure for land resulted in large-scale sea reclamation projects that began in the 1960s and continue to present day (Lu et al. 2005; Koh and Lin 2007). The remaining natural coastal and marine ecosystems exist in a highly urbanised and dynamic environment that is subject to elevated levels of sedimentation, nutrients, and turbidity, as well as depressed light penetration (Tun 2012, Tanzil et al. 2013). Despite these numerous environmental challenges, these ecosystems exhibit high species diversity and relative resilience when compared to neighbouring regions (Huang et al. 2009; Tanzil et al. 2013, 2016). Nevertheless, rising concerns of global-scale impacts of climate change coupled with declining water quality and coastal development, could soon exceed the adaptive capacity of these sensitive coastal and marine ecosystems. This chapter reviews key current and potential threats to the coastal and marine ecosystems of Singapore.

5.2. CLIMATE CHANGE

In this chapter, climate change refers to the warming of Earth in response to human activities, that have directly and indirectly increased the concentrations of atmospheric heat-trapping gases (or "greenhouse" gases) such as carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and compounds such as chlorofluorocarbons (CFCs) (World Bank 2013; IPCC 2014). While these compounds are naturally variable and can fluctuate on timescales of 10s to 100s of years, current increases have been attributed to anthropogenic activities. Present greenhouse gas concentrations surpass natural climate fluctuations and are driven by land-use changes and burning of fossil fuels (IPCC 2014). The impacts of climate change on global environment have been examined based on different emission scenarios (see IPCC 2014). Predicted large-scale and long-term effects of climate change in tropical regions include changing weather patterns, increasing storm surges, warming seas, rising sea levels, ocean acidification, reduced ocean circulation, and changes to ocean salinity and oxygenation (Rhein et al. 2013; IPCC 2014).

5.2.1. Warming Seas

The average global surface air and seawater temperatures in the tropics has risen significantly in recent decades; average surface air temperatures increased from 0.1–0.3 °C per decade (1950–2010) and seawater temperatures (<75 m depth) by 0.11 °C per decade from 1971–2010 (Rhein et al. 2013; IPCC 2014). By the end of the 21st century, it is estimated that sea temperatures (<100 m depths) will rise between 0.6–2.0 °C. In Singapore, analyses of long-term sea surface temperature data indicate that our surrounding sea is warming at a rate of ~0.074 °C per decade (Tanzil et al. 2013; Fig. 5.1). Singapore has also experienced anomalous sea warming events associated with disturbances to the El-Niño Southern Oscillation (ENSO), where sea temperatures rose 1–2 °C above the seasonal maxima (Tun et al. 2010; Chou et al. 2015; Guest et al. 2016; Tanzil et al. 2017; Fig. 5.2). Such short-term acute events or "heat waves" are predicted to further increase in frequency and intensity with climate change (Solomon et al. 2007).

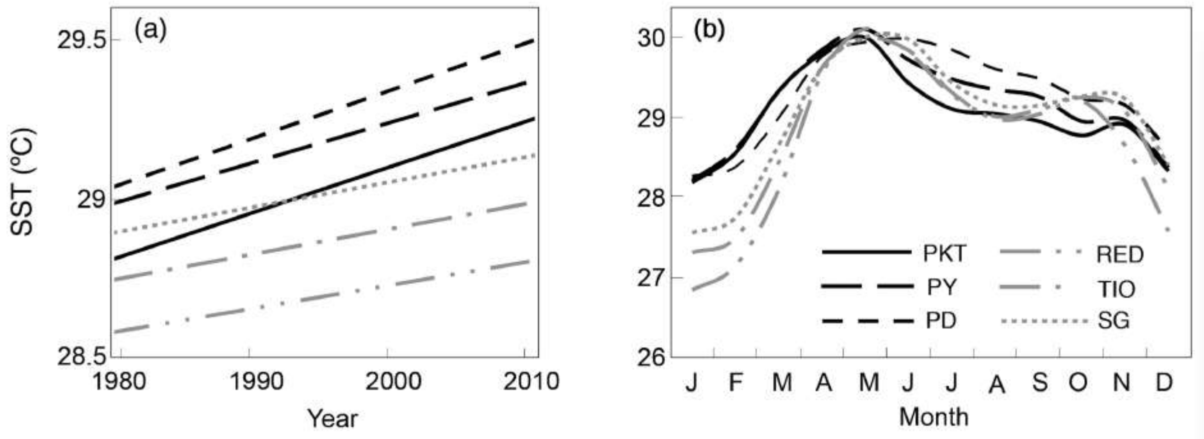


Figure 5.1. Patterns in sea surface temperature (SST) for all study locations based on HadISST 1° gridded data: (a) trends over time (all slopes P < 0.001), and (b) seasonal variation in monthly mean temperatures averaged over the period 1980–2010. PKT, Phuket; PY, Pulau Payar; PD, Port Dickson; RED, Pulau Redang; TIO, Pulau Tioman; SG, Singapore.

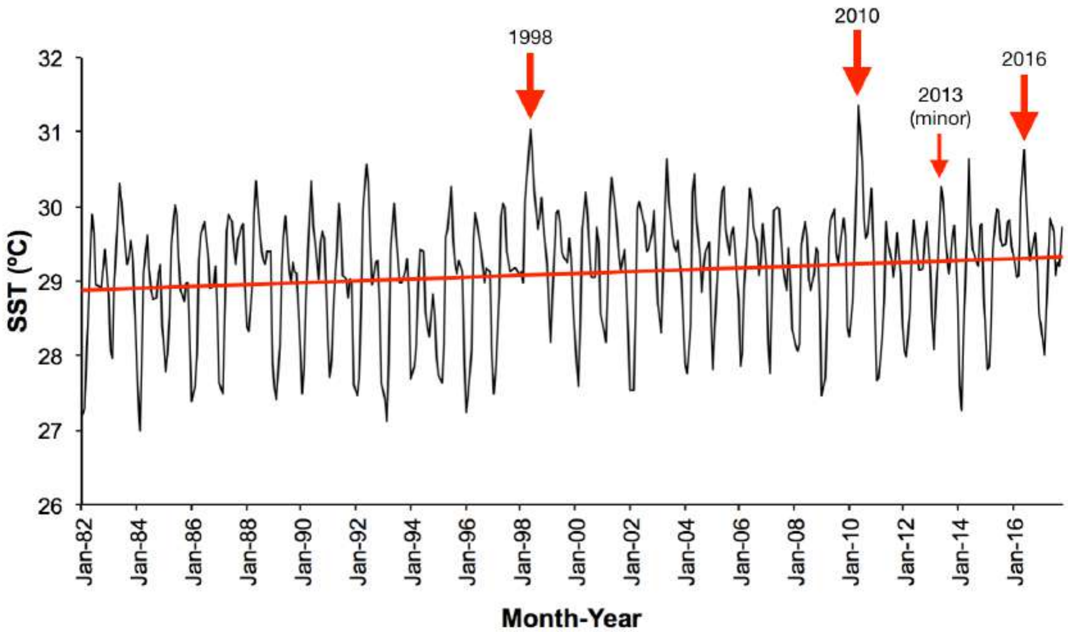


Figure 5.2. Sea surface temperature (SST) around Singapore based on IGOSS Reyn-Smith v.2 (Reynolds et al. 2012) 1° gridded data. Red arrows correspond known mass coral bleaching years 1998, 2010, 2013 (minor mass bleaching event) and 2016 (Chou et al. 2015)

In Singapore, as elsewhere, warming seas are pushing reef-building corals beyond the upper limits of their thermal tolerance (Heron et al. 2016; Hughes et al. 2017). Marine "heat wave" episodes have triggered several mass coral bleaching events on coral reefs within Singapore (Tun et al. 2010; Chou et al. 2015; Guest et al. 2016; Tanzil et al. 2017; Fig. 5.2). Coral "bleaching", the breakdown of symbiotic relationship between corals and zooxanthallae, results in the death or expulsion of the coral's endosymbiont (zooxanthellae), and diminishes a major energy resource for physiological processes for the corals. If bleaching is severe, the symbionts may be unable to re-establish resulting in mortality of the coral host; as was the case for mass bleaching events in 1998, 2010 and 2016. Declines in coral growth rates around Singapore have also been associated with long-term sea warming (Fig. 5.3). In 2010, several long-living massive *Porites* corals were cored and their annual growth rates reconstructed. We found their growth (calcification) rates have slowed down by ~17 % since the 1980s (Tanzil et al. 2013). These corals used to produce, on average, ~2 cm of skeleton a year, but are now growing at a rate of just over 1.6 cm $year^{-1}$. This change in growth rates may not seem substantial, but if the rates of decline continue, there will be negative impacts on future reef accretion rates and reef resilience (see Madin et al. 2012; Roff and Mumby 2012). If the 'business as usual' scenario ensues, these corals may cease calcifying in ~150 years.

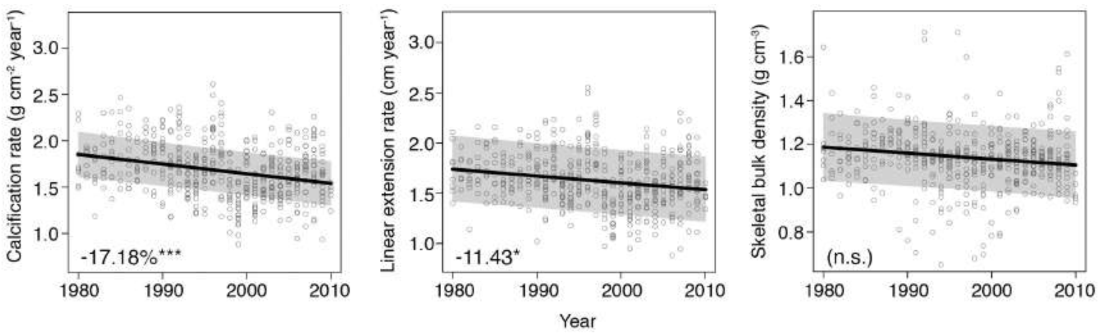


Figure 5.3. Changes in annual growth parameters (calcification rate, linear extension rate and skeletal bulk density) over the period 1980–2010 in Singapore. The solid line represents the best-fit linear mixed-effects (LME) model; *P < 0.05, **P < 0.01, ***P < 0.001, n.s., not significant; grey area denotes 95% CI.

Marine heat waves also have the devastating potential to abruptly decimate seagrass populations. Tropical equatorial seagrasses, such as those found around Singapore, are considered to be living near their thermal limits. Under chronic temperature stress, seagrasses reduced their growth, size, and their number of shoots and leaves (Collier et al. 2011; Thomson et al. 2015). Lowered primary productivity and loss of key ecosystem engineers such as hard corals and seagrasses, are results of warming seas, and attenuate the ecological benefits provided by marine ecosystems. Effects from these are likely to cascade through the trophic system, and affect the health of organisms found or relying on those ecosystems (Wernberg et al. 2013; Thomson et al. 2015).

5.2.2. Ocean Acidification

Sequestration of atmospheric carbon dioxide by the oceans can moderate future climatic changes, but at the same time, causes the reduction of the pH of seawater through the formation of carbonic acid with the dissolution of carbon dioxide (Rhein et al. 2013). The current average seawater pH of ~8.1 is already 0.1 units lower than pre-industrial values, which corresponds to a 26 % increase in hydrogen ion concentration (Feely et al. 2004; Orr et al. 2005). The latest projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) Earth System estimate a reduction in global-mean surface pH that range from 0.06 to 0.32 units by 2100. As pH units are recorded on a logarithmic scale, an increase in 0.32 units represents an increase of three orders of magnitude in the acidity of the ocean (Ciais et. al. 2013). The shift in the seawater carbonate system due to increased hydrolosis of carbon dioxide also drives a decrease in the concentration of marine carbonates, and consequently calcium carbonate saturation levels (Ω); Ω is a measure of the ion activity product of calcium (Ca^{2+}) and carbonate (CO_3^{2-}) relative to the apparent solubility product for a particular calcium carbonate mineral phase (i.e. calcite, high Mg-calcite, or aragonite). Saturation levels of marine carbonates are thought to have decreased by 10 % compared to that of pre-industrial levels (Orr et al. 2005), with ~40 % further decrease estimated by 2100 (Kleypas et al. 1999; IPCC 2014).

Decreases in seawater calcium carbonate saturation state (Ω) related to acidifying oceans are predicted to significantly reduce the rates of calcification in calcifying reef organisms (Gattuso et al. 1998; Kleypas et al. 1999; Kleypas and Langdon 2006; Silverman et al. 2007, 2009; Friedrich et al. 2012). These include, but are not limited to, corals, calcareous algae, tubeworms and foraminifera (Yamano et al. 2000; Jokiel et al. 2008; Comeau et al. 2014). Based on extrapolation of available data, it is thought that decreases in Ω have caused average reef calcification to decline by 6–15 % over the past century, with predicted decreases of 17–35 % by the end of the 21st century relative to pre-industrial levels (Kleypas et al. 1999; Friedrich et al. 2012). Results from field studies in the northern Red Sea by Silverman et al. (2007, 2009) also suggest that large coral colonies, and perhaps entire coral reefs, will start to dissolve if atmospheric CO_2 doubles. Not much yet is known about the seawater carbonate chemistry or the impacts of ocean acidification on Singapore's coral reefs, and further research is likely needed to better predict future responses.

With ocean acidification, higher levels of dissolved inorganic carbon (DIC) will, however, also be available for photosynthesis (Koch et al. 2013). This may be beneficial for marine plants such as seagrasses. Tropical seagrasses can upregulate photosynthetic rates with DIC enrichment (Jiang et al. 2010; Russell et al. 2013; Ow et al. 2015) and possibly increase biomass (Palacios and Zimmerman 2007), benefiting from ocean acidification scenarios. Studies have shown that seagrasses can potentially thrive as the ocean becomes more acidic with anthropogenic climate change (Palacios and Zimmerman 2007; Takahashi et al. 2015). Neverthelss, not all species will present plant-scale responses in the same way, and a shift in seagrass community composition and structure within tropical multi-specific meadows is expected (Hemminga and Duarte 2000; Campbell and Fourqurean 2013; Takahashi et al. 2015; Ow et al. 2016). A shift in the epiphytic community – a reduction in calcareous organisms and increased colonisation of non-calcifying algae (Campbell and Fourqurean 2014) – will potentially affect grazer communities by altering food availability in seagrass meadows.

5.2.3. Sea Level Rise, Changes in Rainfall Patterns, Increased Storm Activities

Global mean sea levels rose at 1.7 mm year^{-1} throughout the 20th century, and 3.2 mm year^{-1} between 1992 and 2012 (Meyssignac and Cazenave 2012). Sea level increases are linked to two processes: thermal expansion and glacial melting. There is large spatial variability in rates of sea level rise thus far, and future projections. In the Indian Ocean, sea level increases have been twice that of the average global rates since 2003, a trend projected as likely to continue (Thompson et al. 2016). In contrast, the rate of sea level rise in the South China Sea, western Pacific Ocean is expected to remain similar to the global mean (Huang and Qiao 2015). The primary cause of such variability is a thermosteric one; differences in rates of thermal expansion related to sea warming drives the rates of sea level rise. Therefore, for locations that sit between large water bodies warming at different rates, such as, there exist large uncertainties in sea level predictions and its impacts on coastal systems.

In Singapore, mean sea level has increased by 1.2–1.7 mm year^{-1} while average rainfall has risen by ~25 % since the 1980s (Marzin et al. 2015). Sea level and rainfall/cloud cover can alter the amount of light that reaches the sub-surface marine ecosystems, such as coral reefs. Light is required for photosynthesis of the symbiotic zooxanthellae in corals. Slowed growth rates associated with sea warming (Fig. 5.3) may also result in corals not being able to adapt to sea level rise. Rainfall patterns can also affect the amount of hydraulic energy and physical damage received by marine ecosystems (e.g. via storm events) as well as increases in terrestrial runoff and river inputs into the coastal system (e.g. Fabricius 2004; Justic et al. 2005), both of which increase sedimentation resulting in higher turbidity.

Tun et al. (1994) found that coral species on Singapore's reefs are barely meeting their daily carbon requirements solely from photosynthesis at 3.4 m water depth. At 6 m water depth, the authors predicted that energy corals obtain from autotrophy would not reach >50 %. Additional reductions in light due to increased cloud cover, sea level as well as increased water turbidity associated with local/regional coastal development could further edge Singapore's corals to their physiological limits for survival. While the effects of increased rainfall/storm events and sea level described above are mostly negative and precautionary, these environmental disturbances also offer ecological benefits. Increased water movement and cloud cover (associated with rainfall/storm events) can help alleviate thermal stress on corals, cooling waters through shading the sea surface from solar radiation and transfer of latent heat (evaporative cooling) reducing the impacts of rising sea temperatures as described above (Heron et al. 2005).

Decreased light levels as a result of sea level rise are also expected to negatively impact seagrass ecosystems in Singapore. Seagrasses that are distributed at their lowest depth limits, i.e. at minimum light requirement, such as those which are already affected by declining water quality due to nutrient or sediment inputs from coastal development and dredging, could be particularly vulnerable to sea level rise (Waycott et al. 2009). To cope with sea level rise, seagrasses will have to adapt or acclimate to the new light and hydrodynamic conditions, and accretionary processes in the habitat will have to keep up with rising sea level (Short and Neckles 1999; Duarte 2002). Furthermore, as new regions become inundated, seagrass could potentially migrate into newly available areas (Duarte 2002). However, in highly developed urban areas such as Singapore, this inland migration is be prevented by armoured shorelines (Nicholls 2011). Sheltered coastal seagrass meadows may also be especially vulnerable to changes in rainfall patterns. Increased rainfall amounts are predicted to deliver higher sediment and nutrient loads from terrestrial runoff and river discharges into the coastal system (e.g. Justic et al. 2005). Acute turbidity events have been linked to seagrass loss through a sharp decline in photosynthetic rates and shoot densities (Ralph et al. 2007; Petus et al. 2014). Storms surges stir up large quantities of sediments, which can lead to further die-off due to burial, smothering and increased turbidity (Ralph et al. 2007; Brodersen et al. 2017). This will further compound the stress experienced by seagrasses, and hamper their ability to recover (Rasheed et al. 2014). As storm events are predicted to increase in frequency and intensity, seagrass ecosystems will likely have narrower recovery windows between disturbances.

Historically, undisturbed mangrove ecosystems have largely kept pace with rising sea level either by gradually migrating inland, or by accreting land vertically (Sasmito et al. 2016; Krauss et al. 2014). Mangrove roots bind and retain sediments as well as mangrove leaf litter and woody debris, which will eventually decompose and add to deposits on the soil surface. Mangrove roots also influence subsurface changes: for example, high soil bulk density or low nutrients both induce root accumulation, which in turn expands soil volume. These processes allow mangrove ecosystems to alter soil elevation and keep up with sea level changes, and vertical accretion rates ranging from 0.7 to 20.8 mm year^{-1} have previously been recorded (Krauss et al. 2010). The impact of mangrove roots on soil level is so significant that even scale harvesting of individuals trees can reduce elevation by reducing root growth and higher root decomposition (Krauss et al. 2010). Changes to surface elevation (e.g. sedimentation, groundwater influx, land movement/uplifting) combined with biological factors drive the net losses or gains in soil elevation within a mangrove area. The predicted rise in sea level as well as increasing frequency of storm surges and extreme high-water events associated with anthropogenic climate change, would increase the inundation duration and confer added physiological stress to the mangroves (Gilman et al. 2008; Krauss et al. 2014; Alongi 2008). There is a real concern that mangrove ecosystems may not be able to keep pace with the rate of rising sea levels (global average rate ~3.2 mm year^{-1}) especially for slower accreting mangrove systems.

5.2.4. Declining Water Quality

The quality of the water within Singapore's territorial boundaries vary widely, influenced to varying extents by a mix of local, regional and cyclic factors (e.g. seasonal currents, climate oscillations) (Sin et al. 2016; Tanzil et al. 2016). The south of mainland Singapore is bound by the Singapore Strait, considered one of the busiest shipping lanes in the world (Gin et al. 2000). It is along this water body that the Port of Singapore Authority (PSA) operates four container terminals – a main one at Keppel Harbour, and the remaining facilities spread out towards the west. The southwestern part of the Singapore Strait also hosts a number of petro-chemical refineries and bunkering facilities. Changi Naval base is situated in the East, serving ships in the Republic's navy as well as vessels from our military allies. While local rivers are typically a major source of contamination for coastal waters (Hungspreugs 1988), the effect of inputs from rivers in the Singapore Strait are, today, largely negated by their damming of the Singapore and Kallang rivers to form the Marina Reservoir.

To the north, Singapore is bound by the Johor Strait, which marks the border between Singapore and Malaysia. In contrast with the Singapore Strait, the Johor Strait is relatively enclosed, and the quality of its waters is influenced largely by terrestrial run-off from surrounding landmasses. The establishment of the Causeway in the early 1920s split the Johor Strait in two, restricting east-west water movement and flushing within the Strait. Both sides of the Johor Strait host a large number of fish farms, while land reclamation works continues on both sides of the Singapore/Malaysia border. Economic expansion in Singapore has resulted in on-going coastal development, in the form of land reclamation and shoreline modification (Fig. 5.4). Intensive land reclamation has increased Singapore's landmass from 578 km^2 in 1819 to 718.3 km^2 in 2015 (Singapore Department of Statistics 2015).

With such extensive and intensive coastal utilisation, it is unsurprising that Singapore's highly urbanised and dynamic marine environment is characterised by elevated sedimentation, suspended sediments, nutrients, turbidity, and depressed light penetration (Tun 2012; Tanzil et al. 2013). Increased sediments in the water column in the marine coastal waters of Singapore have been observed over the last four to five decades. Sedimentation levels on Singapore's reefs increased from ~3–6 mg cm^{-2} day^{-1} in 1979 up to ~5–45 mg cm^{-2} day^{-1} in more recent years (Low and Chou 1994; Dikou et al. 2006), and underwater visibility reduced from ~10 m in the 1960s to 2 m or less today (Tun et al. 1994; Dikou et al. 2006; Tun et al. 2012). Increased levels of oil, grease and heavy metals may also be expected in the immediate vicinity of some industrial establishments (Te 1998).

In addition to local drivers of declining water quality, Singapore's marine environment is also influenced by regional changes/fluctuations in water quality. Seasonal monsoons drive net seawater transport across Singapore: wind-driven circulation flushes more saline, clearer waters from the South China Sea to the Singapore Straits during the northeast (NE) monsoon (~November–March), while the southwest (SW) monsoon (~June–September) allows intrusion of more turbid, lower salinity waters from the Java Sea and Malacca Straits (Rizal et al. 2012; Sin et al. 2016). The regional water masses transported into Singapore from the South China Sea and Malacca Straits would therefore have significant impacts on local water quality. Sources of pollution in local and regional waters include coastal development, seabed dredging, sewage discharge, industrial and agricultural effluents, oil spills from ship collisions and other ship discharges. The changes in Singapore's coastline configuration will also continue to modify and influence local hydrodynamics (e.g. rates of flushing), and the transport behaviour of sediment/other pollutants and biogeochemical cycling in Singapore's coastal environment (e.g. Fig. 5.5).

Figure 5.4. Coastal modification in Singapore (clockwise from top left): rainbowing of dredge spoil; slope mitigation at St. Johns' Island; significant sediment plumes occurring post rainfall during construction of Pasir Panjang Terminal Phase III; construction of Marina Barrage.

5.3. HARMFUL ALGAL BLOOMS

Phytoplankton blooms associated with periods of high nutrient influx (usually in conjunction with other environmental variables such as temperature) result in depleted oxygen and possibly toxic (as in the case of harmful algal blooms) conditions for marine life (Wang et al. 2008). Harmful algal blooms (or HABs) can result in massive fish death and have been observed throughout Southeast Asia, usually related to various regional conditions such as increased upwelling of waters, reversed monsoon winds, eutrophication from coastal aquaculture and river discharges (Susanto and Marra 2005; Azanza et al. 2008; Wang et al. 2008; Baumgart et al. 2010).

In recent years, more frequent bloom events were observed in Singapore. The first reported event reported in Singapore in 2009 incurred ~200,000 fish deaths (Leong et al. 2012, 2015). An event in 2014 resulted in losses amounting to 160 tonnes of fishes (Lee 2014), as well as causing widespread death of many wild fishes. Harmful algal bloom events are more frequent and prominent within the Johor Strait compared to the Singapore Strait; the Johor Strait is generally more enclosed and subjected to higher levels of human activity, coastal development and modification. Singapore waters have a high diversity of bloom-forming phytoplankton species, although toxic species are not well documented. Ballast water exchange by ships is probably one of the major contributors to the high diversity of bloom-forming species in Singapore.

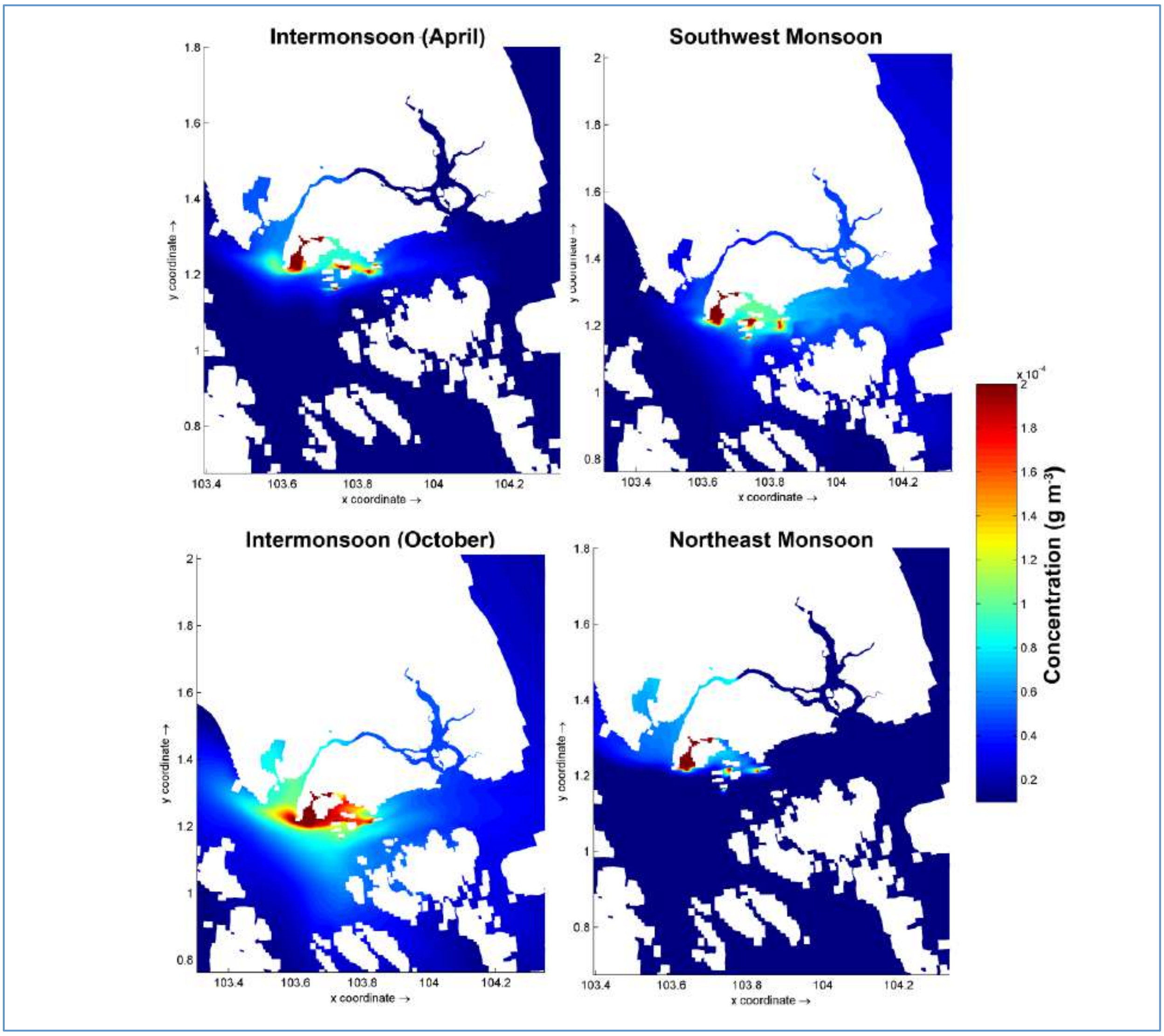


Figure 5.5. Preliminary results of conservative tracer numerical models showing seasonal differences in particle movement in Singapore's coastal waters.

Knowledge about the triggers for harmful algal bloom events in Singapore has largely been descriptive. Each bloom event often involves an assemblage of different species, and does not presently appear to follow any pattern or sequence. The frequency of events similarly also appears to be unregulated, although two major fish-kill events (in February 2014 and 2015) may have been related to changes in water quality associated with the northeast monsoon. During these events, >1000 tonnes of fish were lost from >50 fish farms resulting in massive economic losses to fish farmers (Neo 2015). Climatic changes, specifically warming seas and changes in rainfall patterns, are expected to further exacerbate the expansion and intensification of bloom activity. While harmful algal blooms cannot be easily eradicated, their relative abundance can be monitored and potentially pre-empted, if not predicted. Real-time detection of HABs and forecasting of blooms is very critical for mitigation strategies deployment.

5.4. CAPTURE FISHERIES AND AQUACULTURE

The environmental impacts of coastal aquaculture and the effects of declining water quality on aquaculture development are emerging problems faced worldwide, including Singapore. As of 2017, there are 118 Singapore coastal fish farms in the east and west of the Johor Strait, and the southern waters, that rear high-value food species such as groupers (*Epinephelus* and *Plectropomus* spp.), snappers (*Lutjanus* spp.), Asian seabass (*Lates calcar*ifer), pompano (*Carangidae*) and milkfish (*Chanos chanos*), along with some mollusc (*Perna viridis*, and *Crassostrea* spp.) and crustacean (*Panulirus* spp.) species (Chou et al. 1994). Fish produced from local aquaculture has increased from an average of 2,300 metric tons prior to 2010, to 4,600 metric tons in the last 4 years (Fig. 5.6; SEAFDAC, 2017). Although the quantity of aquaculture production is low compared to other Southeast Asian countries, Singapore produced the second highest average value (US$8,125 per metric ton) in the region in 2014 (SEAFDEC 2017). Local production accounts for around 5–6% of the annual consumption of seafood in Singapore (average of 85,500 metric tons over the last 5 years), while the rest is imported (average of 98,700 metric tons over the last 5 years).

Most of these aquaculture farms discharge their farm wastes, such as excrement as well as uneaten nourishment and supplements, directly into adjacent coastal waters that result in excessive nutrient inputs and eutrophication. Nitrogen and phosphorus levels in the Johor Strait are two to three times higher than levels found in the Singapore Straits (Gin et al. 2006). Reduced dissolved oxygen and high biological oxygen demand (BOD), particularly around and underneath the fish farms/cages, are common occurences (Mok 1982; Bevendge 1984), as are phytoplankton blooms and changes in microfaunal communities (Weston 1990), acidification of farm sites and oxygen depletion (ADB/NACA 1991), and reduction of overall biodiversity (Brown et al. 1987). Sustainable aquaculture in our waters will require execution of proper of operations (including production limits) and close monitoring of the carrying capacity of fish farming in our waters (Tan 2017).

Capture fishery data typically consist of a combination of industrial, artisanal, subsistence and recreational catches. Based on data collection by Food and Agriculture Organization (FAO), capture fisheries production in Singapore averaged about 10,600 metric tons in the 1950s and 1960s. The next two decades saw an increase in production, with an average of 17,300 metric tons and a peak of 25,141 metric tons reported in 1984. By the 1990s, production had decreased to an average of 9,600 metric tons, and continues to decline to below 2,000 metric tons since 2010 (Fig. 5.6). There are two fisheries landing sites in Singapore. The first, Jurong Fishery Port, serves mostly foreign vessels, and is a trading hub for live and frozen aquatic products imported into Singapore. A handful of Singapore-registered commercial fishing vessels (typically utilising trawl nets) operate in the region, while about 100 fishing vessels (typically utilising gill nets) operate only within the territorial waters of Singapore. These vessels land their catches at the second site, Senoko Fishing Port. It is unknown the respective contribution of these two fishing modes to the total production. While commercial fisheries catch has declined over the years, catches from recreational fisheries have increased significantly and is estimated to supersede that of commercial catches since 2010. Reconstructed data suggests that >2,000 metric tons of marine fish are caught recreationally in Singapore waters every year for the last 10 years, and this number is expected to rise in the future (Corpus 2014). Currently, there is no licensing or regulatory guidelines for recreational fisheries such as catch and size limits, although it is illegal to use poisons, explosives, and trawl nets, within the territorial waters of Singapore.

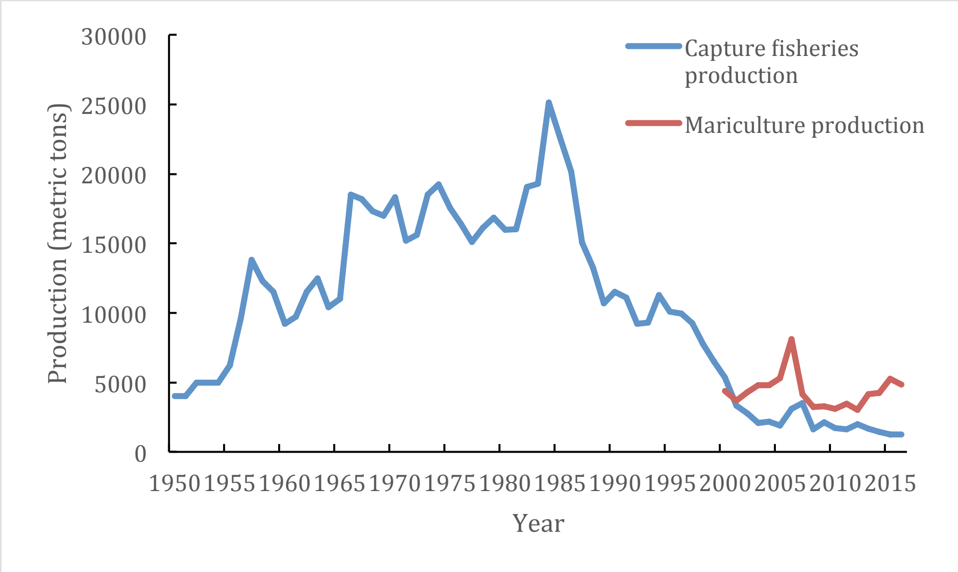


Figure 5.6. Local production of seafood (in metric tons) in Singapore. Data from capture fisheries exist from 1950 to 2016, data for mariculture production (mainly from coastal fish farms) are available from 2000 to 2016. Data were taken from the Food and Agriculture Organization (FAO) website and Southeast Asian Fishery Development Center (SEAFDEC) website.

Increasingly, abandoned, lost, and derelict fishing gear (ALDFG) are being identified as a major threat to marine habitats (Breen 1989). Derelict nets and abandoned baited traps can remain viable trapping devices for years (Giordano et al. 2009). Trapped organisms eventually die of starvation, and in turn attract scavengers and predators which themselves become trapped, continuing the detrimental cycle (Breen 1989). In instances where the organisms manage to escape from ALDFG, they are unlikely to survive from the effects of confinement (Breen 1989). Abandoned nets—with floats at the top end and weights at the bottom end—creates a 'curtain' throughout the water column, that continuously trap organisms and also severely affect their ability to forage and escape predators (Donohue & Foley, 2007). When washed nearshore, the weighted ends of nets often entangle on corals or mangrove roots, seen in Kranji Reservoir Park in January 2018. In the intertidal space, ALDFG also has harmful effects. Aerobic intertidal organisms can die from asphyxiation when trapped during the rising tide.

These gears do not only affect marine organisms. Trapped animals may attract terrestrial mammals (e.g. otters) and birds during the ebb tides, which in turn become trapped as well. There have been several cases in Singapore: a migrant Lesser Frigate ingested a fishing hook in abandoned fishing lines at the Marina South Pier (Ow Yong 2015), a dolphin entangled in 8 kg of fishing lines and weights at the Bedok jetty, otters ensnared in fish traps at Marina Reservoir and Changi Beach (Lam 2017; Chang 2018). Impact from ALDFG in the territorial waters of Singapore is substantial. Incidences have been reported by citizens in blogpages such as project Driftnet and WildSingapore, and in newspapers and printed media. These

ALDFG have been observed at Pulau Semakau, Pulau Ubin, Big Sisters Island, Kranji Reservoir Park, and various other areas. Yet the extent of the impact is unknown and conservation strategies currently in place have not taken ALDFG into account. Awareness to this global issue and its consequences can be improved through education of, and engagement with, members of the public. Understanding the impact of ALDFG in Singapore will allow implementation of effective management and conservation strategies that target the sources of these abandoned gear.

5.5. INVASIVE SPECIES

Singapore lies to the west of the Coral Triangle, a region of rich marine biodiversity. Marine invasive pest species pose a serious threat to the many fragile ecosystems in Southeast Asia, more so given emerging challenges posed by climate change. Many invasive species are aggressive eco-engineers which, given an advantage, can quickly out-compete slow growing reef organisms, reducing the overall ecological value and services of a community. Singapore's strategic location and role as a major transhipment hub port in Southeast Asia renders shipping movement as a key vector and the port as a high-risk area for transfer of non-indigenous marine species around the world (Kaluza et al. 2010; Keller et al. 2013). As such, invasive species present a constant threat for all natural habitats in Singapore.

Knowledge of invasive species in Singapore has significantly improved in the past 10 years. There has been an increase in literature for the terrestrial and freshwater habitats (e.g. Nghiem et al. 2013; Liew et al. 2013; Ng et al. 2014). However, for the marine environment, much less research has been done. Inventories by Tan and Morton (2006) and Jaafar et al. (2012) capture some prominent marine pest species. More recently, Lim et al. (2018) reports the invasion of the South American charru mussel, *Mytella strigata* (Mytilidae) in Singapore.

As a global top transhipment hub, Singapore has the capacity to play a significant regional role in managing the transfer of marine invasive species to/from the Southeast Asia region. Introduction via aquaculture and the aquarium trade also contribute to the problem, but this pathway is perhaps less significant for marine habitats as Singapore has limited mariculture and the aquarium trade. Also, unlike terrestrial invasions, release of animals by private individuals is less important for the marine environment as, numerically, these releases are small and often inconsequential. With 2.6 billion annual gross tonnage (2016), Singapore is an active stakeholder in the International Maritime Organisation (IMO), which serves as the focal organization for international maritime affairs. By implementing IMO environmental policies and instruments such as the International Convention for the Control and Management of Ships´ Ballast Water and Sediments (2004) (BWMC) and the Biofouling Guidelines for the Control and Management of Ship' Biofouling to minimize the Transfer of Invasive Aquatic Species (2011), for managing biosecurity within the Port of Singapore, the passage of invasive pest organisms to/from Southeast Asia will be significantly reduced, leading to substantial reduction of biosecurity risks for the region as a whole. These efforts serve a positive signal of Singapore's resolve with the international shipping community, for environmentally responsible practices. Implementing these international guidelines are in line with Singapore's commitments for protection of the environment under the Convention on Biological Diversity (CBD) and United Nations Convention on the Law of the Sea

(UNCLOS), which Singapore is a party to since the mid-1990s. Our inaction will hinder regional and global efforts to curb biodiversity and ecosystem damage. Singapore may also adopt management practices from regional countries, such as the NZ Ministry of Primary Industries' Craft Risk Management Standards which contain action plans for managing biofouling risk and remediation measures to prevent species transfer.

Overall, progress to address marine invasive species in Southeast Asia has been slow as there remains a lack of political will to address marine biosecurity issues. For Singapore, existing national legislation for marine environment protection (e.g., The State Lands (Encroachment) Act; prohibition of use of explosives, The Fisheries Act) do not address transport of invasive species. Only a few marine areas (Sungei Buloh Wetlands Reserve, Labrador Nature Reserve and Sisters' Islands Marine Park) are gazetted as Nature Reserves/Parks, which enables the National Parks Board to exercise some degree of management of biodiversity within these areas (Parks and Trees Act, amendment dated 13 March 2017). However, invasive species issues are transboundary and require a wider whole-of-government approach. As of November 2017, Singapore has not conducted baseline surveys such as Port Biological Baseline Survey (PBBS) or CRIMP protocol (Australian Centre for Research on Introduced Marine Pests 1996; revised by Hewitt and Martin 2001) as recommended for BWMC.

Singapore must consider to embrace concepts for nature-based coastal engineering to reduce availability of free man-made environments/spaces for establishment of invasive pests. The first point of introduction for most marine pests occur in man-made habitats, from which they proliferate into natural habitats. Singapore will concurrently need to increase resilience of our natural ecosystems as a safeguard: pollution and environment contamination reduces the resilience of habitats to bioinvasion. Managing good water quality remains a useful means to control invasive pests, native and alien, in tropical Southeast Asia environment, as most pest species have a high energy demand to proliferate. Eutrophic, polluted environments increase risk for disease and bio-invasion.

5.6. MICROPLASTICS

Microplastics are defined as plastic particles with diameters less than 5 mm (Thompson et al. 2015). There are two types of microplastics that exist in the environment. Primary microplastics are plastic particles that are being manufactured in microscopic size range. They are commonly found in household items such as exfoliating facial scrubs and cosmetics (Fendall et al. 2009). Secondary microplastics are plastic particles that result from the fragmentation of macro plastic particles such as plastic bottles and styrofoam buoys due to the effects of chemical and biological processes (Cole et al. 2011). Although these microplastics are prevalent in the environment, research among the scientific community and awareness among people is still in its infancy in Singapore. As of 2017, there exist no standard protocol for microplastic monitoring in Singapore and many individuals are unaware of the presence of microplastics in the products they consume. However, there is growing global concern to combat microplastic pollution and Singapore has joined forces with nine other countries in the Western Pacific to do so from this year forward via IOC-

WESTPAC Program. This is a crucial step as countries in the Western Pacific region contribute to about 60% of plastic pollution in the ocean (Kershaw et al. 2011)

To date, the only countries that have ongoing microplastic monitoring strategies and laws to mitigate microplastic pollution in the Western Pacific region are China and South Korea. China has banned the dumping of plastic waste in marine waters (Zhou et al. 2011) while South Korea has banned the sale of cosmetics containing microbeads (Wu et al. 2017). Other countries in the region such as Bangladesh, Philippines and Vietnam do not have any ongoing microplastic monitoring strategies or laws protecting against microplastic pollution.

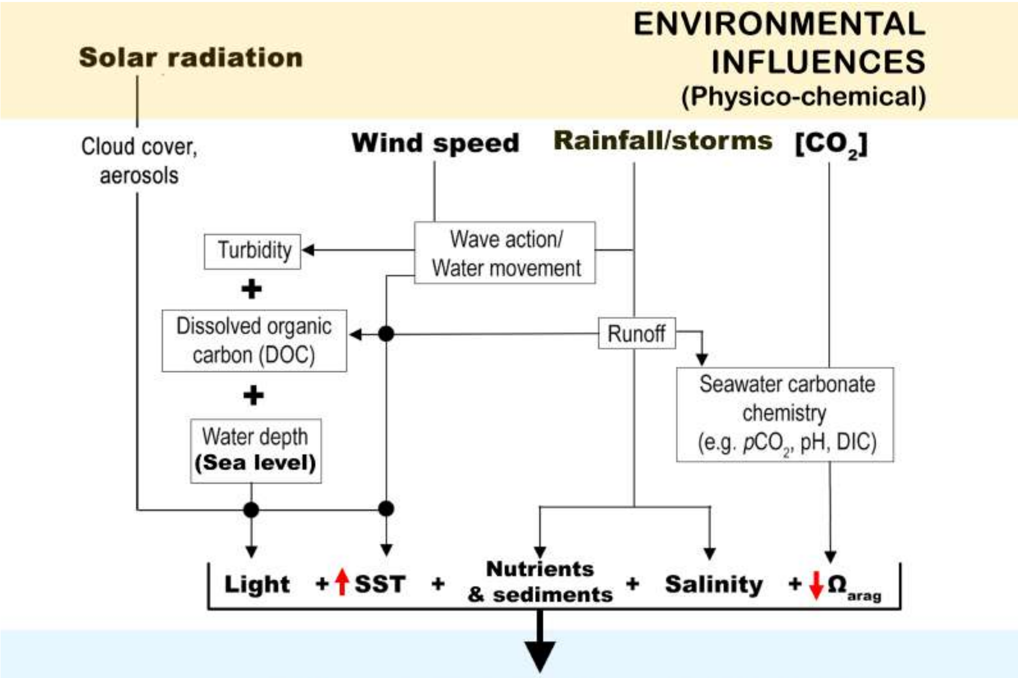
Microplastic monitoring efforts in Singapore began in September 2017. It encompasses documenting microplastic debris on both beaches and surface waters along the Singapore coast and its offshore islands. This will provide crucial insight to the level and type of microplastic pollution existing in the country. This will plug the existing knowledge gap in the scientific community and form a basis to focus future research efforts. The knowledge gathered from research can be used to update the public on the status of microplastic pollution in Singapore waters through seminars, workshops and news coverage. This research will also be part of the contribution towards the joint marine microplastic monitoring and research network among scientists and government agencies in the Western Pacific region. This network was formed as a result of the training workshop on the Distribution, Source, Fate and Impact of Marine Microplastics in Asia and the Pacific organized by the UNESCO's Intergovernmental Oceanographic Commission Sub-Commission for the Western Pacific in September 2017. Furthermore, the data and information collected through the monitoring efforts will be shared during the reconvention among member countries in 2018. With standardized and internationally-accepted sampling methods formulated during the workshop, member states will be able to compare the spatio-temporal microplastic pollution across marine waters, map gaps in current pilot study sites and design solutions for existing monitoring issues. Given that this is the first regional microplastic joint-monitoring program, the formation of this working group is vital as comparisons can be made across monitoring and research approaches from countries around the world. This will enable the region to refine existing or adopt new monitoring measures.

Microplastics are a physical, chemical and biological threat to the local marine ecosystem (Cole et al. 2011). They have been found to be ingested by a wide range of marine biota, ranging from zooplankton, corals, mussels and deep-sea tuna. These organisms have been found with microplastics as they are unable to discriminate microplastics from food particles (Setälä et al. 2014). This is dangerous as toxic substances have been found to leach from these microplastics and accumulate in organisms (Cole et al. 2011). This has resulted in anomalies in growth and development in these organisms (Wright et al. 2013). Furthermore, these toxicities can be transferred to man at the end of the food chain through the ingestion of contaminated seafood. Given that Singapore is a marine hotspot diversity with 17,000 species of marine biota, it is vital to protect these organisms against the harmful effects of microplastic pollution in order to maintain the diversity of the marine community.

5.7. MARINE ECOSYSTEMS AND THE FUTURE

Current trajectories of climate change impacts do not bode well for important tropical coastal and marine ecosystems, especially when other human-related local/regional-scale disturbances are considered. Major and fundamental changes in the marine environment of Singapore is already underway due to human activities, coastal development and in responses to climate change. Coastal and estuarine environments such as those found in Singapore, are less influenced by open ocean events. Consequently, large variability in future responses are expected as local conditions continue to interact with global effects. These changes are predicted to outstrip the abilities of important yet sensitive ecosystems, such as coral reefs, seagrasses and mangroves to adapt (Figs. 5.7-5.9). To mitigate the negative impacts of rapid environmental changes, active conservation, management and restoration measures are becoming increasingly necessary (e.g. Ng et al. 2016). Rehabilitation and restoration efforts, while costly (Bayraktarov et al. 2016), help ecosystem recovery. For example, growing roots of reforested mangroves can help to re-establish sub-surface elevation (McKee 2011). After 20 years, transplanted mangroves in the Philippines have regained about half of the mangrove specialist fish species, and more for the non-specialists species (Honda et al. 2013). Dedicated, committed long-term restoration efforts accompanied by water quality management through monitoring and load restrictions (e.g. of sediment, pollutants and nutrients) from various sources can provide some buffer for climatic disturbances by helping to re-establish habitats and ecosystem services, and to preserve genetic diversity (Collier et al. 2011).

The future fate of Singpaore's marine environment and precious ecosystems will not only depend on our ability to stabilize planetary temperature and carbon dioxide concentrations (e.g. by reducing or at least limiting emissions at current levels, sequestrations of atmospheric carbon dioxide) as quickly as possible, but also on local policies in managing and reducing the pressure from rising human population on resources. By reducing non-climate stresses, ecosystems will have the opportunity to develop resilience (through acclimatization or adaptation) to the challenges of our changing planet (Hoegh-Guldberg et al. 2017). Integrated environmental monitoring and management strategies that consider both upstream and downstream effects, as well as interdependencies between connected ecosystems, will likely provide the highest buffering capacities. Lastly, to promote sustainable environmental practices, scientists must accurately communicate their findings in a way that the layperson can understand. Science communication practices that are not entrenched in the culture of evaluating "impacts" will likely become more socially relevant and crucial for creating real-world solutions.



BIOLOGICAL & ECOLOGICAL IMPACTS

• Sea warming	• Increased coral bleaching, reduced calcification rates
• Ocean acidification (changes in seawater carbonate chemistry)	• Reduced calcification rates, increased bioerosion (reduced reef structural integrity)
• Increase in runoff of freshwater, nutrients, sediment & land-based pollutants	• Corals as ecosystem engineers at competitive disadvantage: change in community structure/ ecosystem shift, algal blooms, increased bioerosion, smothering of corals, coral diseases
• Sea level rise	• Reduced light reaching reefs – "drowning" of reef-builders. • Increased tidal flooding beneficial for intertidal reefs
• Increase in storm frequency and intensity	• Increased physical damage to reef structural framework
• Altered ocean currents	• Changes in reef connectivity

Shortened recovery windows between disturbance events
Overall reduction in reef ecosystem resistance and resilience

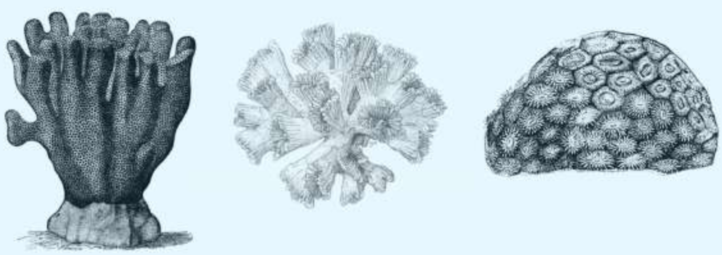


Figure 5.7. A summary of environmental influences, their interactions and the predicted impacts on coral reefs. (Tanzil et al. in press).

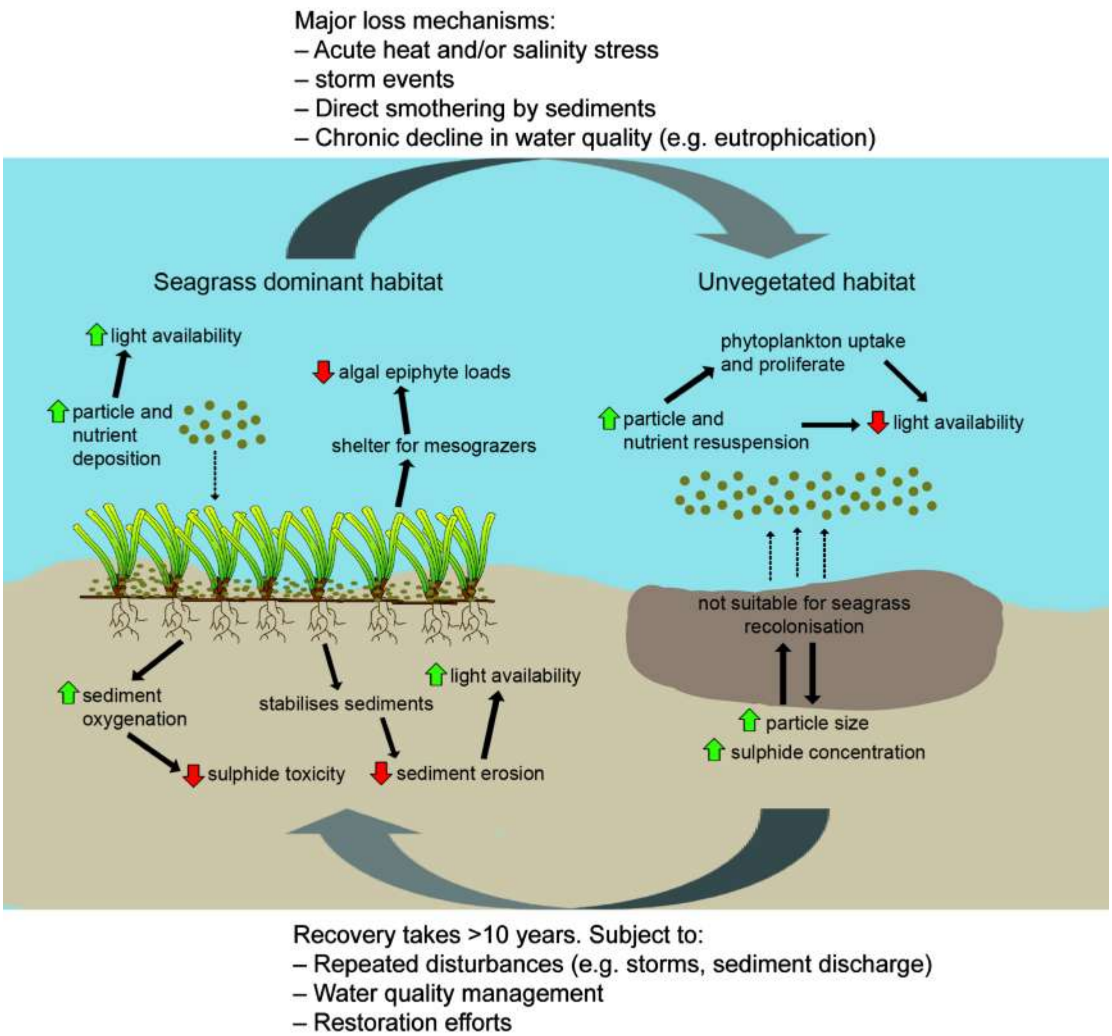


Figure 5.8. In seagrass dominant habitats, seagrass "engineer" their environment via feedback mechanisms. After a devastating loss in seagrass, the ecosystem flips to an alternate regime where the absence of vegetation hinders seagrass recolonization via feedback. Green arrows indicate an increase and red arrows indicate a decrease in levels. Ecosystem services associated with meadow productivity and structural complexity, such as provision of food and shelter for finfish and shellfish, are attenuated or lost. Recovery typically takes a long time and is subjected to many factors. (Tanzil et al. in press)

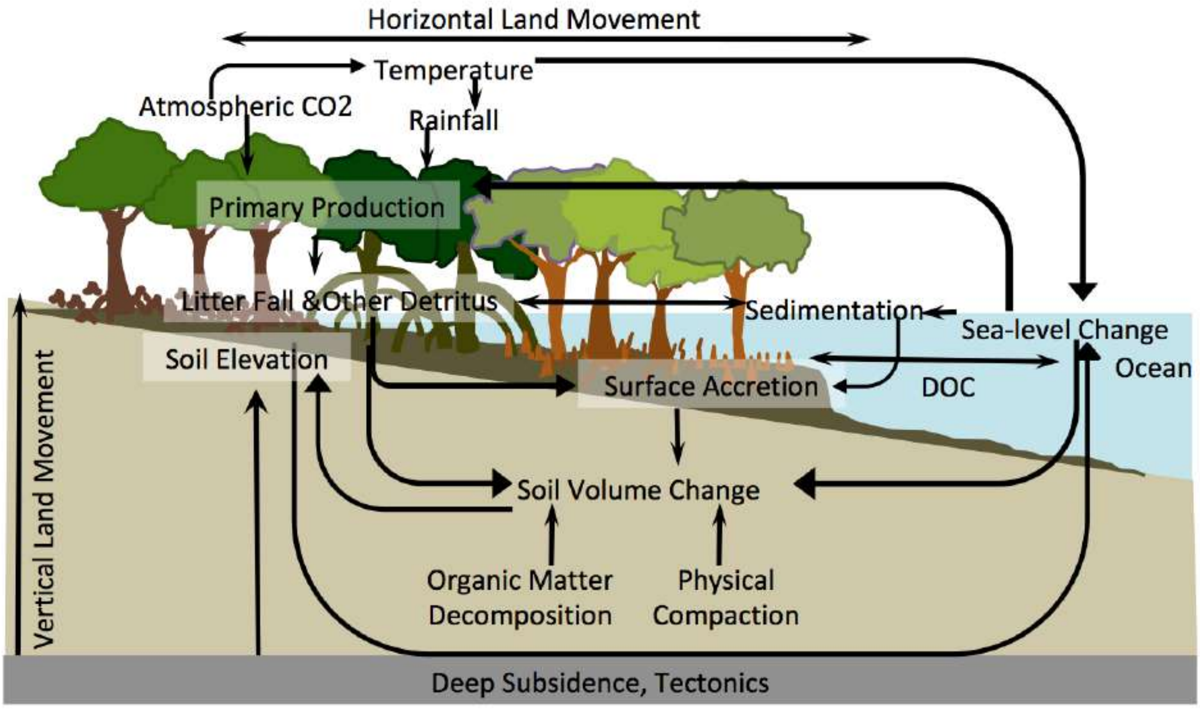


Figure 5.9. Diagram showing the conceptual interacting physical and biological processes in the mangroves (Tanzil et al. in press)

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CHAPTER SIX
MITIGATIVE MEASURES

6.1. CURRENT IMPACTS

Marine ecosystems in Singapore have faced multiple stressors stemming from coastal reclamation and development, pollution, some level of exploitation, harmful algal blooms and climate change. In particular, Singapore's coastal landscape has been drastically transformed due to extensive coastal developmental projects over the past five decades (Chou 2006). Intensive land reclamation has resulted in an expansion of Singapore's land area by over 20% to 719.1 km^2 since 1960s (Tun 2012). However, the scale of such projects has led to more than 60% of our shoreline being replaced by coastal engineered structures, with areal losses of 67.5% of reefs, 91% of mangrove forests and 85% of sand and mudflats (Tun 2012; Lai et al. 2015). As one of the world's busiest ports, Singapore's water is heavily utilized with more than 80% of it being allocated for shipping activities (Chou 2008). Also, Singapore's strategic location in major shipping routes and the rise in marine recreation has led to an increase in both commercial and recreational vessel movement (Drake and Lodge 2004; Chou et al. 2014). With the consolidation of port operations at Tuas, Singapore will be expected to receive up to 65 million twenty-foot equivalent units (TEUs) of cargo (Kaur 2017). The expansion of the maritime industry has earned Singapore's port as the second-best port infrastructure by the World Economic Forum (WEF) and generates over 7% to Singapore's Gross Domestic Product) (MPA 2017). As unabated coastal development continues to support Singapore's growing economy, Singapore must mitigate the loss of coastal ecosystem caused by land reclamation and dredging (Chou 2008; Ministry of National Development 2013; Toh et al. 2016).

Recent studies have shown that Singapore's marine biodiversity continue to persist even with the rapid degradation of the environment. Despite being challenged with chronic sedimentation and loose substrates for attachment, Singapore's coral reefs are resilient with nearly 200 hard coral species (Huang et al. 2009), regular mass spawning events (Guest et al. 2002) and active coral recruitment (Tay et al., 2012, Ng et al., 2016) documented. Natural recruitment and settlement reef communities are observed on man-made structures such as marinas and seawalls suggest reef creations in non-reef areas (Chou et al. 2010; Ng et al. 2012). Amidst intense dredging activities and reduced water quality, seagrass cover and species diversity did not appear to decrease (Yaakub et al. 2014). More than 1200 species of aquatic animals were recorded in mangrove habitats despite degradation (Chou et al. 1980). Highly urbanized coastal zones, such as marinas, reforested mangroves, reclaimed beaches and shores, have shown to support considerable diversity of fish communities (Hajisamae et al. 2003; Jaafar et al. 2004; Chou 2006; Kwik et al. 2010; Toh et al. 2016, Benzeev et al. 2017). Although marine biodiversity remains relatively rich, the species abundance has reduced, likely affecting ecosystem service provisions such as food, medicinal resources and ecotourism. To preserve these benefits, there is thus a need to enhance Singapore's limited port waters. These results also indicate that protection and active restoration of marine ecosystems are indeed viable in Singapore's human-modified coasts.

6.2. ENHANCING MARINE ECOSYSTEMS

As Singapore strives to be a global maritime hub, proper management of Singapore waters to sustain our vibrant marine ecosystems will strengthen Singapore's reputation as a green city. Creation of protected areas for coral nurseries and marine parks and enhancement of ecological function of artificial coastlines can mitigate the future impacts of coastal development and nation expansion. Subsequent regular monitoring and assessment of coastal habitats are important to understand the effects of urbanization on Singapore's biodiversity and to guide effective coastal management. Several of these measures have been put in place in the last decade. In the following, we describe some of these areas of progress and highlight emerging issues that requires further mitigation.

6.2.1. Sisters' Islands Marine Park

Following the recommendations of Singapore's Blue Plan 2009, Sisters' Islands was designated as Singapore's first Marine Park (Ng and Chou 2017). The Marine Park, managed by the National Parks Board, serves to protect our natural heritage, educate and create awareness on Singapore's rich marine biodiversity (Cheong 2016). To further conserve Singapore's biodiversity, NParks have initiated species recovery and reintroduction projects, establishing a coral nursery, Reef Enhancement Units (REUs; described below) and turtle hatchery under the Marine Conservation Action Plan (NParks 2015). Singapore's first Dive Trail in Sisters' Islands Marine Park requires strict dive requirements to safeguard the pristine reefs and long-term sustainability of the programme (NParks 2017).

6.2.2. Marine Restoration

In light of the Tuas mega port project to consolidate all port operations by year 2040, environmental impact studies commissioned by Maritime Port Authority of Singapore (MPA) and conducted by DHI Water and Environment (Singapore) Pte Ltd in 2012 has established that the corals around Sultan Shoal could be impacted by the development of port infrastructures (MPA 2015). Six million dollars was budgeted for the relocation of affected coral colonies, establishment of coral nurseries in sheltered areas, coral transplantation and coral health monitoring (Kaur 2017). A long-term coral restoration project was also initiated with researchers from National University of Singapore (NUS) to mitigate the further loss of Singapore's coral reefs and biodiversity (Chou et al. 2017). A total of 1251 loose coral fragments or 'corals-of-opportunity' from 22 coral genera were retrieved from Sultan Shoal and reared in coral nurseries located in Lazarus and Kusu Island (Chou et al. 2017). To overcome the problem of high sedimentation, coral nursery tables are elevated from the bottom substrate and designed with mesh nets to prevent sedimentation accumulation (Poquita-Du et al. 2017).

Rearing coral fragments and juveniles in *in-situ* nurseries with routine maintenance had shown to improve coral health and even post-transplantation growth in Singapore's challenging environment (Afiq-Rosli et al. 2017; Chou et al. 2017; Poquita-Du et al. 2017; Toh et al. 2017). Other than propagating corals for restoration, the nursery tables and coral fragments were utilized by reef associated organisms such as pufferfish, juvenile butterflyfish and cuttlefish for food and shelter (Taira et al. 2016). Corals were progressively transplanted to a degraded reef in Kusu and on granite boulders on non-reefal Lazarus Island generating a total of 422 m^2 of restored reef area (Chou et al. 2017). Long-term monitoring is mandatory to identify resilient and suitable coral species for future transplantation projects.

6.2.3. Safe Boating and Shipping

The growing popularity of yachting and marine recreational activities has led to the establishment of more support infrastructures such as marinas and jetties (Toh et al. 2016). Pontoons and seawalls are increasingly constructed to facilitate the mooring of smaller vessels against strong wave impacts (Hinwood 1998). Despite poor water quality and contaminants due to yachting activities, fish surveys in Singapore's recreational marinas from 2004 to 2014 had revealed more than 105 fish species from 48 families (Toh et al. 2016). Berthing pontoons offers additional substrate for recruitment and attachment of marine organisms (Toh et al. 2016). A recent study by Toh et al. (2016) recorded 94 taxa of marine animals on floating pontoons across marinas at Marina at Keppel Bay, Raffles Marina and ONE°15 Marina Club. Recreational marinas, if managed and designed well, can complement marine conservation efforts by providing ecological support for recruitment and refuge for marine organisms.

Considering the recent fatal collision events in the Singapore Straits, the confidence of safe navigation through our port waters is being challenged (Kaur 2017). To secure Singapore's top position in the world's maritime industry, Singapore should step up in managing smooth sea operations and safety within her waters. The implementation of Next Generation Vessel Traffic Management System feature in the new Tuas terminal aims to better assist and direct vessels in the expanding maritime traffic (Boh 2016). Collisions of vessels, especially large tankers, can result in oil spills. In early January 2017, 300 tonnes of oil spillage was reported in surrounding waters off Pasir Gudang Port in Johor Malaysia following an incident between a Gibraltar-registered container vessel and Singapore-registered container vessel. Follow up actions were executed with the involvement of MPA, NParks and Agri-Food and Veterinary Authority of Singapore (AVA) to contain the oil patches from the mangroves and mudflats along Singapore's northeastern coasts (Lim 2017).

However, the livelihood of fish farmers in Eastern Johor Straits were impacted by the oil contamination (Kotwani 2017). These farmers could be to tackle oil spillage to improve clean-up response time which will benefit both the environment and their aquaculture stocks. Vessel grounding can be a threat for the marine environment and boaters must be encouraged to report the incidents. Unreported shipwrecks and damage to Singapore's reefs have been encountered by researchers. Reef recovery is slow and the cost of restoration ranges from US$10,000 to US$6.5 million per hectare (Edwards and Clark 1998). To minimise accidental grounding of vessels in important biodiversity sites, the installation of mooring buoys and surveillance cameras should be considered.

6.2.4. Engaging the Public

The public and boating community can play a bigger role in enhancing port waters and marine conservation. Good seamanship and care for the environment should be observed during fishing and diving trips or even a stroll along the shores. Currently, Singapore statutes declare that fishing and removing of animals are prohibited in national parks and nature reserves. However, anglers and fishing boats have been spotted within areas of Sisters' Islands Marine Park after its establishment as a protected area (Chew 2015). Despite increased enforcement and penalties by NParks, cases of illegal fishing and poaching remained high (Xue 2015; Siau 2017). Abandoned fishing nets, traps and gears are commonly seen among Singapore's reefs and will continue to capture and entangle marine animals (Brown and Macfadyen 2007). Instead of continuing to increase the frequency of surveillance, information on fishing areas should be clearly stated or vetted carefully by governing bodies involved in marine conservation. For instance, varying information on permitted fishing grounds across government and fishing enthusiasts' websites can lead to confusion. Anglers and fishermen, for recreational or commercial, should be properly educated on the prohibited fishing areas and the reasons behind designating these important places. By regulating fishing activities, fish communities are more likely to recover and repopulate around Singapore's water.

Illegal and irresponsible disposal of trash are washed up onto shorelines and out into the sea, impacting marine life and posing health risks to human as fishes are reported to mistakenly consume microplastics (Derraik 2002; Sheavly and Register 2007; Todd et al. 2010). While it is encouraging that many coastal clean-ups activities in Singapore are land-based, however there are limited efforts in removing subtidal marine trash. In 2017, community initiatives in Singapore has collected more than 14 tonnes of marine trash along Singapore's coastline and over 350 kg of underwater trash (International Coastal Cleanup Singapore 2017). Public visiting Singapore's offshore islands and coastal localities should be mindful of their trash. Signages and more trash bins can be deployed at places of interests such as St John's Island and Kusu Island. Floating booms and buoys can be installed to minimize marine trash from drifting into the open sea and neighboring islands. In addition, rubbish collection boats at the Southern Islands can be activated more frequently to remove floating marine debris. Members of the public can also take initiatives in reporting of illegal fishing and dumping. Private yacht owners and qualified divers can be trained and given active roles to work together with stakeholders and community initiatives in protecting our seas.

6.3. CORAL REEF RESTORATION

Large areas of reef in Singapore have been degraded by intensive coastal development, land reclamation and seabed dredging since the country's independence (Chou 2006), and further declines are expected with the reclamation of more land for development needs (Ministry of National Development 2013). Restoration and rehabilitation are thus critical in helping to revert degraded reefs to their original condition, or replace the structure and functions that have been reduced or lost. Various projects commenced in Southeast Asian nations in the 1990s to help the embattled reefs recover (Chou et al. 2009), but many were limited in scope and scale as reef restoration is a fledgling discipline.

6.3.1. Restoration of Coral Reefs in Singapore

Since the early 2000s, Singapore researchers have demonstrated the relevance and viability of restoration as a management strategy for areas impacted by heavy sedimentation and reef instability. One approach involved the deployment of artificial reef structures known as REUs. These encouraged coral recruitment and growth, underscoring the importance of substrate stability for coral establishment in Singapore's seas (Loh et al. 2006). More than a decade later, the REUs augmented ecosystem services by acting as habitats for at least 119 reef species, including corals that were sexually mature and which could help seed other reefs (Ng et al. 2017).

Another approach focused on propagating corals to increase live coral cover at less healthy reefs and non-reefal areas. This was achieved by fragmenting large coral colonies, or collecting the sperm and eggs from adult colonies for fertilisation. The small fragments and juvenile corals generated were cultivated in nurseries, enabling useful information on the growth and development of numerous species to be obtained (see review by Ng et al. 2016). Concurrently, researchers developed methods to increase coral yield, e.g. by feeding juvenile corals with brine shrimp, or by orientating nursery frames at angles which improved coral survival and growth (Toh et al. 2014; Poquita-Du et al. 2017). The corals that had grown to suitable sizes were transplanted to degraded reefs and seawalls where many developed into adult colonies (Ng et al. 2015, 2016). While branching corals (commonly used in restoration projects elsewhere) had the highest mortality rates, transplants of boulder-shaped corals, albeit slower growing, fared better over time (Ng et al. 2016). These findings highlighted the potential for scaling up restoration efforts.

6.3.2. Monitoring and Research

A key takeaway from the efforts to date is that monitoring is essential to assessing the overall effectiveness of restoration efforts (Ng et al. 2016). As corals only grow by a few centimetres annually, successes that initially manifest may not persist, or may only be apparent after years. Past projects were only conducted for short durations of not more than four years. Funding for future restoration projects should account for this aspect, so that the research can be supported for longer terms.

Further, the research focus for the next decade should be on increasing our knowledge of species' relationships with the environment, as this will directly influence the provision of ecosystem services, such as shoreline protection and biodiversity maintenance. For example, coral species could be prioritised for restoration based on whether they recover faster from mass bleaching events, whether they are rarer, or whether they possess characteristics that facilitate their establishment in Singapore's highly sedimented marine environment. It is also envisioned that the research will move beyond proof-of-concept studies in ecology and include socio-economic aspects such as the willingness-to-pay for using or rehabilitating reefs, to enable a more comprehensive approach to reef restoration.

One way to enhance restoration and promote environmental stewardship is to involve citizens in both field and administrative aspects of the research programme. In 2007, a collaborative effort between a private entity, government agencies and a research institution led to the establishment of a coral nursery off Pulau Semakau, which volunteer divers helped in setting up (Chou et al. 2009). More recently, the involvement of field volunteers helped reduce overall costs of an initiative to enhance coral diversity on seawalls at Lazarus Island; they also reported greater awareness and interest in marine conservation issues after the series of activities (Toh et al. 2017). In a similar vein, workshops can be conducted to educate interested members of the community on the theoretical aspects of reef restoration, as well as to impart proper techniques used in data gathering and processing to ensure scientific rigour in future citizen science programmes. Volunteers can be roped in to monitor the corals they previously helped to transplant, or assist with broadcasting updates to other volunteers on the status of the restoration site.

Finally, while restoration is a useful intervention to hasten reef recovery, it should never be prioritised over conservation, as the former will never be able to replicate the conditions and integrity of the original environment. Impact assessments should be carried out prior to any coastal and marine activity that has a foreseeable impact on Singapore's coral habitats, as this is akin to a "look before you leap" approach (Lye 2008). If the activity must be conducted, coral relocation and transplantation work should be commissioned and carried out by personnel trained in proper protocols and who are able to do follow-up monitoring. Sites that have been restored or are undergoing rehabilitation should be accorded some protection so that the efforts are not negated. Information pertaining to the restoration programme, such as data on environmental parameters, should also be shared to ensure continuity and reduce duplication of effort.

6.4. MANGROVE REHABILITATION

Singapore's urban coastal landscape has a long history of mangrove deforestation, disturbance, and degradation (Friess et al. 2012; Yang et al. 2011). Disturbances have temporarily or permanently altered ecological and physical conditions, causing mangrove degradation. A disturbed mangrove could undergo secondary succession either naturally or through human-aided mangrove rehabilitation to restore its ecosystem function.

Mangrove rehabilitation aims to restore a level of ecosystem area, diversity and/or function. The success of mangrove rehabilitation is primarily dependent on growing mangroves in locations and physical conditions where they are most suited. Such ecological-based approach involves gaining and utilizing knowledge of site physical conditions as well as mangrove biology to enhance rehabilitation process. Various local economic and socio-political aspects including competing land use and future coastal development plans are also important factors to consider when conducting mangrove rehabilitation.

6.4.1. Mangrove Rehabilitation Efforts in Singapore

Several mangrove rehabilitation projects have been conducted in Singapore in order to increase our national mangrove area (see Tab. 6.1). These restoration projects are commissioned and conducted by government agencies, often together with private consultants. These mangrove rehabilitation projects have different aims and objectives, and are usually one-off efforts. Rehabilitation approaches are also varied.

Table 6.1. Summary of historical and current mangrove restoration projects in Singapore (Friess 2017)

Sites	Area (ha)	Restoration Method	Reasons for Restoration	Reference
Pulau Semakau	13.6	Creation of a nursery and direct planting of *Rhizophora* species	Replacement of mangrove habitat lost to land reclamation	Tanaka et al. 2004
Pulau Tekong	Unknown (8000 saplings)	Hard engineering combined with planting of individual species in protective tubes	Reduction of rapid shoreline erosion	Cheong et al. 2013
Pasir Ris	1.0	Natural colonization of regraded reclaimed land	Redevelopment of reclaimed area and reconnection of other mangrove patches	Lee et al. 1996
Pulau Ubin	8.8 (currently in the design phase)	Ecological Mangrove Restoration adapting physical conditions to encourage natural colonization	Revision of abandoned aquaculture pond back to mangrove	Restore Ubin Mangroves (R.U.M.) 2017

Mangrove rehabilitation commonly involves the direct replanting of mangrove saplings. However, studies have shown that these replanting efforts yield little success (Primavera and Esteban 2008; Wibisono and Suryadiputra 2006). High failure rates are likely caused by a combination of factors including poor site selection, negligence of mangrove biology, lack of understanding of physical conditions such as hydrology and surface elevation at restoration sites (Lewis 2005; Primavera and Esteban 2008). Mangrove plants are evolved to survive in the stressful coastal zone, dealing with flooding, waves and high salinity. However, mangroves will not grow in areas where the physical conditions are beyond their tolerance. Moreover, replanting often produces monospecific stands which does little to restore the ecology of a mangrove forest.

The Ecological Mangrove Restoration (EMR) approach emphasizes understanding the site conditions such as hydrology, coupled with the knowledge of mangrove biology such as inundation frequency tolerance, to assist the process of regeneration and produce self-sustaining mangroves (Lewis 2005; Fig. 6.1). This approach focuses on removing existing stressors and creating the right environment to promote regeneration and survival of mangrove propagules, which could be planted or naturally recruited. The EMR approach has only recently been considered for Singapore (an EMR project on Pulau Ubin is currently in the design phase), and due to its potential to increase rehabilitation success we recommend this approach for future mangrove rehabilitation in Singapore where possible.

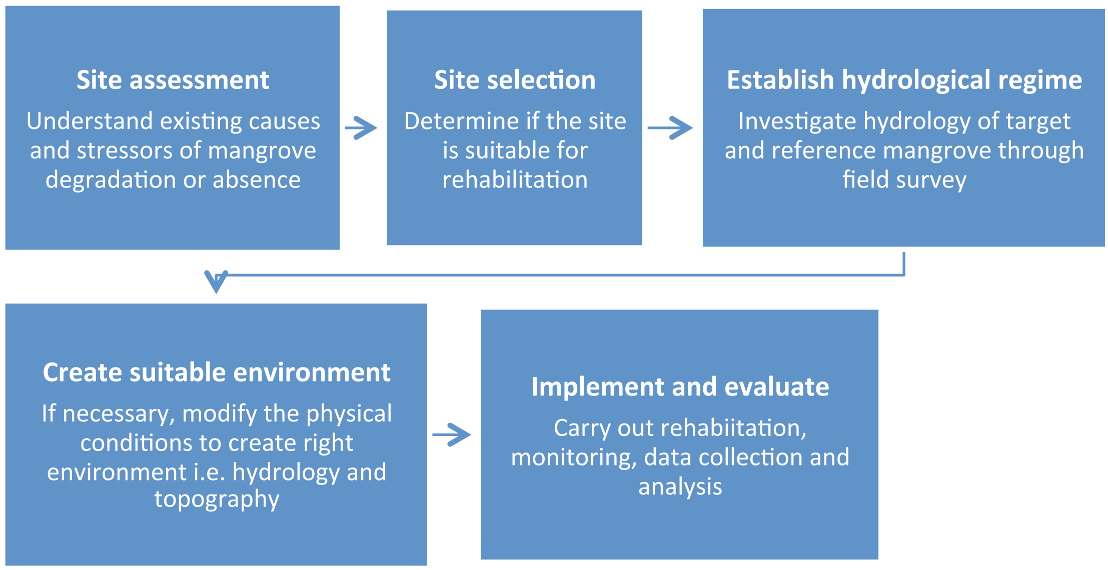

Figure 6.1. Steps in the Ecological Mangrove Restoration (EMR) approach (adapted from Lewis 2005).

6.4.2. Key Considerations in Mangrove Rehabilitation

Restoration aims and targets. A mangrove rehabilitation project should have defined aims and targets. Setting the aim is essential in determining the time horizon of each project stage, resources requirement, and existing knowledge and gap in achieving rehabilitation target. An aim to restoring to pristine mangrove forest condition is impractical and probably not required. It is recommended that the target could be established through identifying a few physical and ecological parameters (Tab. 6.2).

One of the direct and quantifiable assessment of mangrove rehabilitation project is the changes in mangrove area. An increase in mangrove area provide direct evidence to successful mangrove regeneration. Mangrove seedling recruitment could provide an early stage assessment. However, more indicators should also be included to assess the ecological recovery of mangrove such as biodiversity of flora and fauna and physical parameters such as sedimentation/ erosion rate.

Selecting the right rehabilitation site. Rehabilitation in Singapore faces a unique challenge that is not generally encountered in the rest of Southeast Asia: Singapore is an urban nation, with limited coastal area available for mangrove rehabilitation. The traditional areas to conduct rehabilitation would normally include areas of aquaculture that used to be mangrove. In Singapore, there are 74.6 ha of active and abandoned aquaculture ponds that would be suitable for rehabilitation (Friess 2017); however, some of these areas have existing uses such as bird feeding areas, so the true area of ponds available for restoration is likely smaller than this. Thus, we may also need to think of alternative, or novel areas for mangrove restoration and creation. Opportunities may exist, for example, in ecological engineering, where spaces for mangroves are incorporated into seawalls and reclamations (*sensu* Lai et al. 2015).

Table 6.2. Examples of parameters as rehabilitation targets

Parameter	Description	Methods
Mangrove area	Direct evidence of mangrove regeneration Indicate suitability of the site for rehabilitation.	Satellite imagery Historical maps and records
Mangrove seedling recruitment	Natural recruitment of mangrove seedling indicates: i) natural availability of mangrove source; ii) physical environment conducive for seedling establishment.	Field survey
Biodiversity	Presence/absence or changes of flora and fauna abundance and diversity.	Existing biodiversity studies Field survey
Sedimentation/ erosion rate	Indicate the physical changes in mangroves The changes could affect seedling recruitment and vegetation survival	Field survey

Once a potential rehabilitation site has been identified, we then need to understand the site history such as land-use changes, hydrology, and geomorphology at immediate and adjacent areas. The thorough understanding of the sites helps to identify existing stressors and even determine whether rehabilitation is feasible. Potential mangrove rehabilitation sites should have a correct hydrological regime, surface elevation for seedling recruitment and survival (Oh et al. 2017). Abandoned aquaculture ponds such as those on Pulau Ubin or Sungei Khatib Bongsu may be too low in elevation for mangrove colonization, and their hydrology is affected by the presence of bund and tidal gates. Understanding biophysical factors of target sites could be done through field surveys. For example, extensive elevation surveys have been conducted during the design phase of the EMR project at Pulau Ubin to understand the elevations required for rehabilitation.

Land ownership. Another key consideration when choosing a mangrove rehabilitation site is land ownership. Ideally, mangrove rehabilitation should be conducted at mangroves that are designated to be conserved in foreseeable future. A proportion of Singapore's coastline have already been demarcated as either reclamation area, industrial areas, residential areas, or open spaces (URA 2017). In the Master Plan 2014, only Sungei Buloh Wetland Reserve was categorized as nature reserve with some form of legal protection; while Mandai mangroves, Pulau Ubin, and Pulau Tekong were classified as reserve sites or open space. Resources for mangrove rehabilitation should prioritize mangroves and adjacent sites within an ecological landscape that are likely to be conserved. Working with government agencies is, therefore, important to identify suitable long-term rehabilitation sites.

Figure 6.2. Restore Ubin Mangroves (R.U.M.) initiative conducting elevation survey to understand the physical conditions at Pulaub Ubin mangroves. Photo credit: Ria Tan

<u>Legal requirements for rehabilitation</u>. While Singapore has strong environmental legislation, it is not mandatory for developments to replace habitats that are lost during construction. Legislation can make rehabilitation of lost or damaged habitats a stronger priority for developments. Potential instruments can include "No Net Loss" policies (such as the US 2002 National Wetlands Mitigation Action Plan or the European Union's 1992 Habitats Directive). These instruments are used in many nations globally to encourage the creation of compensatory habitat to offset losses due to development, and to encourage the incorporation of habitats into the design of developments.

<u>Funding Sources</u>. Mangrove rehabilitation in Singapore is primarily funded by government agencies, who have budgetary constraints and other management objectives to consider. There is scope to supplement government funding of rehabilitation activities with other sources, including through Corporate Social Responsibility (CSR). Companies in Singapore are keen to fund mangrove activities, with several CSR projects conducted in Singapore's mangroves since 2008 (Friess 2017). This includes US$370,000 donated by an international Food and Beverage company in 2015 for mangrove rehabilitation activities in Sungei Buloh Wetland Reserve.

<u>Community participation</u>. Participation of community could have impact on the success of mangrove rehabilitation project (Nguyen et al. 2016). Past rehabilitation works are mostly conducted by government agencies and consultants. The recent rehabilitation project by R.U.M. initiative has been encouraging public participation and has conducted various public outreach programs (Fig. 6.2). Public engagement will help to improve awareness on mangrove rehabilitation, enhance knowledge of general public, promote sense of personal involvement towards Singapore's mangrove conservation, and improve public discussion in environmental issues in the long term.

To summarise, mangrove rehabilitation aims to restore particular levels of mangrove area, diversity and/or function of a disturbed mangrove, by taking into consideration of ecological, physical, local economic and socio-political factors. Ecological Mangrove Restoration (EMR) which emphasizes rehabilitation through ecological and biological understanding of mangroves is recommended. Selection of rehabilitation sites requires knowledge of biophysical conditions such as hydrological regime for initial feasibility assessment and subsequent mangrove recruitment and regeneration. Abandoned aquaculture ponds and novel coastal structures such as seawall could be targeted (more discussion next section). Rehabilitation along Singapore's urbanized coastline should observe land ownership and associated coastal development plans for long term rehabilitation planning. Mangrove rehabilitation in Singapore could be promoted through establishing legal requirements, expanding source of funding through partnership with private industries, and encouraging community participation.

6.5. ECOLOGICAL ENGINEERING OF SEAWALLS

It is predicted that, by the next decade, approximately three quarters of the world's population will reside in coastal zones (Small and Nicholls 2002; Bulleri and Chapman 2015). Coastal land is therefore in high demand and development and reclamation are occurring at unprecedented scales (Yeung 2001; Duarte et al. 2008). In addition, the risks of accelerated sea level rise and more frequent and intense storms and flooding due to climate change, have resulted in an urgent need for greater shoreline protection, and this is usually in the form of man-made coastal armouring, especially with seawalls (French and Spencer 2001; Hinkel et al. 2014), which are already widespread in Asia. For example, at Victoria Harbour, Hong Kong, close to 95% of the coast comprises vertical seawalls (Lam et al. 2009) while in Japan, Koike (1996), estimated that seawalls and similar structures have already replaced ~27% of the coastline, with more in the works especially after the tsunami in 2011 (e.g. a $6.8 billion, 400 km chain of seawall is currently being built along Japan's northeastern coast; Burnett et al. 2016).

6.5.1. Biodiversity on seawalls

As a habitat, seawalls differ from natural shores in some fundamental ways. One of the most obvious is the slope of hard substrate; natural rocky shores tend to be more gently sloping with longer and wider intertidal extents than seawalls, for instance, which are often built simply as a barrier, and are typically very steep. Vertical steepness also results in a concomitant reduction in the area of the intertidal zone. This results in species loss and may lead to greater overlap in the home range of individuals or distribution of species that are normally spaced far apart. Such changes may in turn alter intraspecific and/or interspecific competitive interactions and broader community dynamics, as well as the overall composition and diversity of seawall assemblages (Chapman et al. 2009; Bulleri and Chapman 2015). Compared to natural hard-bottom habitats, seawalls also have low structural complexity and a lack of microhabitats (e.g. pits, rock-pools, overhangs and crevices) which are important for the occurrence and survival of many intertidal and benthic species (Moreira et al. 2007; Chapman and Blockley 2009). It is therefore unsurprising that many direct comparisons between rocky shores and seawalls often reveal the latter host lower species richness, reduced functional and genetic diversity, and different community compositions (e.g. Chapman 2003; Bulleri et al. 2005; Lai et al. 2018). However, with the growing realization that existing seawalls cannot be removed, and more seawalls are going to be built in the near future, it is necessary to look beyond their negative impacts and to find ways in which seawalls can be constructed and/or modified to increase their ecological value as a habitat (Chapman and Underwood 2011; Firth et al. 2016).

6.5.2. Ecological Engineering Solutions

Internationally, there is growing interest in the potential to engineer artificial coastal structures to improve their capacity to support more bio-diverse communities while still retaining their engineering function (Mitsch and Jørgensen 2003; Firth et al. 2014; Nordstrom 2014). This endeavour to design and engineer urban infrastructure congruent with ecological principles is a form of reconciliation ecology generally known as 'ecological engineering' (Mitsch 1996; Chapman and Blockley 2009).

Recent estimates by Lai et al. (2015) indicate that seawalls comprise 63.3% (or 319 km) of Singapore's coastline, with another 125 km to be added within the next fifty years based on the 2011 Concept Plan (Lai et al. 2015). Except for a 0.3 km stretch of beach at Labrador Park, coastal modifications have replaced all of the natural shoreline along the southern coast of Singapore's main island, a distance of over 60 km (Todd and Chou 2005). Such large scale "hardening" of the shoreline is typical of many coastal cities around the world (e.g. Tokyo, New York, Hong Kong, and Sydney) where the need to protect coastal land, usually sites of high economic and social value, against the effects of flooding and erosion take precedence (Lai et al. 2015; Dafforn et al. 2015).

Given that the majority of Singapore's coastline is already artificial, it is crucial to see beyond the negative impacts of seawalls and recognise their latent role in the conservation of coastal biodiversity. As Chapman and Underwood (2011:303) emphasize: "now is the time to stop wringing our hands in dismay that little can be done about the problem and to be pro-active in attempting to build shorelines in a manner that will meet societal needs, constraints of engineering and costs and which will also cause less impact and/or provide improved habitat for species other than humankind." Despite the huge quantity of seawalls in Singapore, only a few studies have attempted to document the type of assemblages that live on them (they are: Lee et al. 2009a, 2009b; Lee and Sin 2009; Ng et al. 2012; Lai 2013; Loke 2015; Loke et al. 2016; Lai et al. 2018). Although seawalls are and should be considered novel habitats in their own right, the limited research conducted to date has, nevertheless, shown that that a variety of intertidal and subtidal communities occupy these structures, and that they often compositionally most resemble assemblages on natural rocky shores (Lai et al. 2018). Therefore, further studies are required to better understand the ecological processes and drivers that shape and maintain the communities on seawalls so that useful predictions can be made regarding the assemblages that will likely result from different engineering scenarios.

Ecological engineering can help mitigate some of the most negative effects of coastal armouring. For existing seawalls that cannot be removed, adding structural complexity (such as pits and crevices) is generally considered one of the most feasible and cost-effective approach internationally (Naylor et al. 2012; Perkins et al. 2015); further, this is an approach that has been developed and tested in Singapore. Based on a theoretical framework for operational complexity (Loke et al., 2015), Loke et al. (2014) created computer software to help incorporate different aspects of informational complexity into artificial substrates and several experiments have been performed on seawalls in Singapore using these novel tools (e.g. Loke and Todd 2016). Results indicate that at local scales, greater habitat complexity supports greater biodiversity and this can be achieved via retrofitting the surfaces of Singapore's granite rip-rap seawalls with concrete tiles moulded with complex structural components (Loke et al. 2017). Further studies also showed that the amount and arrangement of tiles mattered, and that these can be optimized (Loke 2015). Therefore, we suggest that while the protection of natural ecosystems remains the ideal conservation strategy that should always be prioritized, the potential of ecologically engineering coastal defences should not be ignored. Given the ubiquity of seawalls in many regions and their increasing prevalence globally, there is a real imperative to mitigate the negative impacts they have on shorelines. Artificial structure research and ecological engineering efforts to date suggest this is possible, particularly if future studies can effectively identify the mechanistic linkages between enhancements and ecosystem response and harness this knowledge in the development of increasingly effective design solutions.

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PART III

LEGISLATIVE SUPPORT FOR THE BLUE PLAN 2018

ENVIRONMENTAL LAWS AND POLICIES

This section provides the status of domestic and international laws relevant to Singapore pertaining to the protection and management of coastal and marine ecosystems and biodiversity. Key themes identified in Part II are grouped into six categories for the purpose of discussion: coastal development and planning, including land reclamation; conservation measures for coastal and marine environment inside and outside of protected areas; pollution from coastal and marine activities, including ship-based pollution and the management of fisheries, aquaculture and invasive alien species; pollution from land-based activities, including impacts to coastal and marine ecosystems from land-based construction work and industrial activities; regulation of greenhouse gas emissions and climate change adaptation measures; and environmental impact assessments, restoration, rehabilitation, and monitoring of coastal and marine ecosystems.

Legal recommendations are made to address these issues. A recurring concern emphasized in the scientific documents—a need for greater inter-agency cooperation to resolve dynamic coastal and marine issues—is outside of the scope of this review of applicable rules and regulations. In this regard however, the recent announcement that the animal related functions of the Agri-food and Veterinary Authority are to be transferred to the National Parks Board in 2019 is a step in the right direction from a marine environmental protection perspective. Presentation of references for this section follows standards for legal scholarship and therefore departs from the preceding section in which the scientific referencing method was used.

1. COASTAL DEVELOPMENT AND PLANNING

International law provides some useful guidance with respect to coastal developments. First States have an obligation to ensure that activities under their jurisdiction or control not cause environmental harm, in particular transboundary harm to shared resources or the marine resources of assets of neighbouring States. Second, the *1982 United Nations Convention on the Law of the Sea* (“**UNCLOS**”), to which Singapore is a party, requires States to undertake Environmental Impact Assessments (EIAs) activities that ‘may cause substantial pollution of or a significant and harmful change to the marine environment’.[1] Although general international law does not specify the scope and content of an EIA, the obligation to act with due diligence to protect and preserve the marine environment provides guidance in the minimum standard that would be expected. The term 'marine environment' includes the living and the non-living environment; it therefore includes but is not limited to biodiversity.

Furthermore, UNCLOS, the *1992 Convention on Biological Diversity* (“**CBD**”) (to which Singapore is also a party) and other rules of international law, highlight the need for States to balance their right and need for development with their obligation to protect and preserve the marine environment. This section examines the provisions included in Singapore law to proceed with this balancing. EIAs are discussed in section 7 below.

[1] UNCLOS Article 206 uses the language ‘assess the potential effects of such activities’ instead of EIA although this provision is included in Section 4 of Part XII of UNCLOS titled ‘Monitoring and Environmental Assessment’.

1.1. Urban Planning

Coastal land, like land elsewhere in Singapore is subject to urban planning under the Planning Act ("**PA**"),[2] administered by the Urban Redevelopment Authority ("URA"), a statutory agency under the Ministry for National Development. Urban planning is carried out through a statutory Master Plan which is required to be reviewed at least once every five years,[3] to guide development over a rolling 10 to 15 year planning horizon; and a longer term non-statutory Concept Plan, which is reviewed once every 10 years, to guide development over a 40 to 50 year planning horizon.[4] While the objectives of urban planning are not stated in the Act itself, the URA states that the goal is to "[b]y balancing economic, social and environmental considerations… create a sustainable Singapore that provides a quality living environment, offers plentiful growth opportunities and jobs for the people, and safeguards our clean and green landscape".[5] The integration of environmental considerations with existing plans is critical to sustainable development.[6] The importance of public participation in urban planning, as underscored in Principle 10 of the Rio Declaration, has been given effect to under the *Planning (Master Plan) Rules* ("**MPR**"),[7] which provides for the process of amending the Master Plan, including requirements for proposed amendments to be publicised, and for the public to have minimum periods to view such amendments, and submit representations and objections in respect of such proposed amendment. Whether the MPR is strictly complied with however, is a different matter.[8] Furthermore, there is no legal requirement for the Master Plan or the Concept Plan to be subject to strategic environmental assessment ("**SEA**"),[9] nor is it known whether SEAs are carried out as a matter of administrative policy or practice.

1.2. Development Control

The PA also controls land development, including coastal development; developments (including change of land use) may not be carried out without planning permission.[10] Applications for planning permission are by default but not necessarily considered according to the Master Plan. Unlike proposed amendments to the Master Plan, planning permissions need not be publicised, but may be inspected by the public upon payment of the prescribed fee.[11] As further discussed in paragraph 1.1.4 on land reclamations and in section 1.7 below, there is no legal requirement for development projects to be subject to Environmental Impact Assessment ("**EIA**"), although some projects are as a matter of policy and practice subject to EIAs.

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[2] Cap 232, 1998 Rev Ed.
[3] PA, section 8. See also Urban Redevelopment Authority, "Master Plan", <https://www.ura.gov.sg/Corporate/Planning/Master-Plan>.
[4] Urban Redevelopment Authority, "About the Concept Plan", <https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/About-Concept-Plan>.
[5] Urban Redevelopment Authority, "Planning", <https://www.ura.gov.sg/Corporate/Planning>.
[6] See *1992 Convention on Biological Diversity* ("**CBD**"), Article 6; and 1992 Rio Declaration on Environment and Development ("**Rio Declaration**"), Principle 4.
[7] Cap 232 R1, 2000 Rev Ed.
[8] See Jack Tsen-Ta Lee, "We Built This City: Public Participation in Land Use Decisions in Singapore", (2015) *Asia Journal of Comparative Law* 10(2):213.
[9] For more information on what a SEA entails, see Barry Sadler and Mary McCabe, (eds), *EIA Training Resource Manual* (2nd Ed) (UNEP, 2002), p 491 et seq, <https://unep.ch/etu/publications/EIA_2ed/EIA_E_top14_body.PDF>.
[10] PA, section 12.
[11] PA, section 23.

1.3. Building Works

Building works are defined in the *Building Control Act* ("**BCA**"),[12] inter alia as the erection, alteration, or demolition of a "building";[13] which is in turn defined inter alia as "a dock, wharf or jetty", and a floating structure, not being a boat or vessel, constructed or to be constructed on a flotation system that is or is to be supported by water; is not intended for or useable in navigation; and is or is to be permanently moored".[14] Plans for building works and building works themselves are subject to approval by the Commissioner of Building Control.[15] Building works must also be carried out under the supervision of appropriate qualified persons,[16] and are subject to applicable pollution control laws.[17] Building works are legally not subject to EIAs, nor is there any legal requirement or administrative policy or practice for the public to be consulted before approvals are given for building plans or building works. Such consultation would be welcomed by the public and consistent with international practices and guidelines on EIAs.

1.4. Land Reclamation

The *Foreshores Act*[18] empowers the government to "construct quays, wharves, jetties or other public works along or out from the foreshore of Singapore or in the sea-bed adjacent thereto; dredge the sea-bed; and erect buildings upon any areas of land reclaimed from the sea…". It may, subject to the approval of Parliament, reclaim any part of the foreshore or seabed of Singapore. Again, there does not appear to be a legal requirement for EIAs to be conducted before the government proceeds with such construction or works; or before parliamentary approval is given for land reclamation. However, it appears to be the government's current administrative practice to subject land reclamation projects to EIAs. Such a practice would be consistent with Singapore's obligations under international law.[19] Reports of such EIAs are not always made public, nor is the public always invited to participate in decisions to reclaim land.[20] It has been argued that the foreshore is subject to the public trust doctrine i.e., the State holds the legal ownership to certain natural resources for specific purposes for the common benefit of the public; and to discharge its duty as a 'trustee', the government should require EIAs to be carried out and made available to Parliament before parliamentary approval is given for land projects.[21]

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[12] Cap 29, 1999 Rev Ed.
[13] BCA, section 2.
[14] BCA, section 2.
[15] BCA, section 20.
[16] BCA, section 7.
[17] See Section 6 below.
[18] *Foreshores Act*, section 4.
[19] See UNCLOS Article 206 and *Case concerning Land Reclamation by Singapore in and around the Straits of Johor (Malaysia v Singapore), Provisional Measures, Order of 8 October 2003*, <https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_12/12_order_081003_en.pdf>; and *In the Matter of the South China Sea Arbitration before an Arbitral Tribunal constituted under Annex VII to the 1982 United Nations Convention on the Law of the Sea between the Republic of the Philippines and the People's Republic of China, Award of 12 July 2016 of the Arbitral Tribunal*, <https://pca-cpa.org/wp-content/uploads/sites/175/2016/07/PH-CN-20160712-Award.pdf>.
[20] See Alice Chia, "New Reclamation Method Aims to Reduce Singapore's Reliance on Sand", (16 November 2016) *Channel NewsAsia*, <https://www.channelnewsasia.com/news/singapore/new-reclamation-method-aims-to-reduce-singapore-s-reliance-on-sa-7701000>. It was reported that to ensure there would not be significant impact on the surrounding marine environment and wildlife, an environmental study had been carried out for the land reclamation project which uses the polder development method, but the EIA report has not been made public.
[21] See Joseph Chun, "Reclaiming the Public Trust", (2005) SAcLJ 17:717.

1.5. Marine Works and Operations

The consent of the Maritime and Port Authority of Singapore ("**MPA**") is required inter alia, for the construction, alteration or improvement of any work on, under or over any part of a river, waterway or the seashore (including the seabed under the territorial waters of Singapore) lying below the high-water mark of ordinary tides; or the deposit or removal of any object or material on any part of a river, waterway or the seashore.[22] Administratively, projects involving the foreshore or marine development require approval of the MPA's Committee for Marine Projects (COMET).[23] The Committee's function is to ensure that such projects to not affect the navigational safety of vessels.[24] There is no legal requirement for EIAs to be carried out or for public participation in the approval process.

1.6. Coastal and Marine Spatial Planning

Coastal and marine spatial planning ("**MSP**") are at least as important, if not more important, for marine nature conservation as it is for terrestrial nature conservation; ecologically sensitive coastal marine areas in the ocean are more vulnerable to threats from developments and activities sited in proximity to such areas. The government adopted in 2009, an integrated coastal management framework developed by the Partnerships in Environmental Management for the Seas of East Asia (PEMSEA); and later developed the Integrated Urban Coastal Management ("**IUCM**"), said to be a "proactive planning and management framework for sustainable development of the marine and coastal areas in an urban context".[25] Coordination under the framework takes place through an inter-agency committee, Technical Committee on the Coastal and Marine Environment ("**Technical Committee**"), the workings of which are not publicly known. It appears that National Parks Board ("**NParks**") is the lead agency for nature conservation issues, and the National Environment Agency and the MPA as the lead agencies for pollution issues for the committee.[26] While the URA is the lead agency for land use planning and the Ministry for Trade and Industry is the lead agency for economic planning, it is not clear whether the framework provides for any coastal and marine spatial planning, and if so, how this is carried out.[27]

1.7. Recommendations

Analogous to its terrestrial counterpart, MSP is a "public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve

[22] *Maritime and Port Authority of Singapore Act* (Cap 170A, 1997 Rev Ed), section 79.
[23] Maritime and Port Authority of Singapore, "Foreshore and Marine Development Projects", <https://www.mpa.gov.sg/web/portal/home/port-of-singapore/operations/marine-projects/foreshore-and-marine-development-projects>.
[24] *Singapore's Integrated Urban Coastal Management* (Technical Committee on the Coastal and Marine Environment, 2013), p 4, <https://www.nparks.gov.sg/-/media/nparks-real-content/biodiversity/programmes-and-initiatives/nparks_iucm-booklet_mar2013.pdf?la=en&hash=82D4666436E262EC4319FBE6C8F94F05D58A38FA>.
[25] National Parks Board, "Integrated Urban Coastal Management (IUCM)", <https://www.nparks.gov.sg/biodiversity/community-in-nature-initiative/iucm>.
[26] Lena Chan, "Marine Biodiversity Conservation in Singapore", Presentation at the 29th International Coral Reef Initiative General Meeting (20 October 2014), p 11, <https://www.icriforum.org/sites/default/files/GM29_1_2_Marine_Biodiversity_Conservation_Singapore.pdf>.
[27] Lena Chan, "Marine Biodiversity Conservation in Singapore", Presentation at the 29th International Coral Reef Initiative General Meeting (20 October 2014), p 11, <https://www.icriforum.org/sites/default/files/GM29_1_2_Marine_Biodiversity_Conservation_Singapore.pdf> and *Singapore's Integrated Urban Coastal Management* (Technical Committee on the Coastal and Marine Environment, 2013), p 14, <https://www.nparks.gov.sg/-/media/nparks-real-content/biodiversity/programmes-and-initiatives/nparks_iucm-booklet_mar2013.pdf?la=en&hash=82D4666436E262EC4319FBE6C8F94F05D58A38FA>.

ecological, economic and social objectives that are usually specified through a political process".[28] Formally including MSP as an aspect of the IUCM framework (if this is not already being done) through laws that provide for its implementation, the legal status of such plans, and establishing a lead agency which performs a role not unlike that of the URA ensures a systematic and structured approach to managing conflicting uses of the coasts and the sea. A formal MSP framework, incorporating provisions for SEAs, EIAs and public participation will promote greater transparency and accountability in environmental governance, and the observation and sustainable use of the coastal and marine environment.

2. COASTAL AND MARINE NATURE CONSERVATION

2.1. Rules of International Law on the Conservation of the Marine Environment

UNCLOS provides States' rights and obligations with respect to all activities at sea. It is drafted to have pre-eminence and/or incorporate other treaties that deal with components of the marine environment. Provisions of other treaties can also be used to interpret UNCLOS. UNCLOS clearly makes it an obligation for States to protect and preserve the marine environment and take all measures necessary to prevent, reduce and control pollution of the marine environment from all sources as well as measures necessary to protect and preserve rare or fragile ecosystems and the habitat of depleted, threatened or endangered species and other forms of marine life. Its framework provisions allow it to tap on the more detailed or specialised rules and standards set out in existing instruments, and adapt to changed circumstances through subsequent instruments through open-ended rules of reference, giving it a 'living' quality.[29] These detailed rules and standards can assist States with the fulfilment of their obligation under UNCLOS to protect the marine environment and act with due diligence in doing so (as required under international law). Application of States' obligation to take measures necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life are informed by applicable treaties such as:

(i) The CBD provides for an obligation to establish system of protected areas or areas where special measures need to be taken to conserve biological diversity and the Conference of the Parties (COP) to the CBD has adopted criteria to identify Ecologically or Biologically Significant Areas ("**EBSAs**") where the protection of biodiversity should be prioritised. Regional workshops have been prioritized for the identification of such EBSAs. In this context, most of the Straits of Malacca and Singapore (SOMS) have been included in an EBSA.[30] This EBSA includes waters of Singapore, Malaysia and Indonesia and focuses on foraging and nesting sites for

[28] Charles Ehler and Fanny Douvere, Marine Spatial Planning: A Step-by-Step Approach Toward Ecosystem-Based Management (UNESCO, 2009), p 18, <http://unesdoc.unesco.org/images/0018/001865/186559e.pdf>.

[29] Richard Alan Barnes, "The Continuing Vitality of UNCLOS", in J Barrett and R Barnes (eds), *The United Nations Convention on the Law of the Sea: A Living Instrument* (BIICL, 2016), 459. See also Article 237 of UNCLOS which provides that the provisions in the convention relating to the protection and preservation of the marine environment are without prejudice to the specific obligations assumed by States under agreements concluded previously which relate to the protection and preservation of the marine environment and to agreements which may be concluded in furtherance of the general principles set forth in this Convention.

[30] This is one of 279 EBSAs. The workshop took place in Xiamen on 13-18 December 2015 and the conclusions were presented to CBD COP XIII in December 2016. Workshop report: <https://www.cbd.int/doc/meetings/mar/ebsaws-2015-03/official/ebsaws-2015-03-04-en.pdf>. See also CBD/COP/DEC/XIII/12, 17 December 2016, https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-12-en.pdf>.

green sea turtles and hawksbill sea turtles. An important provision of the CBD relates to the obligation of States to monitor the components of biodiversity and the impact of activities on them. The standard of care expected from States in the discharge of their obligation to act with due diligence to protect and preserve the marine environment (an obligation under UNCLOS) is also expected to be higher in globally recognised sensitive marine areas.

(ii) The *1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora* ("**CITES**"), an international treaty between 182 member states, including Singapore, regulates international trade in specimens of threatened and endangered species of flora and fauna (including marine and coastal species) and lists these species in appendices, according to the degree of protection deemed necessary for their survival.[31] Species listed in CITES' Appendix I and II require particular management measures.

(iii) Under the *1971 Convention on Wetlands of International Importance especially as Waterfowl Habitat* ("**Ramsar Convention**"), State parties must designate suitable wetlands in their territory, on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology, for inclusion in a List of Wetlands of International Importance.[32] They must formulate and implement their plans to promote the conservation of the wetlands included in the List, and as far as possible the wise use of wetlands in their territory. State parties must also promote the conservation of wetlands and waterfowl by establishing nature reserves on wetlands, whether they are included in the List or not, and provide adequately for their wardening.[33] Singapore is not a party to the Ramsar Convention.

(iv) The *1979 Convention on the Conservation of Migratory Species of Wild Animals* ("**CMS**"), is designed for the purposes of conserving terrestrial, marine and avian migratory species. The Convention provides inter alia, that subject to limited exceptions, State parties that are Range States of endangered migratory species listed in Appendix I of the Convention must prohibit the taking of animals belonging to such species.[34] They must also endeavour to conserve and, where feasible and appropriate, restore those habitats of the species which are of importance in removing the species from danger of extinction (critical habitats include breeding, spawning, feeding and resting grounds); endeavour to prevent, remove, compensate for or minimize, as appropriate, the adverse effects of activities or obstacles that seriously impede or prevent the migration of such species; and to the extent feasible and appropriate, prevent, reduce or control factors that are endangering or are likely to further endanger the species.[35] Singapore is also not a party to the CMS nor CMS Memoranda of Understanding ("**MOUs**") despite being a Range State for several species listed in Appendix I and being the subject of a MOU applicable to

[31] CITES, Appendices I, II & III.
[32] Ramsar Convention, Article 2.
[33] Ramsar Convention, Article 4.
[34] CMS, Article 3.5.
[35] CMS, Article 3.4.

species known to be present in Singapore. The most relevant MOUs in this context are the 2001 MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia and the MOU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range.

2.2. Singapore Law on the Conservation of Marine Environment Including Biodiversity

Domestically, the *Endangered Species (Import and Export) Act* ("**ESA**")[36] gives effect to Singapore's obligation under CITES. The ESA is critical in controlling the import and export of species threatened by unsustainable trade. In the context of the Blue Plan that focuses on the Singapore marine environment, CITES is particularly relevant in the export of CITES-listed specimens of wild fauna and flora that are caught within Singapore's jurisdiction. Domestically, the sale of rhinoceros and tigers, including their parts and meat, is prohibited,[37] but there is no similar prohibition on marine wildlife.

Operationally, challenges in the implementation of CITES continue to exist. For example, Appendix I and II of CITES list 30 shark and ray species threatened with extinction, requiring all trade in such species to be accompanied by a permit. However, Singapore does not contain species-specific product codes for all 30 of the CITES-listed species, which could allow certain illegal trade to be overlooked[38]. The Agri-Food and Veterinary Authority of Singapore ("**AVA**")'s Product Codes for Fish and Fish Products, most recently updated on 1 October 2017, provides species-specific product codes for 167 shark species[39]. It is unclear if all CITES-listed fauna and flora now have their own product codes.

Apart from endangered wild animals, such as marine turtles, whether by virtue of being listed in CITES or CMS, or listed in the Singapore Red Data Book,[40] have no special legal status or receive special protection other than those also enjoyed by other wild animals.[41] In this regard, the *Wild Animals and Birds Act* ("**WABA**")[42] deals with the protection of wild animals and birds outside Singapore's protected nature areas (such as nature reserves and marine parks). It mainly seeks to reduce poaching and regulate the killing, taking, keeping or importation of wildlife without permits from the AVA, which has drawn many questions from the environmental community about its effectiveness in conserving biodiversity over its narrow scope.[43]

A question arises as to whether WABA is sufficiently coherent in addressing marine wildlife protection, including threatened and endangered species located outside protected areas.

[36] Cap 92A, 2008 Rev Ed.
[37] *Endangered Species (Import and Export) (Prohibition of Sale) Notification* (Cap 92A N1, 2006 Rev Ed).
[38] Tan, Audrey. "Singapore Ranked Third in Shark Fin Trade: Report", *The Straits Times,* May 25, 2017, <https://www.straitstimes.com/singapore/environment/spore-ranked-third-in-shark-fin-trade-report>.
[39] Agri-Food & Veterinary Authority of Singapore. Quarantine & Inspection Group Import & Export Regulation Department (Seafood),), *Product Codes for Fish and Fish Products*, (1 October 2017), <https://www.ava.gov.sg/docs/default-source/default-document-library/product-code-for-fish-and-fish-products-(updated-1-oct-2017)7f2b8e1875296bf09fdaff00009b1e7c>.
[40] G W H Davison, P K L Ng, and H C Ho, (eds), *The Singapore Red Data Book: Threatened Plants and Animals of Singapore* (Nature Society, 2008).
[41] Wild plants are not protected outside of nature reserves and public parks.
[42] Cap 351, 2000 Rev Ed.
[43]Vinayagan, Dharmarajah. "Review of Wild Animals and Birds Act (WABA): Proposals for Its Improvement",", *Proceedings of Nature Society, Singapore's Conference on 'Nature Conservation for a Sustainable Singapore'*, October 16, 2011.

Section 2 defines “wild animals and birds” as “[including all species of animals and birds of a wild nature”, but [excluding] domestic dogs and cats, horses, cattle, sheep, goats, domestic pigs, poultry and duck”[44]. It is not clear whether marine animals and invertebrates come within the definition, although a plain reading of the definition suggests they do. With respect to application to marine animals, marine mammals (unlike birds) are specifically the objects of an exceptional licensing scheme provided for in the Wild Animals (Animal Licensing) Order that was adopted under WABA; this indirectly suggests that WABA is applicable to marine animals. Operationally, the AVA appears to be enforcing the Act against the killing, taking, and keeping, of terrestrial species; but not marine and inter-tidal species[45]. This could possibly be because in colonial times, the focus of the Act was on keeping hunting sustainable, and recreational fishing largely took place unregulated. A strong recreational fishing lobby exists in Singapore today[46].

Another issue is the low maximum punishment for offences under WABA; a fine of $1,000. This maximum punishment has not been revised since 1965, and is hardly a deterrent today.

2.3. Recommendations

The recommendations are as follows: 1) To monitor components of coastal and marine biodiversity, and to give the public access to such monitoring records; 2) To accede to the CMS and relevant MOUs; 3) To update the Product Codes for Fish and Fish Products to include each of the ESA’s list of scheduled species of marine flora and fauna, to promote the open availability of product-specific trade data and to ensure that illegal wildlife trade is not overlooked by the lack of specification; 4) To define “wild animals” in WABA to explicitly cover aquatic and marine wild animals (including invertebrates) unless an activity or species is specifically excluded, so as to better ensure the protection of intertidal, aquatic, coastal, and marine species; beyond the species protected and activities regulated under the Fisheries Act.

3. PROTECTED AREAS IN SINGAPORE

In Singapore, the level of legislative protection a natural area receives depends on its status under the *Parks and Trees Act* (“**PTA**”),[47] which is administered by NParks. National parks and nature reserves receive the greatest protection, through more comprehensive regulation of activities that may be carried out therein and higher penalties for infringement of such regulations, as compared to other protected areas such as public parks. They are defined by their boundaries in the Schedule of the PTA, and by law, they are set aside for the propagation, protection and conservation of the flora and fauna of Singapore; the study and preservation of objects and places of aesthetic, historical or scientific interest; the study of knowledge in botany, horticulture, biotechnology, or natural and local history; and/or recreational and educational use by the public.[48] Currently, two coastal areas have been designated as nature reserves;[49] but no marine areas have been designated as national parks

[44] WABA, section 2.
[45] WABA, section 2.
[46] Commercial fishing is regulated under the *Fisheries Act* (Cap 111, 2002 Rev Ed).
[47] Cap 216, 2006 Rev Ed.
[48] PTA, section 7(3).
[49] These are Labrador Nature Reserve and Sungei Buloh Wetland Reserve.

or nature reserves to date. Alterations to the designation of national parks and nature reserves must be gazetted by the Minister and presented to Parliament as soon as practicable.

Public parks, including coastal public parks, also receive protection. While the scope of regulated activities within public parks is almost comparable to those in national parks and nature reserves, penalties for infringing these regulations are generally lower. Public parks are by definition land, and thus while there some coastal areas are public parks; sea areas cannot become public parks. A public park is defined in the PTA inter alia as an area is utilized as a public park. An area can therefore cease to become a public park at the government's administrative discretion.

Seven coastal areas[50] are also designated as 'nature areas'. These are areas with amorphous boundaries, and are "subjected to administrative safeguards under the Parks and Waterbodies Plan" ("**PWB**").[51] The PWB is a Special and Detailed Control Plan that supports the Master Plan but appears to be separate from the Master Plan itself. Hence, any designation of nature areas may be altered without the statutory safeguards accorded to the alteration of the Master Plan under the MPR. According to the 'legend' in the PWB, nature areas "will be kept for as long as possible until required for development. If development falls within or in the vicinity of the demarcated areas, ecological studies may be required as advised by the relevant authority before any development proceeds".[52]

Singapore's only protected marine area is the Sisters' Islands Marine Park ("**SIMP**"). The SIMP is home to an array of coral reefs, sandy shores and seagrass areas.[53] Legally, the SIMP is a marine park, defined as "*any area of the sea or seabed* that is set aside for conservation of marine organisms and is designated in Part III of the Schedule".[54] The PTA further defines public parks inter alia as "… *land* utilised as marine parks" and managed by NParks.[55] It is not clear how the two definitions can be read harmoniously other than to anomalously construe the Sisters' Islands, being land used as marine parks (i.e., for the conservation of marine organisms) are public parks but not marine parks; while the sea and sea bed areas around the island are construed as marine parks but not public parks. If this construction is correct, then marine parks currently designated under the PTA (ie, the designated sea and seabed areas) receive no legal protection.

The designation of the SIMP as a marine park is a conservation milestone. Yet, it should be noted that marine parks receive significantly less legal protection than nature reserves. Apart from the fact that the designated sea and sea bed areas of a marine park may receive no legal protection, the punishment for offences in public parks under the Parks and Trees Regulations is lower than that for similar offences committed in nature reserves under the PTA. Furthermore, while an area designated as a nature reserve is set aside by law for

[50] Urban Redevelopment Authority, "Parks and Water Bodies Plan", <https://www.ura.gov.sg/maps2/?service=PWB>

[51] National Parks Board, "Nature Areas & Nature Reserves", <https://www.nparks.gov.sg/biodiversity/our-ecosystems/nature-areas-and-nature-reserves>.

[52] Urban Redevelopment Authority, Parks and Waterbodies Plan", <https://www.ura.gov.sg/maps2/?service=PWB>.

[53] National Parks Board, "Sisters' Islands Marine Park", <https://www.nparks.gov.sg/sistersislandsmarinepark>.

[54] PTA, section 2. Emphasis added.

[55] PTA, section 2. Emphasis added.

specific purposes, an area designated as a marine park is not similarly set aside and can be put to any use at the discretion of the government.

3.1. Recommendations

Recommendation is as follows: 1) To introduce provisions to regulate activities in the sea and seabed areas that constitute marine parks with the involvement of stakeholders.

4. POLLUTION FROM COASTAL AND MARINE ACTIVITIES

4.1. Ship-based Pollution

Under UNCLOS, Singapore is required to adopt laws and regulations for the prevention, reduction and control of pollution of the marine environment from Singapore-registered vessels. These laws and regulations must be at least equivalent, if not more stringent than "generally accepted international rules and standards established through the competent international organization" (ie, the International Maritime Organisation ("**IMO**") and its conventions.)[56]

Notably, the definition of marine pollution as adopted by UNCLOS is broadly inclusive: "introduction by man, directly or indirectly, of *substances* or *energy* into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities." Thus, arguably, even greenhouse gas emissions could be regulated by UNCLOS[57], as it is effectively the introduction of (heat) energy into the marine environment.[58]

The specific regulations on marine pollution, as referred to by UNCLOS, are the IMO conventions, including:

- **1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* ("**London Convention 1972**")") (regulates dumping of specified materials at sea)
    - * 1996 Protocol *to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (regulates dumping of all materials (other than those specified) at sea)
- MARPOL 73/78 (pollution of sea by operation of ships)
- *1990 International Convention on Oil Pollution Preparedness, Response and Co-operation* ("**OPRC 1990**") (establishes measures for dealing with marine oil pollution incidents)
    - *2000 Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances* ("**OPRC-HNS Protocol**")

[56] UNCLOS, Articles 211(2) to (4).
[57] Meinhard Doelle, "Climate Change and the Use of the Dispute Settlement Regime of the Law of the Sea Convention", (2006) Ocean Development & International Law 37:319.
[58] Rajendra K Pachauri and Leo Meyer, (eds), *Climate Change 2014 Synthesis Report* (Intergovernmental Panel on Climate Change, 2014), at pp 60 to 62.

(establishes measures for dealing with marine pollution incidents involving hazardous and noxious substances)

- *1992 International Convention on* Civil Liability Convention *for Oil Pollution Damage* ("**CLC 1992**") (sets up compulsory insurance for compensation for oil pollution damage)
- **1992 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage* ("**Fund Convention 1992**") (sets up fund to provide compensation for accidental cargo oil pollution damage to the extent that the protection afforded by the CLC 1992 is inadequate).
    - *2003 Protocol establishing an International Oil Pollution Compensation Supplementary Fund* ("**Supplementary Fund 2003**")(sets up additional coverage for accidental cargo oil pollution damage)
- **1996 International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea* ("**HNS Convention 1996**")(civil liability for HNS pollution damage)
    - **2010 Protocol to the 1996 International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea* (sets up compulsory insurance and fund for accidents at sea involving hazardous and noxious substances) (not yet in force)
- *2001 International Convention on Civil Liability for* Bunker *Oil Pollution Damage* (Convention), (sets up compulsory insurance for accidental bunker oil pollution damage)
- *2001 International Convention on the Control of Harmful Anti-fouling Systems in Ships* ("**AFSC 2001**"), (bans use of harmful marine anti-fouling systems)
- *2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments* ("**BWMC 2004**") (regulates transfer of aquatic organisms in ballast water)

Singapore is a party to all the above conventions except those marked with asterisks (*), and has implemented domestic legislation for conventions it is party to.

4.1.1. Ship-based Operation Pollution

MARPOL 73/78 covers most forms of marine pollution by ships caused by their operation. The provisions are replicated in Singapore's legislation through the *Prevention of Pollution of the Sea Act* ("PPSA"),[59] along with the AFSC 2001 and the BWMC 2004.

Broadly speaking, the PPSA and its regulations adopt MARPOL73/78 provisions on the design, construction, equipping, and certification of Singapore-registered ships to ensure that they do not discharge the various pollutants below, or ensure that they are treated to safe levels before discharge. Additionally, Singapore is required to provide reception facilities to collect the below-mentioned pollutants for safe treatment in port. The forms of pollution covered are:

[59] Cap 243, 1999 Rev Ed.

Pollutant	MARPOL 73/78	PPSA Regulation
Oil	Annex I	*Oil Regulations 2006*[60]
Noxious liquid substances	Annex II	*Noxious Liquid Substances in Bulk Regulations 2006*[61]
Sewage (i.e., liquid waste)	Annex IV	*Sewage Regulations 2005*[62]
Garbage (i.e., solid waste)	Annex V	*Garbage Regulations 2012*[63]
Air pollution (by ship exhaust) (Ozone-depleting substances, carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur oxides (SOx), particulate matter, and volatile organic compounds (VOCs))	Annex VI	*Air Regulations 2005*[64]

Biodiversity harm	Convention	PPSA Regulation
Organotin compounds which act as biocides in anti-fouling systems	AFSC 2001	*Harmful Anti-Fouling Systems Regulations 2010*[65]
Harmful aquatic organisms and pathogens carried in ballast water	BWMC 2004	*Ballast Water Management Regulations 2017*[66]

4.1.2. Ship-based Accidental Pollution

Accidental ship-based pollution comes mainly in two forms: persistent oil, and hazardous and noxious substances ("**HNS**") (including non-persistent oil such as light diesel, as well as liquid natural gas ("**LNG**").

Preparedness, Response, Cooperation

The OPRC 1990 facilitates international co-operation and mutual assistance between States and regions when preparing for, and responding to, major oil pollution incidents, and requires States to develop and maintain an adequate capability to deal with such emergencies. The operators of ships, offshore platforms, ports and oil terminals are also required to prepare oil pollution emergency plans.

The OPRC 1990 was extended to hazardous and noxious substances by the OPRS-HNS Protocol 2000.

Compensation

The relevant conventions are the CLC 1992 and Fund Convention 1992 for cargo oil; Bunker Convention 2001 for bunker oil; and the HNS Convention 1996 and 2010 Protocol for HNS. However, the HNS Convention and Protocol are not in force, Singapore is not a party to

60 S685/2006.
61 S686/2006.
62 S135/2005
63 S663/2012.
64 S135/2005.
65 S198/2010.
66 S504/2017.

either. In all these schemes, the ship owner is made strictly liable (i.e., the owner is liable even in the absence of proof of fault) for pollution damage caused by oil or HNS spills as a result of an incident, but subject to limits unless it is proved that the spill was intentional or done in the knowledge that any such damage or cost would probably result.

Pollutant	**Convention**	**Singapore Legislation**	**Civil liability limit (in SDR)**	**Fund compensation limit (in SDR)**
Cargo oil	CLC 1992 Fund Convention 1992 *Supplementary Fund 2003	*Merchant Shipping (Civil Liability and Compensation for Oil Pollution) Act* (Cap 180) (COPA)	Between 4.51 million and 89.77 million (depending on ship tonnage)	203 million per incident (main Fund) 750 million per incident (main Fund + Supplementary Fund)
Bunker oil	Bunker Convention 2001	*Merchant Shipping (Civil Liability and Compensation for Bunker Oil Pollution) Act* (Cap 179A) (BOPA)	Begins at 167,000[67]	NA
HNS	*HNS Convention 1996 *2010 Protocol (both not in force)	NA (Singapore not a party)	Begins at 10 million for bulk HNS; 11.5 million for packaged HNS	250 million per incident

4.1.3. Disposal of Waste at Sea from Ships

Dumping of waste cargo carried by ships into the sea is governed by the London Convention 1972, as well as its 1996 Protocol. The London Convention 1972 establishes a "black list" (Annex I) and a "grey list" (Annex II). Dumping of materials in the black list at sea are absolutely prohibited, while those in Annex II must be regulated and controlled under a permit system when dumping at sea. The 1996 Protocol adopts a "reverse list" (or a "white list") approach, allowing the dumping of a restricted category of eight types of waste (Annex 1), and subject to an impact assessment and permit system (Annex 2).

Singapore is neither a party to the London Convention, nor its Protocol.

Nonetheless, it is arguable that the London Convention (and to a lesser extent its Protocol given the limited number of State Parties) referred to in Article 210(6) of UNCLOS, in which UNCLOS State Parties are required to adopt national laws and regulations against pollution by dumping at sea which are "no less effective in preventing, reducing and controlling such pollution than the *global rules and standards*" – the latter possibly referring to the London Convention. Provisions of the London Convention can be seen as setting the minimum

[67] Singapore acceded to the 1976 Convention on Limitation of Liability for Maritime Claims ("**LLMC 1976**") in 2005. The LLMC 76 limits the liability of claims for loss of life or personal injury, or loss or damage to property occurring on board or in connection with the operation of a ship or salvage operations, and safeguards and provides greater certainty in the event of a claim, without the need to resort to litigation. The *Protocol of 1996 to amend the Convention on Limitation of Liability for Maritime Claims of 19 November 1976* ("**1996 LLMC Protocol**") (with 2012 amendments) would have increased this to 1.51 million SDR. Singapore is not a party to the Protocol.

standard for the placement of waste of sea; disposal of waste streams such as dredge waste require a prior EIA including physical, chemical and biological characteristics, a dumping-site review and the granting of a licence.

4.1.2. Recommendations

Recommendations are as follows: 1) Singapore should accede to the Supplementary Fund Protocol 2003[68]; 2) Singapore should accede to the 1996 LLMC Protocol, to update the limitation of claims under the LLMC 1976, to keep up with the times[69]; 3) Singapore should accede to the HNS Convention 1996 and 2010 Protocol to take into account the risks accompanying the increasing use of LNG-powered ships, as well as other alternative-fuelled ships; 4) Singapore should accede to the London Convention 1972 and explore the possibility of furthering its commitment to protecting the marine environment by acceding to the 1996 Protocol; in any case, to comply with UNCLOS, Singapore's legislation must include regulations on the disposal of waste at sea by its nationals and vessels flying its flags.

4.2. Non-ship Sea-based Pollution

The PPSA, with its prohibitions on throwing pollutants into Singapore waters.[70]

Another body of legislation concerns coastal and offshore fisheries and fishing vessels in Singapore – the *Fisheries Act* (“**FA**”)[71] and its subsidiary regulations and is managed by the AVA. This includes the *Fisheries (Fishing Vessels) Rules*,[72] which creates a registry of Singapore fishing vessels, and the *Fisheries (Fishing Gear) Rules* (“**FGR**”),[73] which creates a licensing scheme for nets, stakes, traps, and lines with more than 3 hooks[74]. Rule 7 of the FGR requires the licensee of fishing gear, when abandoning the fishing gear or upon the expiry or revocation of the license or when ceasing to use or operate the fishing gear, to remove the gear; but in the event of non-compliance, the Rules only appears to empower the Director-General to remove the gear at the expense of the licensee but does not appear to criminalize the non-compliance.

The FA also regulates the fish farms in Singapore, including those that are offshore but within Singapore’s territorial waters. Specific regulations are found in the *Fisheries (Fish Culture Farm) Rules* (“**FCFR**”).[75] While they are under an obligation to “ensure waters *in and around the fish farm* are clean and pollution-free at all times”, Pollution of the marine environment is regulated under the PPSA, but it would seem that the EPHA could also apply to their wastes as they are “industries” (any trade, business, manufacture or building construction)[76], and therefore required them to store their industrial waste in a “proper and

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[68] Singapore imports more than 1 million tonnes of oil annually, so it would not be disadvantaged by the Supplementary Fund’s 1 million-tonne floor used to reckon annual contributions. Acceding to Protocol would give Singapore a much larger amount of protection than the Fund Convention 1992 alone.
[69] See fn 82 above.
[70] PPSA, section 5.
[71] Cap 111, 2002 Rev Ed.
[72] Cap 111 R 2, 1994 Rev Ed.
[73] Cap 111 R 6, 1994 Rev Ed.
[74] FGR, rule 2.
[75] Cap 111 R 7, 1994 Rev Ed.
[76] EPHA, section 2.

efficient manner",[77] and to dispose of the waste in an approved disposal facility.[78] However, again, the EPHA is administered by the National Environment Agency (NEA); this leaves the question of whether the NEA can successfully and efficiently enforce the EPHA against fish farmers. It may afford better enforcement coordination to replicate these provisions in the FCFR or in the licence conditions for fish farm licences (if this is not already the case), bringing the issue under the AVA's jurisdiction. Rule 8 of the FCFR requires the licensee to upon expiry or revocation of the license or ceasing to operate the fish culture farm, remove the equipment used for fish culture; but in the event of non-compliance, the Rules only appears to empower the Director-General to remove the gear at the expense of the licensee but does not appear to criminalize the non-compliance.

Another question is if fish farms could inadvertently introduce invasive foreign species as livestock, bait, or food, which would threaten Singapore's marine biodiversity. While there are no such control measures on fish farms in the FCFR when they seek to import live specimens of foreign species, it is not known whether restrictions are imposed though licensing conditions (since these are not made public).

Finally, pursuant to CBD COP Decision XIII/10,[79] State parties to the CBD are encouraged to take appropriate measures to avoid, minimize and mitigate the potential significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity. It is not known whether such measures are taken in Singapore.

4.2.1. Recommendations

Recommendations are as follows: 1) Amend the FA to make clear that the PPSA is applicable to fishing vessels, bringing these offences in relation to fishing vessels under the AVA's jurisdiction, *unless* the AVA specifically exempts fishing vessels from specific regulations; 2) Amend the FCFR to include prohibition on improper storage and disposal of wastes generally, control measures on fish farms when they seek to import live specimens of foreign species; and criminalize the indiscriminate disposal or abandonment of fish culture equipment; and 3) Amend the FGR to criminalize the indiscriminate disposal or abandonment of fishing gear.

5. CONTROL OF POLLUTION FROM LAND-BASED ACTIVITIES

5.1. Introduction

Threats to the marine environment can stem from many sources, of which a large amount is due to pollutants from land-based sources. Globally, the United Nations Educational, Scientific and Cultural Organization (UNESCO) estimates that as much as 80% of marine pollution stems from land-based sources.[80]

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[77] EPHA, section 25.
[78] EPHA, section 24.
[79] CBD/COP/DEC/XIII/10, 10 December 2016, <https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-10-en.pdf>.
[80] United Nations Educational, Scientific and Cultural Organization, "Facts and Figures on Marine Pollution", <http://www.unesco.org/new/en/natural-sciences/ioc-oceans/focus-areas/rio-20-ocean/blueprint-for-the-future-we-want/marine-pollution/facts-and-figures-on-marine-pollution/>..

This section will provide a brief summary of legislative measures with regards to pollution from land-based activities, with reference to international legal frameworks. While the sources of land-based pollution can be many and diverse, this section will focus on four broad components, namely a) airborne pollutants from land-based activities, b) pollution from inland sources of water leading to the sea, c) pollution from waste discharged from land and d) light and noise pollution. This categorisation of land-based sources is not new and are consistent with that as already identified by Osborn.[81]

5.2. International Legal Framework

Article 194 of UNCLOS requires states to take measures to 'prevent, reduce and control' pollution of the marine environment and Article 207 of UNCLOS, imposes an obligation on states to adopt laws and regulations to prevent, reduce and control pollution of the marine environment from land-based sources, including the release of toxic, harmful or noxious substances, especially those that are persistent into the marine environment. In addition, states must take any other measures necessary, endeavour to harmonise their policies at the appropriate regional level and endeavour to establish global and regional standards and recommended practices and procedures for this purpose.

5.3. Air Pollution

Airborne pollutants can affect the marine environment as air pollutants can enter the water from the atmosphere.[82] Marine pollution "to and from the atmosphere", is provided for under Article 212 of UNCLOS. In addition to the general obligation under Article 212, UNCLOS also gives effect to international conventions such as the *1992 United Nations Framework Convention on Climate Change* ("**UNFCCC**") and the *1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change* ("**Kyoto Protocol**") under Article 212 (3).

However, even under Article 212 of UNCLOS, there is no conclusive list of what land-based sources of pollution are to be considered, leaving states to identify and legislate for specific forms of atmospheric pollution and levels of "acceptable" pollution. In Singapore, the sources of atmospheric pollution include industry and motor vehicles.

Singapore's air quality targets are in line with World Health Organisation's generic recommended targets;[83] these take into account general risks to human health, but do not appear to consider the specific ecological requirements of particular ecosystems. Singapore is currently not meeting these targets.

5.3.1. Industrial Premises

Domestically, the Environmental Protection and Management Act (EPMA), governs industrial emissions and pollution. Part IV of the EPMA puts the onus on occupiers of any

[81] David Osborn, "Land-based Pollution and the Marine Environment", in Rosemary Rayfues, (ed), *Research Handbook on International Marine Environmental Law* (Elgar, 2015), p 81.

[82] James Harrison, "Pollution of the Marine Environment From or Through the Atmosphere", <https://lawexplores.com/pollution-of-the-marine-environment-from-or-through-the-atmosphere-james-harrison/#law-9780199683949-chapter-6-note-838>.

[83] National Environment Agency, "Air Quality and Targets", <http://www.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/air-quality-and-targets>.

industrial or trade premises to comply with the requirements under the Act with regards to air pollution control.

The *Environmental Protection and Management (Air Impurities) Regulations* prescribe emission standards for specified air impurities; for air impurities that are unspecified, the owner or occupier must conduct the trade or industrial process or operate fuel burning equipment or industrial plant on the premises by the best practicable means available as may be necessary to prevent or minimise air pollution).[84]

5.3.2. Vehicular Emissions

The *Environmental Protection and Management (Vehicular Emissions) Regulations*, regulating private vehicle carbon emissions, making it an offence for any person to use or permit the use of any smoky vehicle on the road.

5.4. Land and Inland Water Pollution

Apart from atmospheric pollution, pollutants can also come from inland waters which find their way to the sea. For these type of pollutants, section 15 of the EPMA makes it an offence for polluting matters to be discharged into any drain[85] or land without prior approval. Similarly, the discharge of trade effluents into sewers requires prior approval under the *Sewerage and Drainage Act*.[86]

Section 17(2) of the *Environmental Public Health Act* ("**EPHA**") also provides for pollution of" "any refuse or any other matter or thing" into watercourses or any part of the sea abutting the foreshore to constitute an offence.

5.5. Waste Management

Marine trash also accounts for a large amount of pollution from land-based pollution. Marine trash can constitute trash such as plastics, litter or refuse that ends up in waterways and the seas.

Under the EPHA, throwing refuse etc in any public place constitutes an offence.[87] Industrial waste must be brought to public or licensed disposal facilities, and to ensure that waste is properly transported and disposed of, only licensed waste collectors may carry on the business of collecting waste.[88]

5.6. Noise and Light Pollution

Additionally, apart from the above-mentioned sources of pollution, it is worth questioning if light and noise pollution are encompassed in the definition of pollution in UNCLOS. Arguments have been made that these would fall under the definition of energy under

[84] EPHA, section 12(2).
[85] Drains are defined in the Act as including any watercourse or river; and watercourse, by definition in the Act, include any part of the sea abutting on the foreshore.
[86] Cap 294, 2001 Rev Ed, section 16.
[87] EPHA, section 17(1).
[88] EPHA, section 31.

Article 1 of UNCLOS.[89] However, as yet Singapore has no legislation to regulate light pollution (although land use is regulated under the PA),[90] while noise pollution from construction works and from work places are regulated under the EPMA.

5.7. Recommendations

More targeted legislation is required in waste management as plastics and microbeads are not the subject of specific legislation under the EPHA and the EPMA. In contrast, the PPSA legislates against the disposal of plastics and discharge of sediments into the sea. Other jurisdictions have enacted legislation to ban or levy a tax on the manufacture, import and/or use of single-use plastics[91].

6. CLIMATE CHANGE MITIGATION

6.1. UNCLOS

In addition to Singapore's obligations under Article of the 2015 Paris Agreement, Singapore has international obligations under UNCLOS to protect and preserve the marine environment;[92] and to prevent, control and reduce pollution of the marine environment from any source, including taking measures necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life[93]. These obligations would point to a duty to exercise due diligence in mitigating climate change.

6.2. Shipping

Although the impact of climate change on marine biodiversity may not be primarily resulting from ocean-related activities, ocean climate change mitigation is critical to curbing long-term climate change. A large contributor to climate change is that of the shipping industry, that has lobbied consistently and successfully to be excluded from any obligations to reduce emissions under the Kyoto Protocol, and the 2015 Paris Agreement.[94]

Shipping and aviation are the sole industries that remain unregulated under the UNFCCC and its protocols. Even the Copenhagen Summit of 2009 failed to address the reduction of emissions from international shipping.[95] Besides the successful lobbying of the powerful shipping industry, another issue that resulted in the omission of any provisions for the industry is that of difficulty in allocating a quantum of emissions to regulate. Moreover, countries rarely are able to set emissions targets on a sectorial scale, much less for sectors so exposed to international trade as the shipping sector.

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[89] Robin Churchill, "The LOSC Regime for Protection of the Marine Environment – Fit for the Twenty-First Century?", in Rosemary Rayfues, (ed), *Research Handbook on International Marine Environmental Law* (Elgar, 2015), p 3.

[90] Cap 232, 1998 Rev Ed.

[91] See Dirk Xantos and Tony R Walker, *"International Policies to Reduce Plastic Marine Pollution from Single-Use Plastics (Plastic Bags and Microbeads): A Review",* (2017) *Marine Pollution Bulletin* 118:17, <https://www.sciencedirect.com/science/article/pii/S0025326X17301650?via%3Dihub#f0005>; and Claudia Giacovelli, et al, *Single-Use Plastics: A Roadmap for Sustainability* (UNEP, 2018), <https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf?sequence=1&isAllowed=y>.

[92] Article 192.

[93] Article 194. Pollution of the Marine environment is defined in Article 2 as inter alia the anthropogenic introduction, whether directly or indirectly, of substances or energy into the marine environment. The definition could cover the emission of greenhouse gases ("**GHG**") resulting in warmer and more oceans.

[94] Beatriz Garcia and Jolene Lin, "The Shipping Sector is Finally On Board in the Fight Against Climate Change", *The Conversation*, 18 April 2018, <https://theconversation.com/the-shipping-sector-is-finally-on-board-in-the-fight-against-climate-change-95212>.

[95] "Shipping Emissions Regulations", *Gard Insight 209, 2013* (16 January 2013), <http://www.gard.no/web/updates/content/20734079/shipping-emissions-regulations>.

6.2.1. MARPOL 73/78

MARPOL Annex VI regulates emissions of sulphur and nitrous oxides from GHG shipping as well as ship design for better energy efficiency.

As far as climate change mitigation is concerned, the most important technical measure adopted by the IMO is the Energy Efficiency Design Index (EEDI). The EEDI is a mandatory measure that requires all flag states to adopt minimum energy efficiency level per capacity mile for different ship types and size segments.

The EEDI is developed for the largest and most energy intensive segments of the world merchant fleet and embraces emissions from new ships covering the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. In 2014, MEPC adopted amendments to the EEDI regulations to extend the scope of EEDI to LNG carriers, roll on/roll-off ("**ro-ro**") cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion. These mean that approximately 85% of the carbon dioxide ("**CO_2**") emissions from international shipping are incorporated under the international regulatory regime.

The EEDI is to be ratcheted up incrementally every five years beginning in 2015, calculated from a reference line value ("**RLV**") representing the average efficiency for ships built between 2000 and 2010. However, the EEDI does not prescribe design regulations, and is a purely performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of CO_2 per ship's capacity-mile (the smaller the EEDI, the more energy efficient the ship design is) and is calculated by a formula based on the technical design parameters for a given ship.

Additionally, at the 72nd session of the IMO's Marine Environment Protection Committee, IMO member States agreed on a 40% reduction in carbon intensity by 2030 (as compared to 2008) and 50% reduction of carbon emissions by 2050 (as compared to 2008). While this is a non-binding agreement, it was a breakthrough commitment to engage on a decarbonisation path of international shipping.

It has been noted by the OECD International Transport Forum that the current business-as-usual model, even including IMO energy efficiency measures, would still result in a 23% growth of emissions by 2035 compared to 2015.[96] LNG-powered ships are seen as an alternative to current marine diesel bunkers, but are not carbon emission free. Thus, LNG can only be a transitional phase towards true zero-carbon emission technologies, such as electricity, hydrogen, and ammonia[97]; increased awareness and action on climate change means that Singapore should prepare for higher levels of adoption of zero-emission ships as the industry aligns itself with changing global norms.

[96] OECD International Transport Forum, *Decarbonising Maritime Transport: Pathways to Zero-Carbon ShippingZero-Carbon Shipping by 2035* (International Transport Forum, 2018), <https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport.pdf>.

[97] Lloyd's Register, *Zero-Emissions Vessels 2030. How Do We Get There?* (*Do We Get There?* (Lloyd's Register, 55 February 2018) <https://www.lr.org/en/insights/articles/zev-report-article/>.https://www.lr.org/en/insights/articles/zev-report-article/>.https://www.lr.org/en/insights/articles/zev-report-article/>.https://www.lr.org/en/insights/articles/zev-report-article/>.

Table 9.1. Reduction factors (in percentage) for the EEDI relative to the EEDI RLV, as mandated by regulation[98]

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20	30
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**	15	30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**	20	30
	1,000 – 2,000 DWT	n/a	0-5*,**	0-20*	0-30*
Ro-ro passenger ship***	1000 DWT and above	n/a	5**	20	30
	250 – 1,000 DWT	n/a	0-5*,**	0-20*	0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20	30
	25,000 – 85,000 GT	n/a	0-5*,**	0-20*	0-30*

Note: n/a means that no required EEDI applies.

* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

** Phase 1 commences for those ships on 1 September 2015.

*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of regulation 2.

6.2.2. Maritime Singapore Green Initiative

To reduce GHG from shipping and port related activities in Singapore, the MPA has introduced measures for Singapore ships and ships calling into Singapore, including financial incentives for the adoption of energy efficient ship designs, the adoption of approved Sox scrubber technology, the adoption of LNG fuel.[99]

6.3. Other Provisions of International Law

Apart from its obligations to mitigate climate change under the carbon footprint of 2015 Paris Agreement, Singapore's obligations under UNCLOS to protect and preserve the marine

[98] Table reproduced from International Maritime Organisation, *IMO Train the Trainer (TTT) Course on Energy Efficient Ship Operation: Module 2 – Ship Energy Efficiency Regulations and Related Guidelines* (IMO, 2016) at p 14, <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M2%20EE%20regulations%20and%20guidelines%20final.pdf>

[99] Maritime and Por Authority, *Maritime Singapore Green Initiatives*, <https://www.mpa.gov.sg/web/wcm/connect/www/3ec8f455-5efb-434b-943e-92260a042d39/msgi_leaflet_and_ebrochure.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=3ec8f455-5efb-434b-943e-92260a042d39&attachment=true>.

environment,[100] and take measures to protect and preserve rare or fragile ecosystems[101] may also extend to adopting adaptive measures to protect and preserve the marine environment from the changing climate. Under the CBD, Singapore is also under a duty to, as far as possible and as appropriate, identify and monitor, important components of biodiversity, in particular for the purposes of conservation and sustainable use, using indicative criteria specified in Annex I of the Convention.[102] The Convention also requires State parties to, as far as possible, and as appropriate, rehabilitate and restore degraded ecosystems and promote the recovery of threatened species.[103]

6.4. Singapore Measures

Climate change is projected to bring about, inter alia, higher mean temperatures, higher sea levels, stronger winds (and storms and waves), and ocean acidification. These changes carry risks including changes to coastal and marine biodiversity, coastal erosion and flooding. Singapore's response to these additional risks so far appears to be focussed on administratively developing strategies and plans rather than enact legislation to respond to these challenges.[104] Adaptation projects reported to be underway include the strengthening of coastal protection, and mangrove restoration.[105]

6.5. Recommendations

A formal MSP regime within the IUCM framework,[106] coupled with institutionalised SEAs and EIAs and opportunities for public participation, would promote a systematic and comprehensive process for identifying and monitoring the impacts of climate change on the marine environment, especially in the ecologically sensitive areas, and coordinating and planning adaptive responses to these impacts, including the removal or reduction of local stressors to the environment.

7. MONITORING OF ACTIVITIES AND ENVIRONMENTAL IMPACT ASSESSMENTS

The EIA is "a systematic process to identify, predict and evaluate the environmental effects of proposed actions and projects… applied prior to major decisions and commitments being made".[107] EIAs generally involve the following stages: screening, scoping, impact analysis, mitigation and impact management, review of EIA quality, decision-making, implementation, and monitoring and audit.[108]

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[100] UNCLOS, Article 192.
[101] UNCLOS, Article 194(5).
[102] CBD, Article 7.
[103] CBD, Article 8(f).
[104] Melissa Low, "Challenges in Implementing Climate Adaptation Law: the Singapore Approach", (22 March 2017) <http://esi.nus.edu.sg/docs/default-source/doc/challenges-in-implementing-climate-adaptation-law-in-singapore_melissa-l-.pdf?sfvrsn=2>.
[105] *Singapore's Climate Action Plan: A Climate-Resilient Singapore, For a Sustainable Future* (Ministry of the Environment and Water Resources, 2016), pp 11 to 13, 20, <https://www.nccs.gov.sg/docs/default-source/publications/a-climate-resilient-singapore-for-a-sustainable-future.pdf>.
[106] See Section 2 above.
[107] See Barry Sadler and Mary McCabe, (eds), *EIA Training Resource Manual* (2nd Ed) (UNEP, 2002), p 103. https://unep.ch/etu/publications/EIA_2ed/EIA_E_top1_body.PDF>.
[108] See Barry Sadler and Mary McCabe, (eds), *EIA Training Resource Manual* (2nd Ed) (UNEP, 2002), p 115, <https://unep.ch/etu/publications/EIA_2ed/EIA_E_top1_body.PDF>

7.1. International Law

Obligations exist under international law to carry out EIAs. Principle 17 of the *1992 Rio Declaration on Environment and Development* (soft law) provides that "[e]nvironmental impact assessments, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority".[109] Principle 10 of the Declaration also emphasises the importance of public participation, declaring that environmental issues are best handled with the participation of all concerned citizens, at the relevant level. To ensure effective participation, each individual must inter alia have appropriate access to information and the opportunity to participate in decision-making processes.[110]

EIAs have been recognised by international courts and tribunals as a requirement under international law where there is a risk that a proposed activity may have a significant adverse impact in a transboundary context, in particular on a shared resource.[111] The conduct of EIAs is also a direct obligation under UNCLOS and therefore critical to the State parties' discharge of their obligations under UNCLOS. They are expected to observe, measure, evaluate and analyse the risks or effects of pollution of the marine environment, in particular of the activities under their jurisdiction or control, i.e., activities carried out within Singapore jurisdiction, or by a vessel flying its flag or by its nationals (whether private or natural persons).[112] The results of such observations must be provided to the competent international organisations, which should make them available to all States.[113] In this regard, it is important to keep in mind that there are fundamental differences between land-based developments and marine activities, and therefore different considerations and assessments may apply when carrying out EIAs in the marine environment.[114]

Many specialised treaties require EIAs for specific activities and international bodies have developed EIA guidelines. Article 14 of the CBD requires State parties to introduce appropriate procedures requiring EIA of its proposed projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effects and, where appropriate, allow for public participation in such procedures;[115] the COP to the CBD has developed EIA Guidelines (Voluntary Guidelines on Biodiversity-Inclusive Impact Assessment) to assist States with the implementation of this provision.[116] Similar guidelines have been developed by the competent international organisation for deep seabed mining, fisheries, disposal of waste at sea including dredging sludge, activities in Wetlands of International Importance, etc.

[109] Rio Declaration, Principle 17.
[110] Rio Declaration, Principle 10.
[111] See also *Case concerning Land Reclamation by Singapore in and around the Straits of Johor (Malaysia v Singapore), Provisional Measures, Order of 8 October 2003*, <https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_12/12_order_081003_en.pdf>; and *In the Matter of the South China Sea Arbitration before an Arbitral Tribunal constituted under Annex VII to the 1982 United Nations Convention on the Law of the Sea between the Republic of the Philippines and the People's Republic of China, Award of 12 July 2016 of the Arbitral Tribunal*, <https://pca-cpa.org/wp-content/uploads/sites/175/2016/07/PH-CN-20160712-Award.pdf>.
[112] UNCLOS, Article 204,
[113] UNCLOS, Article 205.
[114] Flávia Guerra, Catarina Grilo, Nuno M Pedroso, and Henrique Cabral, "Environmental Impact Assessment in the Marine Environment: A Comparison of Legal Frameworks", (2015) *Environmental Impact Assessment Review* 55:182, 190.
[115] CBD, Article 14.
[116] Roel Slootweg, Arend Kolhoff, and Robert Hoft, (eds), *Biodiversity in EIA and SEA: Background Document to CBD Decisions VII/28: Voluntary Guidelines on Biodiversity-Inclusive Impact Assessment*, Netherlands Commission for Environmental Assessment, 2006), <https://www.cbd.int/doc/publications/imp-bio-eia-and-sea.pdf>; and CBD COP Decision VIII/28 (UNEP/CBD/COP/DEC/VIII/28, 15 June 2006), <https://www.cbd.int/doc/decisions/cop-08/cop-08-dec-28-en.pdf>.

7.2. Implementation of EIA Laws

Given that States are obliged to ensure the undertaking of EIAs for activities with a risk of adverse impacts to the marine environment, it would be apt for laws to be implemented such that both the public and private sectors will undertake the EIAs. The criteria for projects to be subject to EIA should be well defined. The essentiality of public participation is also clear EIA laws should make EIA reports available online to facilitate public access and scrutiny. They should also prescribe minimum time frames to give the public a reasonable time to view, consider, and comment on EIA reports.

Rather than leaving EIAs to the discretion of the government of the day, enacting EIA laws will better promote environmental governance and ensure legal security. The United Nations Environment Programme (now UN Environment) has also noted that experience in many countries indicates that the foundations of an effective EIA system are established inter alia by an explicit basis in law and regulation, mandatory compliance and enforcement, prescribed process of steps and activities.[117]

EIAs are not legally mandated in Singapore, though the authorities' current administrative policy and practice is to conduct or require such assessments in "major development projects… especially when they are near to sensitive areas such as nature reserves, nature areas, as well as marine and coastal areas". The EIA reports are said to be gazetted[118] and made public, and stakeholders' views are sought. The Government uses the studies to finalise plans and mitigate any development impact by modifying the scale or scope of such works;[119] but apparently not for deciding whether the project should even proceed in the first place. These assessments have identified impacts of proposed developments to the environment and proposed the necessary mitigation measures. Notable inadequacies in the past EIAs involving coastal developments include having questionable scope and prediction of impacts in the EIAs, e.g., the EIA which was announced to have been conducted in respect of the proposed land reclamation at the Tanjung Chek Jawa wetlands;[120] and the lack of facilitation of public viewing of EIA reports.[121] Over the years, there have been many calls for EIA legislation,[122] including from Singapore's environmental law luminary, Tommy Koh.[123]

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[117] Barry Sadler and Mary McCabe, (eds), *Environmental Impact Assessment Training Resource Manual* (2nd Ed) (UNEP, 2002), pp 143 and 144, <https://unep.ch/etu/publications/EIA_2ed/EIA_E_top2_body.PDF>.

[118] In fact, the EIA reports themselves are not gazetted; only the announcements of the availability of the EIA reports for public viewing are gazetted.

[119] See *Singapore Parliament Reports* (11 March 2015), Vol 93, 12.15pm (Desmond Lee, Minister of State for National Development).

[120] The contents of the EIA report were not made public, but the Urban Redevelopment Authority shared that the report concluded that Chek Jawa did not appear to have a resident population of dugongs and did not have any established coral reefs or reef communities. As such, there was no biodiversity worthy of protection. This conclusion was considered "startling". See Sivasothi, N, "Chek Jawa, Lost Forever?" (2001) *Asian Geographic* 10:12, <http://chekjawa.nus.edu.sg/articles/AG/AGart5.htm>.

[121] For example, the then Ministry of the Environment's Semakau Landfill development conducted impact assessments of coral reefs and mangroves, but these studies were not made available to the public. See Clive Briffett and Jamie Mackee, "Environmental Assessment in Singapore: An Enigma Wrapped Up in a Mystery!", (2002) *Impact Assessment and Project Appraisal* 20(2):113; and Loke Ming Chou, "Nature and Sustainability of the Marine Environment" in Wong, Tai-Chee; Yuen, Belinda; and Goldblum, Charles, (eds), S*patial Planning for a Sustainable Singapore* (Springer 2008) pp 169, at 171. See also, Ria Tan, "Email exchange with Sentosa on Viewing of the EIA", 2003", <http://www.wildsingapore.com/news/20070708/070815-0.htm>. According to Tan, the Marine Environment Report for Resorts World on the reclamation project for the Sentosa Integrated Resort project was announced to be available for public viewing in the Government Gazette, but no online viewing was available and interested members of the public could only peruse the report in a particular room with no photography and no electronic devices allowed.

[122] See for example, Lye Lin Heng, "Legal Protection of the Natural Environment" in Clive Briffett and Hua Chew Ho, (eds), *State of the Natural Environment in Singapore*, (Singapore Nature Society, 1999), p 83; Clive Briffett, "An Evaluation of Environmental Planning Assessment and Management in Singapore", in Clive Briffett and Hua Chew Ho, (eds), *State of the Natural Environment in Singapore*, (Singapore Nature Society, 1999), p 95; Lye Lin Heng, "Singapore's New Environmental Law: The Environmental Pollution Control Act 1999", [2000] *Singapore Journal of Legal Studies* 1; Clive Briffett and Jamie Mackee, "Environmental Assessment in Singapore: An Enigma Wrapped Up in a Mystery!", (2002) *Impact Assessment and Project Appraisal* 20(2):113; Foo Kim Boon, Lye Lin Heng, and Koh Kheng Lian, "Environmental Protection: The Legal Framework" in

The push for an EIA law requires a mind-set shift – that cost and benefit analyses can be conducted not only in terms of the economy, but also the environment. Mangroves, for example, protect shores against erosion and coral reefs help to dissipate wave energy; they also serve as nursery ground and natural waters filtration and to protect and preserve our biodiversity.[124] The government can do better to engender this shift for itself and then amongst the people.

7.3. EIA Scope and Content, Restoration, Rehabilitation, Monitoring

Based on international standards for EIAs of marine and coastal activities, EIAs require baseline data on physical oceanography, chemical and biological characteristics of the area considered (including with respect to depleted, threatened or endangered species and rare and fragile ecosystems) and assessment of likely impacts. Alternative solutions must also be considered to limit impact as well as, where necessary, recommendations for the taking of restoration or rehabilitation measures. This would be particularly useful where adverse impacts to sensitive marine areas or endangered species cannot be avoided.

7.4. Recommendations

Recommendations are: 1) Introduce an EIA law with clear provisions on the criteria for requiring projects to be subject to EIAs and on the scope of impact assessments; 2) To facilitate public participation, EIAs should by default be viewable online (unless special circumstances dictate otherwise) and the government should consult the public for a reasonable time frame; 3) Marine and coastal EIAs should take into account cumulative impacts and the time and resources expended on doing a proper EIA should be commensurate with the nature and scale of the proposed development project and ecological sensitivity of the site; 4) Ensure that the scope and content of the EIA meet or exceed applicable international standards including risks of impacts on depleted, threatened or endangered species and rare and fragile ecosystems.

Giok Ling Ooi, (ed), *Environment and the City: Sharing Singapore's Experience and Future Challenges* (Times Academic Press, 1995), p 47; Koh Kheng Lian, "The Garden City and Beyond: The Legal Framework", in Giok Ling Ooi, (ed), *Environment and the City: Sharing Singapore's Experience and Future Challenges* (Times Academic Press, 1995), p 148; Joseph Chun, "Beyond Real Estate: Sowing the Legal Seeds for an Ethical Public Land Stewardship in Singapore", (2006) MqJICEL 3:1; Lin Heng Lye, "Land Use Planning, Environmental Management, and the Garden City as an Urban Development Approach in Singapore", in Nathalie J Chalifour, Patricia Kameri-Mbote, Lin Heng Lye, John R Nolon, (eds), *Land Use Law for Sustainable Development* (Cambridge University Press, 2006); Lye Lin Heng, "A Fine City in a Garden — Environmental Law and Governance in Singapore", [2008] *Singapore Journal of Legal Studies* 68; Joseph Chun, "Wildlife Law in Singapore: Protecting Wildlife in the "Garden City"", in Raj Panjwani, (ed), *Wildife Law: a Global Perspective* (ABA Publishing, 2008), p 201; Lye Lin Heng, "Land Law and the Environment: Re-Examining the Concept of Ownership and Forging New Rights and Obligations in A Changed World", (2010) SAcLJ 22:189; Lye Lin Heng, "Environmental Law, Policy and Governance: Environmental Management Systems for Cities", in Robert V Percival, Jolene Lin, and William Piermattei, (eds), *Global Environmental Law at a Crossroads* (Edgar Elgar, 2014), p 228; and Nidhi Mehra and Lin-Heng Lye "Environmental Impact Assessment Laws of Malaysia and Hong Kong: Lessons for Singapore", in Lin-Heng Lye, Victor R Savage, Harn-Wei Kua, Loke-Ming Chou, Puay-Yok Tan, (eds), *Sustainability Matters: Environmental and Climate Changes in the Asia-Pacific* (World Scientific, 2015), p 163.

[123] See Tommy Koh's foreword in Clive Briffett, (ed), *Master Plan for the Conservation of Nature in Singapore* (Malayan Nature Society (Singapore Branch) [now known as Nature Society (Singapore)], 1990), p iii; and Tommy Koh, "Green Thoughts Inspired by Stockholm and Rio: Ambassador Tommy Koh: How Far Has the World Come in Creating Awareness of the Environment?" (12 June 2012) *The Straits Times*.

[124] Loke Ming Chou, "Nature and Sustainability of the Marine Environment", in Wong, Tai-Chee; Yuen, Belinda; and Goldblum, Charles, (eds), S*patial Planning for a Sustainable Singapore* (Springer, 2008), p 169, at 174.

PART IV

STAKEHOLDERS AND COMMUNITY PARTNERS

STAKEHOLDERS AND COMMUNITY PARTNERS

Stakeholders are important partners in the management of natural areas. Singapore is fortunate to have amongst her citizens those empowered to share their passion of marine areas, native biodiversity, and sustainable development. Stakeholders ofen have intimate knowledge or experience concerning issues that arise because of their ground expertise. Engaging stakeholders in management of nature areas helps to quickly identify emerging issues which together with agency involvement, can contribute towards an integrated, holistic, and sustainable outcomes. In this chapter, we showcase (non-exhaustive list, listed in no particular order of priority) ground-up initiatives, and non-government organizations that have contributed significantly to the stewardship of coastal and marine areas of Singapore through outeach acitivities.

1. WILDSINGAPORE.COM

wildsingapore.com is an online resource that Ria Tan solely runs and funds as a volunteer. Ria first started wildsingapore.com in 2003 as a companion website to the Chek Jawa Guidebook as a portal for photographs and information that could not be fit into the guidebook. Nearly 15 years later, the website has grown tremendously, to accommodate the wild places, wild activities and wild people Ria had encountered.

Ria's hope is that wildsingapore.com can provide useful information for those who want to learn about Singapore's wild places; and do more for them.The theme of wildsingapore.com is one person CAN make difference for nature in Singapore. Simply explore, express and ACT!

The key features of wildsingapore.com are:
1. Wild news, daily updates of news for Singaporeans: local and global.
2. Wild happenings, updated weekly. Nature events in Singapore: talks, walks, volunteer opportunities and more. Many of them free, suitable for kids and the family.
3. Wild places: fact sheets on what to see and do, how to get there, tips on preparing for an enjoyable wild visit.

Since 2001, together with a small team of seasoned volunteers, Ria surveys intertidal shores in Singapore every low spring tide. Ria does about 100 surveys a year covering 50 Singapore seashore locations. The results of these surveys are shared through these resources: Notes on survey sightings are shared on the wild shores of singapore blog.

The wild facts sheets are a layman's introduction to hundreds of common intertidal marine flora and fauna of Singapore. It also hopes to help volunteers with a special section for shore guides. More than 60,000 Singapore seashore photos are available for free download at wildsingapore flickr.

For more information, email Ria Tan hello@wildsingapore.com

2. HANTU BLOG

Hantu Blog was formed in 2003 in response to apathy amongst local community towards Singapore reefs. This group believes that positive and optimistic attitudes towards local reefs is necessary to foster a proactive community, that would be willing to participate in the protection and conservation of this habitat. Following an extremely positive response from local divers to pilot efforts, the program is now regularly held at Pulau Hantu. Interest persists, especially amongst new divers who greatly rely on having good guides to enhance their experience of local waters.

The main aims of this group are: raise public awareness about Singapore's coral reefs through the documentation and communication of of coral reef biodiversity; improve diver attitudes towards diving in local waters; and, facilitate long-term protection of local reefs through collaboration with various stakeholder agencies and organisations.

Activities that the Hantu Blog promote include:

1) Train SCUBA diving guides to lead dives for members of the public. Guided tours allow new divers to encounter more marine fauna than if they were on their own. Having a guide to assist in underwater navigation also helps new divers overcome the challenge of diving in limited visibility, enhancing the overall experience of diving in local waters.
   Frequency: Once a year
   Target participants: SCUBA divers
2) Document and publish news about the wonders of our reef to the best of our abilities. We also actively engage the popular press, to extend the outreach efforts beyond the diving community.
   Frequency: At least once month
   Target participants: Members of the public (diving, non-diving) who may already be aware of local reefs, and want to learn more.
3) Participate in public outreach events such as the Festival of Biodiversity, and Envirofest. We also regularly give talks at schools, companies, and at public venues.
   Frequency: At least once a year
   Target participants: Non-diving community that may have no awareness about reefs.

For more information, email Debby Ng hantublog@gmail.com

3. TEAM SEAGRASS

Started in 2007, TeamSeaGrass is a collaboration between the National Biodiversity Centre of the National Parks Board and Seagrass-Watch HQ (www.seagrasswatch.org). The Seagrass-Watch monitoring program is the largest scientific, non-destructive, seagrass assessment and monitoring program in the world. The long-term information about the meadows provides us with a means of gauging the health of this important ecosystem, which could be used to guide management and conservation strategies. TeamSeaGrass data is shared with NParks for a better understanding and management of Singapore's seagrasses and shores. Data is also sent to Seagrass-Watch HQ for QA\QC checks on the data collected, thus contributing to a regional and global understanding of seagrass meadows.

TeamSeaGrass was formed following the Sentosa Seagrass Transect Survey in 2006. This survey, led by Siti Maryam Yaakub and Ria Tan gained the attention of Seagrass-Watch HQ, and together with NParks, the first seagrass monitoring sites were established at Chek Jawa on Pulau Ubin, and on the western coastline of Pulau Semakau in early 2007. A third permanent monitoring site, Cyrene Reef, was established in April 2007. Monitoring was conducted four times a year at the three permanent sites, coinciding with the monsoon and inter-monsoon periods between 2007 and 2010. This was done in order to understand seasonal variations in seagrass cover at each of the sites. Monitoring frequency was dropped to three times a year per site, from 2011 to present. Other sites that have been monitored for short periods in the past include Labrador Beach, Tanjung Rimau on Sentosa, and Tuas.

Monitoring trips are well attended, with as many as 30 volunteers participating when we monitor large sites like Pulau Semakau. We have approximately 100 active volunteers representing a wide demographic, ranging from students to professionals and retirees. Membership is managed entirely online: interested members of the public register via the Team blog. Registration includes a short questionnaire to determine suitability for the Team. Due to liability issues, the minimum age of entry is 19 years.

Most volunteers are trained on-the-job, with senior volunteers pairing up with fresh volunteers to teach them the various techniques used. Scientists from Seagrass-Watch HQ ran a training workshop in March 2007, training the initial crop of 19 volunteers as transect leaders, thus ensuring the quality of data being collected. In 2009 and 2013, we also organised a training workshop with Seagrass-Watch for volunteers to get certified, ensuring that our standards are in line with those used internationally. Data collected by TeamSeaGrass has contributed towards important scientific publications.

Aside from citizen science, the Team is also involved in outreach efforts such as public exhibitions and in giving talks to improve awareness of seagrasses and their importance. In recent years, TeamSeaGrass has been a regular participant at public events like the Festival of Biodiversity and Ubin Day. We also try to expand our reach through social media platforms such as Facebook and Instagram
For more information, email Siti Maryam Yaakub teamseagrass@gmail.com

4. NAKED HERMIT CRABS
Started in 2007, The Naked Hermit Crabs conduct free monthly guided walks for families and young children at Chek Jawa and Pasir Ris. When the opportunity arises, this group of volunteer guides also do so at other shores within Singapore, especially if the area is under threat. They do so to raise awareness of the importance of coastal areas, and to share information of native biodiversity of Singapore.This group is always willing to train interested members of the public if they wish to volunteer.
For more information, email Sumita Thiagarajan nakedhermitcrabs@gmail.com

5. OUR SINGAPORE REEFS

Our Singapore Reefs (OSR), is a non-profit initiative founded in 2017 by two divers that share a love for our ocean and educating the public. OSR was initiated with the desire to show people how marine trash is affecting our reefs, and promote the vast biodiversity our reefs have to offer. OSR aims to create public awareness and incorporate that with science education. OSR also aims to work with, and partner, different businesses, non-government organisations (NGOs), and agencies that want to make a difference to the community and are seeking a platform to do so.

One main activity that OSR promotes is marine debris clean-up dive, 3-4 times in a year, with divers across all ages. Clean-up dives are based on PADI's Project AWARE Dive Against Debris® programme to supplement Singapore's marine debris data to the global map. These data will be the baseline of underwater marine debris in Singapore and the information will be available for any persons or organizations. OSR also sees the potential of different communities working together to drive positive change to our environment. OSR will be the pioneering effort in helping Singapore to reduce marine debris and ensure environmental sustainability.

OSR also invites researchers onboard our outreach sessions to share their works or views on marine conservation. We also work with various organizations to conduct educational roadshows and sharing sessions.

The public can be involved in either as participants in scheduled activities or as partners in organizing meaningful marine conservation programmes.

For more information, email Sam Shu Qin oursingaporereefs@gmail.com

6. RESTORE UBIN MANGROVES (R.U.M.) INITIATIVE

R.U.M. is established under the Friends of Ubin Network, and is a ground-up community effort to apply Ecological Mangrove Restoration, so mangroves will be naturally restored at abandoned aquaculture ponds on Pulau Ubin. R.U.M. was proposed in December 2014, and formal approval was obtained in January 2016. R.U.M brings together those passionate about restoring mangroves in the abandoned aquaculture ponds on Pulau Ubin. This included experts from tertiary institutions, NGOs, commercial enterprises that depend on Ubin mangroves, and individual enthusiasts, with the support of the National Parks Board.

R.U.M. members include:

- The Mangrove Lab, Department of Geography, National University of Singapore
- Marine Conservation Group of the Nature Society (Singapore)
- Gamefish and Aquatic Rehabilitation Society (GARS)
- Sea Angel representing Pulau Ubin fish farmers
- wildsingapore.com

Activities of R.U.M includes:

Ecological Mangrove Restoration: Surveys, Studies and Workshops

Phase I involves collection of essential baseline data on the physical environment. This will show where Ecological Mangrove Restoration is likely to be successful, and what locations need to be modified in order to increase restoration success. Key activities include:

- Conduct baseline elevation surveys of abandoned ponds to understand their physical and hydrological condition.
- Conduct baseline elevation surveys of neighbouring natural mangrove forests, to understand species-specific requirements for restoration.
- Conduct baseline fish and bird surveys to understand the biodiversity of the proposed areas.

The main output of this study will be a series of maps which will show where:

- Mangroves will likely establish and grow.
- Modification of the physical environment is required (e.g. sediment enrichment to raise surface elevations, earthworks to lower elevations).
- Drainage channels are required.

After study outputs were completed, a two-day scientific workshop was conducted in February 2018 to brainstorm restoration design issues. Participants included agencies, mangrove managers, academics, engineers, NGOs, with special guest Mr Ben Brown of Blue Forests and pioneer of Ecological Mangrove Restoration in Asia. During the same period, final feedback and ideas were gathered from Ubin villagers, and from the public via a workshop by youths for youths, and an online survey.

With the completion of Phase I, R.U.M. will next design and conduct a pilot Ecological Mangrove Restoration project on Pulau Ubin, in conjunction with the National Parks Board and other stakeholders as part of Phase II of this project.

Mangrove Clean Up

To help prepare the mangroves for Ecological Mangrove Restoration, clean ups are conducted to remove marine litter, abandoned nets, large trash. Open to the public to volunteer, these are also opportunities to share about mangroves and R.U.M.'s restoration effort. As at September 2018, 400 people were involved in removing 2 tonnes of trash from the Jalan Durian site.

Mangrove Outreach

It is important to R.U.M. that the community who live on Ubin and who love Ubin have a part to play in mangrove restoration. Our hope is to restore Ubin mangroves not just ecologically and biologically, but also their social and cultural role and value to the community on Ubin and beyond. Therefore, a R.U.M. priority is to reachout to Ubin villagers, to update them on our activities and learn from them their memories about Ubin mangroves.

For more information, email Ria Tan on behalf of R.U.M. hello@wildsingapore.com

7. THE DORSAL EFFECT

The Dorsal Effect is a for-profit social enterprise that promotes ecotourism through snorkeling and beach-hopping boat trips as a way of providing alternative livelihoods to shark fishermen in Tanjung Luar, Lombok, Indonesia. This group also offers marine conservation trips to Lombok for students and independent travellers interested in marine conservation issues such as shark hunting and responsible tourism. This is done through half, one day-, or 2 day- snorkelling and beach-hopping boat trips captained by the ex-shark fishermen.

The Dorsal Effect runs 4-5 day marine conservation service and science programs for international and government schools in Singapore and internationally, in the hope to make a difference to sharks and have a broader understanding of the marine problems. About 5-6 school trips are organised per year They hope to attract more travellers to Lombok as well as schools and corporates to make a difference through responsible tourism with The Dorsal Effect. In addition, The Dorsal Effect is carrying out a study of shark landings in fish ports in Singapore.

For more information, email Kathy Xu kathy@thedorsaleffect.com

8. SEA SHEPHERD SINGAPORE

Sea Shepherd was founded in 1977 by Captain Paul Watson in Vancouver, Canada, with the mission to protect and conserve all marine wildlife. Incorporated in Oregon in 1981 as the Sea Shepherd Conservation Society, today the movement has independent entities in over 20 countries working together on direct-action campaigns around the world. In 2013 Sea Shepherd Global was established in Amsterdam to coordinate communications and logistics for the Sea Shepherd fleet on campaigns outside the United States. In Singapore, activities that that the Sea Shepard promotes are coastal clean-ups. They participate in three events annually: the Asian Dive Expo, Pesta Ubin, and Earthfest Singapore.

For more information, email James Chua james@seashepherd.asia

9. ZERO WASTE SG

Zero Waste SG started as a website in 2008 providing tips and resources on waste minimisation and recycling, and was officially registered as a non-governmental organisation on 13 July 2015. Zero Waste SG is a non-governmental organisation dedicated to help Singapore eliminate the concept of waste, and accelerate the shift towards zero waste and the circular economy. Zero Waste SG aims to promote education and engagement on the 3Rs (Reduce, Reuse and Recycle) among individuals and households; increase waste minimisation and recycling among businesses and organisations; and reduce specific waste such as plastic disposables and food waste.

Key campaigns and programmes are in 4 categories: Food Waste; Plastic Disposables; Household Recycling; and Business Waste.

Food Waste

Zero Waste SG manages the Save Food Cut Waste (SFCW) campaign to educate individuals, businesses and organisations in Singapore about the environmental and social impacts of food waste, and to encourage everyone to take action in reducing food waste. SFCW provides tips for individuals and best practices for businesses to reduce, redistribute and recycle food waste, and also work with volunteers to conduct outreach talks for companies and schools.

Plastic Disposables

Zero Waste SG published our Position Paper on the Reduction of Single-Use Plastic Disposables in Singapore on 1 June 2016. The Position Paper describes the current situation and problem, highlights the considerations and responses, and lists several recommendations to reduce plastic disposables. Through the Position Paper, Zero Waste SG urges the government and businesses in Singapore to consider these recommendations, and develop concrete plans and take bold actions to reduce the consumption of single-use plastic disposables. The Position Paper was sent to the Minister for Environment and Water Resources, MEWR and NEA.

Recommendation Paper on the Implementation of a Plastic Bag Charge in Singapore

As a follow-up to the Position Paper on plastic disposables and to focus specifically on the problem of excessive usage and wastage of single-use plastic bags in Singapore, Zero Waste SG conducted a public survey on a plastic bag charge.Based on the survey results, Zero Waste SG published a Recommendation Paper on the Implementation of a Plastic Bag Charge in Singapore on 12 September 2016, which shows the results of the survey and recommends that the government introduce a mandatory plastic bag charge scheme to reduce the excessive usage and wastage of single-use plastic bags and to encourage people to bring their own reusable bags. Zero Waste SG submitted the recommendation paper to NEA for their consideration. This issue was also discussed in Parliament in November 2016.

BYO Singapore

Zero Waste SG started the BYO (Bring Your Own) Singapore campaign (from Sep to Dec 2017) to sign up retailers to offer incentives for customers who bring their own reusable containers, bottles or bags. The campaign would provide information, incentives and resources to encourage people to bring their own reusables and reduce plastic disposables. Under the campaign, retailers would offer incentives to customers who bring their own reusable bags, bottles or containers. The main campaign goal is to sign up 500 retail outlets and reduce 1,000,000 pieces of disposables in 2017.

BYO Schools

Zero Waste SG is partnering with the S.E.A. Aquarium from Resorts World Sentosa on a new nationwide BYO (Bring Your Own) Schools Programme. The S.E.A. Aquarium supports conservation efforts, educational and public engagement activities to help protect our ocean health. Marine litter is mostly made up of plastics, and poses harm to marine animals through ingestion or entanglement. The BYO Schools Programme will inculcate good BYO habits among the young and encourage them to reduce plastic disposables and protect the marine environment. The programme aims to engage students on plastic disposables and marine litter through assembly talks and exhibitions, and to encourage them to bring their own reusables (bottle, container, utensils or bag) and reduce plastic disposables in the school via a reward card system.

Household Recycling

Let's Recycle Together is a campaign that aims to encourage more HDB residents to recycle using the existing blue recycling bins in their estates, and to educate them on recycling correctly. The campaign is carried out in 2 phases. Phase 1 involves online engagement through photos, videos and influencers on social media, and aims to spread the message on household recycling to the general public. Phase 2 involves education and engagement with residents at housing estates and the community through posters and signage, roadshows and door-to-door engagement.

Business Waste

We manage the online business waste exchange platform, Waste is not Waste (WINW). The platform facilitates the exchange of waste materials and unwanted items from companies and organisations that no longer need them to businesses, non-profit organisations, designers and schools that can utilise that waste.Through WINW, we also plan to conduct waste matching and industrial symbiosis workshops to gather companies and find out what waste they are generating and whether there are opportunities to connect them to companies that want their waste.

Circular Economy Singapore

Zero Waste SG manages the Circular Economy Singapore (CES) network, an informal network of individuals, businesses and organisations that support and embrace the concept and principles of the circular economy.

CES aims to spread awareness and accelerate the shift towards a circular economy through organising regular talks and networking sessions; sharing news and resources; and connecting individuals, businesses and organisations to explore collaboration opportunities.

For more information, email Eugene Tay eugene@zrowastesg.com

10. BLUEWATER VOLUNTEERS: REEFFRIENDS

BlueWater Volunteers was formalized in 2006 by a group of volunteer-scientists passionate about marine conservation. This group trains volunteers to carry out scientific surveys (e.g. Reef Check) for assessment of coral reefs in Singapore and the region. One of the longest-running programme is ReefFriends, an effort to assess the diversity and status of coral reefs in Singapore, in partnership with National Parks Board.

For more information email Jeffrey Low at cat64fish@yahoo.com

11. LEE KONG CHIAN NATURAL HISTORY MUSEUM: TODDYCATS

The Toddycats was formalized in 2002 as the volunteer arm of the then Raffles Museum of Biodiversity Research, now known as Lee Kong Chian Natural History Museum. These group of volunteers are passionate about sharing information and stories on biodiversity present in Singapore. They are committed to engage the public with accurate scientific, but easily-digestible, information. In 2017 alone, the Toddycats reached out to 8638 members of the public. This group works actively in partnership with other volunteer groups, agencies, and institutions on programmes, events, and action plans for biodiversity and natural ecosystems.

Some of the activity highlights that the Toddycats have been involved in are:

a. Exhibitions: Festival of Biodiversity (annual)
b. Symposia: Organising and supporting Biodiversity Symposia of Singapore (every 3 years)
c. Guided walks: Sungei Buloh Anniversary Walk (annual, December)
d. Nature appreciation through cycling: Pedal Ubin!
e. Guided walk: Love Our MacRitchie Forest
f. Historical guided walk: Kent Ridge/Pasir Panjang Heritage Trail (to Bukit Chandu)
g. Clean-ups: International Coastal Clean-up Singapore.

For contact, and updates on events, please visit https://toddycats.wordpress.com

12. NATURE SOCIETY SINGAPORE: MARINE CONSERVATION GROUP

The Society's predecessor, the Singapore Natural History Society (SNHS), was formed in 1921 to develop 'friendly intercourse between local naturalists and the increase and diffusion of knowledge concerning natural history.' In 1940, the Malayan Nature Society ('MNS') was formed, in colonial 'Malaya', based in today's Malaysia. The Singapore section of MNS was established in 1954 as the Malayan Nature Society (Singapore Branch). In 1991, the Singapore Branch separated from MNS to form the independent Nature Society (Singapore) in 1992. Through its activities and outreach programmes, the society aims to a) promote nature awareness and nature appreciation; b) advocate conservation of the natural environment in Singapore; and c) forge participation and collaboration in local, regional, and international efforts in preserving Earth’s biodiversity.

The society holds citizen science programmes, species and habitat conservation projects,nature awareness and appreciation events, and international partnership activities.

Members of the society are welcome to all events. In addition, the society regularly reaches out to schools and educational institutes, general public, government officials, policy makers, and corporate partners. Schedule of events available at http://nss.or.sg

For more information, pleae contact Stephen Beng stephen@nss.org.sg

13. HERPETOLOGICAL SOCIETY OF SINGAPORE

The society was formed in 2015 by youths sharing a passion for the study and conservation of herpetofauna, and in the hope to share information with other aspiring naturalists. These individuals were driven by the realisation that herpetofauna are unnecessarily feared by the Singaporean public and thus seek to educate members of the public on their importance, and promote a culture of respect for these animals instead.

Some of the activity highlights that the society have been involved in are:
a. Guided walks: Various locations (monthly)
b. Exhibitions: Festival of Biodiversity (annual)
c. Citizen Science Contribution: Bioblitz
d. Citizen Science Contribution: Field Surveys

For more information, please contact Serin Subaraj herpsocsg@gmail.com

14. THE ENVIRONMENTAL LAW STUDENTS' ASSOCIATION

The Environmental Law Students' Association (ELSA) is an NUS Law interest group affiliated to the Asia-Pacific Centre for Environmental Law (APCEL). Founded in 2016, ELSA seeks to become the undergraduate centre in environmental law and policy, anchored in Singapore but with a continuing interest in Southeast Asia and the wider Asia-Pacific region.

Our substantive focus is on Singapore environment and land use law. Guided by the overarching principle of intergenerational environmental justice, we encourage students to get involved in environmental law and policy. We contribute to environmental law research, pro bono projects, experiential learning, and collaboration with environmental law and policy leaders.

For more information, please contact elsa.nuslaw@gmail.com

PART V

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with contributions from marine scientists, key stakeholders, and the marine community.

Part I
The Singapore Blue Plan 2018
Jaafar Z, Huang D, Tanzil JTI, Ow YX, and Yap N (Editors)
with contributions from marine scientists, key stakeholders, and the marine community.

Part II
Scientific Support for The Blue Plan 2018

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Chapter 4. Environmental Reconstruction
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Chapter 5. Threats to the Marine Environment
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Chapter 6. Mitigative Measures
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Part III
Legislative Support for The Blue Plan 2018
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