8. SINGAPORE

Summary of research topics: *The majority of studies in Singapore focused on ecological and environmental impact, followed by survey and monitoring to understand pollution status and plastics as a transport vector.*

Summary of understanding at national level: *The body of plastic research in Singapore is still at an early stage with only a few published studies. However, the results from field studies (e.g. ICCS, Project Aware) provide insights into the status of marine plastic pollution in Singapore, with most of them indicating negative impacts of marine debris on numerous marine taxa groups and environments. To date, there is no study examining the sources, accumulation and hotspot areas of marine plastics along Singapore's coastline.*

Keywords/research fields: *National approach; solid waste; trade of plastic waste; research foci; marine environs; surveys and monitoring; ecological and environmental impact; plastic as transport vector; main players*

8.1 Context

8.1.1 National approach to plastic waste and its management

Singapore generated almost 949,300 tonnes of plastic waste in 2018, but only 4% of these were recycled (MEWR, 2019). The remainder (possibly non-recyclables) became incinerated, where the ashes were deposited in the country's only landfill on Semakau Island. This landfill is planned to reach full capacity by 2035, although waste reduction and recycling could change this projection.

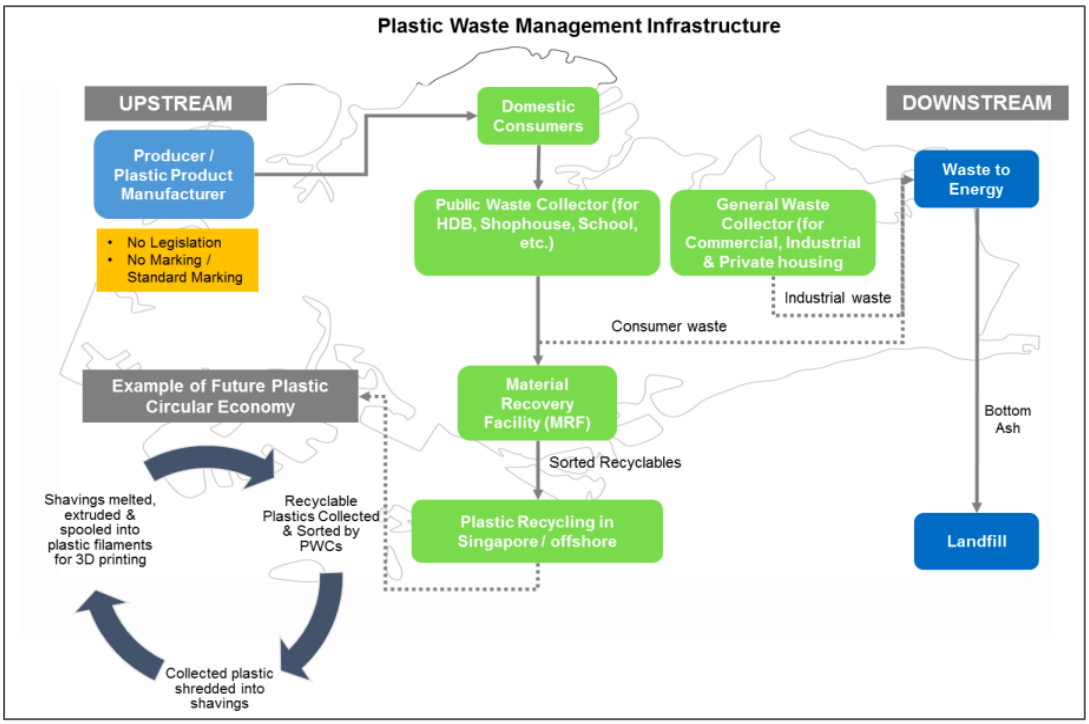

Figure 1.2.8.1. The plastic ecosystem and life cycle in Singapore (source: Singapore Environment Council).

Under the National Recycling Programme (NRP) led by National Environment Agency (NEA), several initiatives have been launched to encourage recycling habits. These include the blue recycling bins for commingled recyclables at every block in public housing estates, and the dual chutes for refuse and recyclables fitted in public housing developments since 2014. While the amount of recyclables collected under NRP has been steadily rising, perception surveys conducted by the Singapore Environment Council (SEC) found that close to 70% of respondents are not fully aware of what can be recycled and the know-hows of recycling in Singapore (SEC, 2018; Figure 1.2.8.1).

In a bid to further reduce plastic waste, Singapore has adopted the Singapore Packaging Agreement and the 2019 Zero Waste Master Plan, which include a new mandatory packaging reporting framework set to take effect latest by 2025 (Zero Waste Master Plan, 2019). After Singapore marked its Year Towards Zero Waste in 2019, there appears to be more awareness among businesses of the pressure of consumption on the planet, and they are taking steps to reduce waste (The Straits Times, 2020: available https://www.straitstimes.com/singapore/environment/byoc-thats-bring-your-own-container).

8.1.2 Plastics as a proportion of solid waste

In 2016, MSW for Singapore was estimated at 7.6 million tonnes, and with a projection of reaching 9.3 million tonnes in 2030 and 10.0 million tonnes in 2050 (Kaza et al., 2018). The Ministry of the Environment and Water Resources (MEWR) of Singapore reported that 7.70 million tonnes of solid waste was generated in 2018, which is approximately 9,000 tonnes less than that produced in 2017 (MEWR, 2019: available https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling).

In 2012, the World Bank estimated that the plastic composition in solid waste for Singapore was at 12% (Hoornweg and Perinaz, 2012). However, local statistics suggest a much lower part of 3% (National Environmental Agency: available https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling).

It was also estimated that people in Singapore use 467 million PET plastic bottles, 820 million supermarket plastic bags and 473 million polypropylene plastics annually (SEC, 2018).

8.1.3 Illegal trade of plastic waste

Based on Greenpeace (2019), plastic waste imports almost tripled between 2016 and 2018 for Singapore, where it increased from 3,354 tonnes in 2016 to 9,018 tonnes in 2018. Singapore would also have been one of the countries illegally sending plastic scrap into Malaysia and Indonesia, without the correct permits.

New regulation on hazardous waste (on control of export, import and transit) is in the process of adoption in Singapore. It is designed to govern plastic waste exports and avoid plastic exporters in Singapore to ship out plastic waste that is contaminated, difficult to recycle or mixed with other materials. This new act is designed to implement in Singapore the new amendment to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.

(Parliament session on the draft bill on 2 February 2020 - Singapore Law Watch: available https://www.singaporelawwatch.sg/Headlines/Singapore-passes-law-in-line-with-global-pact-to-restrict-export-of-plastic-that-is-contaminated-difficult-to-recycle).

8.2 Research review of pollution from marine plastic

8.2.1 Research overview

Research on pollution in marine plastics in Singapore is generally limited to particular research foci, with a total of nine publications. These nine studies found for this study were conducted in different decades: one study in 2006, and eight studies between 2014 and 2020. Geographically, they cover both the coastline and shallow coastal waters of Singapore (Table 1.2.8.3). The majority of studies had research topics focused on the ecological and environmental impact (n=9), followed by survey and monitoring to understand pollution status (n=7), and plastics as transport medium (n=1) (Figure 1.2.8.2).

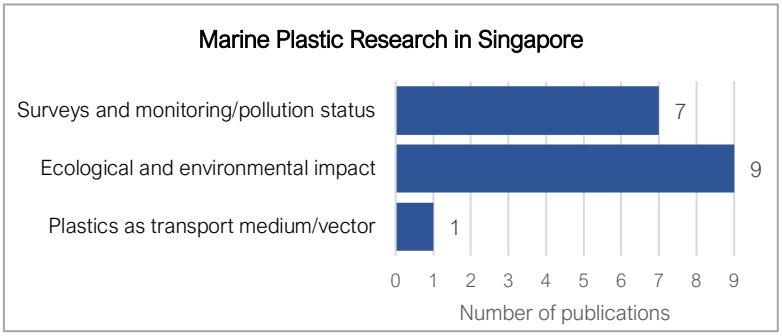

Figure 1.2.8.2. Research foci of marine plastic research conducted in Singapore.

Table 1.2.8.3. List of published work identified and examined in this study for Singapore.

Published Peer-Reviewed Work/Research Team	Aim of Research	Period of Study
Seng et al. (2020) National University of Singapore; National Parks Board	Quantify and characterise microplastics found on the surfaces of three species of intertidal seagrasses and two species of subtidal macroalgae	Sep 2018
Curren and Leong (2019) National University of Singapore; St John's Island National Marine Laboratory	Understand the distribution of microplastics in the marine environment, coupled with profiling of bacterial communities on surfaces of microplastics	Apr-Jul 2018
Bhargava et al. (2018) National University of Singapore; St John's Island National Marine Laboratory	Investigate the potential toxicity of PMMA particles on the larvae and microalgae feed, ingestion, egestion, retention and translocation of nanoparticles through various larval stages of acorn barnacle	N.A.
Chim et al. (2015) National University of Singapore	Document the impacts of trammel nets on marine life in Singapore	Aug 16, 2015
Chim and Lim (2014b) National University of Singapore	Document the presence of coral cat-shark, reporting impacts of fish traps on marine life in Singapore	Apr 20, 2011
Chim and Lim (2014a) National University of Singapore	Document the presence of blackspot shark, reporting impacts of gill nets on marine life in Singapore	Jul 6, 2012

Yeo (2014) Citizen science	Document the presence of black-tipped reef shark, reporting impacts of gill nets on marine life in Singapore	May 29, 2010
Mohamed Nor and Obbard (2014) National University of Singapore	Document the presence and abundance of microplastics from mangrove sediments	Aug-Nov 2012
Ng and Obbard (2006) National University of Singapore	Document the presence and abundance of microplastics in Singapore's coastal environment	Aug-Dec 2004

There is clear awareness of pollution from marine plastics in the scientific community, but it is not a main research thrust for any research group focusing on marine environmental sciences currently. In addition to two earlier studies (Ng et al., 2006; Mohamed Nor et al., 2014), preliminary research had been conducted by the National Parks Board (NParks) and National University of Singapore (NUS) from 2017 to 2019 in an attempt to investigate the baseline occurrence of microplastics in Singapore and its potential sources (ICCS: available https://coastalcleanup.wordpress.com/nus%E2%80%92nparks-marine-debris-monitoring-programme/).

Since 2016, there have also been efforts (such as symposiums, workshops and conferences) to bring local and regional scientists together to discuss scientific and societal issues raised by marine plastics and microplastics.

8.2.2 Types of research conducted

Types of plastics research foci

Of the nine studies examined, the emphasis on either microplastics (n=5) or macroplastics (n=4) appear to be of almost similar concern. One of the studies even investigated the impacts of nanoplastics (ca. < 200 nm in diameter) on marine larvae (Bhargava et al., 2018); this study is categorised under 'microplastic' work. Four studies were also published on the impacts of trammel nets (i.e. macroplastics) on marine life (see Part 1, Section 2.8.2.7). The remaining studies investigated the presence/absence of microplastics in marine biota, such as seagrass, mangrove, seaweed, and sea surface waters.

Although there are few published papers on macroplastics, volunteer groups such as the International Coastal Cleanup Singapore (ICCS) and Our Singapore Reefs (OSR) run clean-up events and collect debris data. These groups cover different habitats in Singapore: ICCS on mangroves and beaches and OSR on subtidal reefs.

No published peer-reviewed study on plastic associated organic or inorganic contaminants.

Coverage of marine environs

Of the nine studies examined, two of them focused on shoreline environments, specifically sandy beaches (Ng et al., 2006; Curren and Leong, 2019), while one focused on sediments found in mangroves (Mohamed Nor et al., 2014). All studies examined the presence/absence of marine plastics in the environment, but only Curren and Leong (2019) further analysed the presence/absence and

composition of bacterial assemblages found on marine plastics. Ng et al. (2006) also further analysed the presence/absence of microplastics in subsurface water samples.

One study looked at the long-term effects of nanoplastics on marine larvae life cycle, under an experimental setting (Bhargava et al., 2018), while the other studies looked at the impacts of abandoned fishing nets and cages on marine life (Chim and Lim, 2014a, 2014b; Yeo, 2014; Chim et al., 2015). The most recent study by Seng et al. (2020) provided early evidence of the presence of microplastics in three intertidal seagrasses (*Cymodocea rotundata*, *Cymodocea serrulata* and *Thalassia hemprichii*) and two subtidal seaweeds (*Padina* sp. and *Sargassum ilicifolium*) in coastal environments.

There is no published peer-reviewed study on marine plastics in the seabed or subsoil.

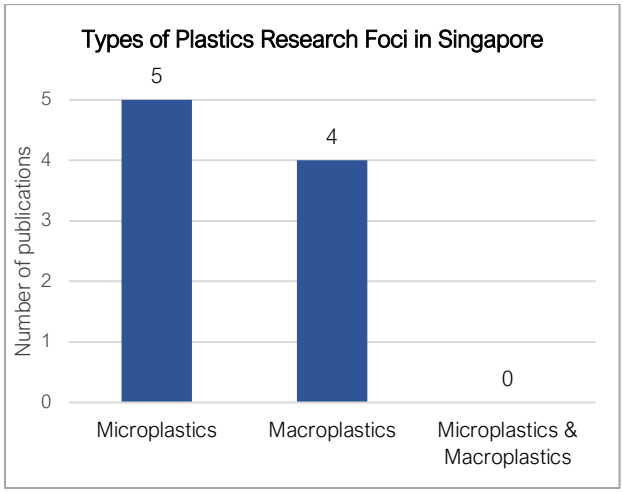

Figure 1.2.8.4. Distribution of marine micro-/macro-Plastics researched in Singapore.

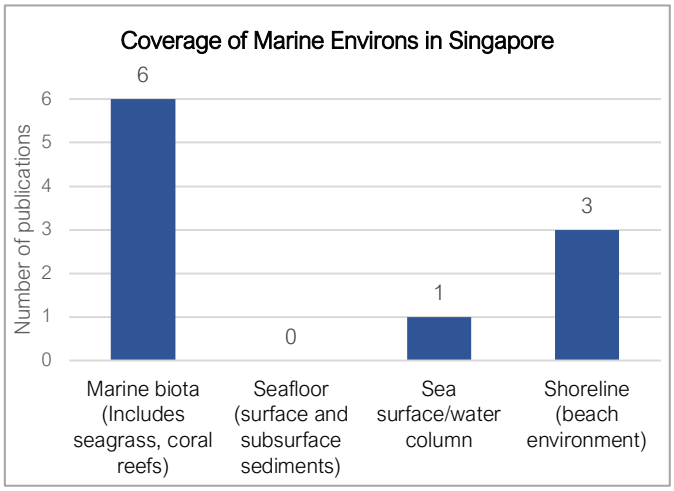

Figure 1.2.8.5. Distribution of marine environs researched in Singapore.

8.2.3 Survey and monitoring

Two out of nine published articles sought to quantify the presence and abundance of microplastics in mangroves and other coastal areas. As these studies were led by the same research leader (Obbard, J.), the methodologies used are similar and comparable, though the environs studied were different.

Of the five studies focused on microplastics, two focused on microplastics found in shallow coastal habitats (Ng et al., 2006; Mohamed Nor et al., 2014). Microplastic-focused studies quantified the abundance of plastics based on counts (i.e. number of microplastic particles, number of particles per 250g dry sediments, density of microplastics per unit area of blade), but none measured weight of debris. Studies of microplastics adhered to the definition of size <5 mm, but only 2 articles noted the shapes of microplastics (such as fibre, fragment, granule). Two studies (Ng et al., 2006; Mohamed Nor et al., 2014) attempted to identify the types of plastic polymers including PE, PP, PVC, PVA and nylon.

Four studies on macroplastics identified fishing gear (i.e. trammel nets, cage fish traps) as part of the ALDFG debris (see Part 1, Section 2.8.2.7 below), with no mention of the plastic polymer of the nets.

Though the data has not been formally published, groups based in Singapore contribute annually to large international surveys, namely: ICCS and Project AWARE's Dive Against Debris. The ICCS is coordinated by Toddycats, who are volunteers of the Lee Kong Chian Natural History Museum, NUS. Using the protocol from Ocean Conservancy, 14,566 kg of trash (195,706 items) was collected across 62 km of coastline (Ocean Conservancy, 2018).

Enumerated marine plastics include:

- 20,355 cigarette butts,
- 9,379 food wrappers,
- 18,238 plastic beverage bottles,
- 6,564 plastic bottle caps,
- 4,604 plastic grocery bags,
- 7,986 other plastic bags,
- 14,227 straws and stirrers,
- 3,020 plastic take out/away containers,
- 1,838 plastic lids, and
- 2,454 foam take out/away containers.

Several independent groups, all led by volunteers, have been conducting underwater clean-ups in Singapore. These groups include OSR, Small Change, The Submersibles, Zen Freediving, DHI Water & Environment (S) Pte Ltd, Resorts World Sentosa, Marlin Divers, and Asia Dive Academy. They collect the data and upload it to the global database, Project AWARE's Dive Against Debris. As of April 2019, Singapore has collected 9,881 pieces of underwater marine debris under Project AWARE's Dive Against Debris (Project AWARE, 2019).

8.2.4 Source differentiation and pathways

There is no published peer-reviewed study on source differentiation and pathways of marine plastics.

8.2.5 Movement of plastics, accumulation and hotspots

There is no published peer-reviewed study on the movement, accumulation and hotspots of marine plastics.

8.2.6 Ecological and environmental impacts

A study by Bhargava et al. (2018) demonstrated the impacts of nanoplastics on early life larvae of the acorn barnacles (*Amphibalanus amphitrite*) under two exposure periods: acute and chronic conditions. For both exposures, the barnacle larvae had ingested and egested the nanoplastics, but the nanoplastics had also translocated and became assimilated by the larvae. Overall, the study found that the barnacle larvae bioaccumulate low concentrations of nanoplastics throughout its life cycle.

Another study by Curren and Leong (2019) analysed the assemblages of bacteria found on the surfaces of microplastics collected from three beaches in Singapore. Of the bacteria identified, the study found several notable bacterial strains, namely: one that is commonly associated with coral

bleaching, one that has harmful effects on humans (e.g., gastroenteritis and wound infection), one that is capable of degrading plastic, and one that have been used to clean up oil spill.

The most recent study by Seng et al. (2020) provided early evidence of the presence of microplastics, specifically microfibres and micro-fragments, on the surfaces of macrophytes collected from the wild. They also found significantly higher microplastic densities on seagrasses than seaweed, proposing that epibionts (i.e. animal and plant attached to the surfaces) could increase entrapment of microplastics. However, they found no correlation between microplastic density and epibiont cover found on either seagrass or seaweed.

There have been several informal accounts of ingestion, entanglement, and asphyxiation of marine animals. They include hawksbill sea turtles, dugongs, as well as a female sperm whale (*Physeter macrocephalus*). The latter was found floating off Jurong Island in 2015, and the autopsy revealed the presence of marine plastic waste in the gut (Chua et al., 2019).

8.2.7 ALDFG

Four scientific peer-reviewed articles have been published on impacts of ALDFG on marine organisms (Chim and Lim, 2014a, 2014b; Yeo, 2014; Chim et al., 2015). Notably, all studies had reported different shark species (coral cat-shark, blackspot shark, black-tipped reef shark) as casualties of abandoned fishing gear, with the most severe case of 13 juvenile blacktip reef sharks (*Carcharhinus melanopterus*) and other myriad of marine life found dead in three trammel nets set in a lagoon (Chim et al., 2015). Observations on the impacts of ALDFG were noted, such as entanglement, lacerations, and suffocation.

There have also been several informal accounts of impacts of ALDFG on marine organisms that have been documented on the Facebook page of Project Driftnet Singapore (https://www.facebook.com/Project-Driftnet-Singapore-114400678619886/). This page displays informal accounts of impacts of abandoned fishing gear on marine life. In addition, a study led by undergraduate students from NUS also assessed the impacts of ALDFG on local marine life in 2018 (pers. comms., Anya). The data is presently unpublished.

8.2.8 Social perceptions and socio-economic impacts

There is no published peer-reviewed study on social perceptions and socio-economic impacts of marine plastics in Singapore.

The Singapore Environment Council (SEC) is a major non-profit organisation in Singapore that facilitates and coordinates environmental causes in Singapore. In 2018, they addressed the plastic issue in Singapore through producing a position paper: Consumer Plastic and Plastic Resource Ecosystem in Singapore. The study was motivated by the increased concerns of plastic usage, coupled with the low recycling rates in Singapore. In this study, SEC conducted literature reviews and surveys to understand Singapore's plastic ecosystem and plastic lifecycle. Results found that people had diverging views on introducing financial penalties for using plastic bags, as well as low awareness of the know-how of recycling plastics. Finally, the paper presented recommendations to help improve

Singapore's plastic ecosystem. (SEC, 2019: available http://sec.org.sg/wp-content/uploads/2019/07/DT_PlasticResourceResearch_28Aug2018-FINAL_with-Addendum-19.pdf)

8.3 Main players in marine plastic research

Based on the published articles found and examined for this study, marine plastics research in ASEAN+3 is limited in Singapore. The publications that were found related to studies conducted and led by Singapore-based researchers from NUS. Whilst the authors are aware of relevant expertise held by several local colleagues in other research institutions in Singapore, they could not be identified from the published literature. Related works on pollution from marine plastics have been carried out by the Singapore Centre for Environmental Life Sciences Engineering (SCELSE) from the Nanyang Technological University (NTU) but published studies are not focused on Singapore or the rest of ASEAN+3. Other institutions such as NUS Department of Mechanical Engineering and Agency for Science, Technology and Research (A*STAR) are carrying out plastics research on polymer materials which is not specific to marine plastics.

The National Parks Board (a government agency) has played an active role in leading preliminary studies of macro-and microplastics on Singapore beaches (together with NUS researchers), as well as local stakeholder discussions and outreach and education campaigns.

8.4 Summary of understanding

There is a good understanding of the status of marine plastic pollution in Singapore, though not all information has been formally published. A 15-month long nationwide study between 2017 and 2019 on microplastics on beaches revealed the presence of microplastics in beach sediments, with data currently being analysed. Combining this study with quantitative sampling of ICCS marine debris data (of >20 years of annual September data since 2000), the combined data will provide an overall assessment of temporal and seasonal variations of macro- and microplastics in Singapore.

Microplastic studies were able to categorise samples into various forms including those of fibres, fragments, granules, and identify plastic polymer types. Notably, there was one study investigating the transfer of nanoplastics between the life stages of an acorn barnacle larvae, thus implying marine plastics as a pathway for pollution by other organic substances, polymers or inorganic contaminants (e.g. POPs and heavy metals).

The research focus of published articles is dominated by ecological and environmental impacts from marine plastics, especially through marine plastic being a transport vector or pathway. These articles also include investigations in the ingestion of microplastics by marine life, trophic transfer of plastics and changes in microbial assemblages. In particular, Bhargava et al. (2018) demonstrated the potential for marine species to retain and adsorb nanoplastics in their bodies, which suggest potential effects on human health. However, more research is needed to verify this pathway of plastics to human bodies and understand their possible impact.

Three out of four environs were investigated, lacking studies looking at the seafloor.

Although there is no peer-reviewed article on ingestion of macroplastic by wild animals, informal accounts of endangered marine species (i.e. sea turtles, dugongs, a sperm whale) have been reported. Four studies also correlated the physical impact of plastics on marine life, specifically ALDFG.

No research has been found so far on polymer-specific research to understand differences in degradation of different polymer-types in the marine environment.

There is also an increasing awareness of the topic among the scientific community, especially with the recent UK-SG (NERC-NRF) joint grant call on Understanding the impact of plastic pollution on marine ecosystems in Southeast Asia (Southeast Asia Plastics). See NERC, available: https://nerc.ukri.org/research/funded/programmes/seap/news/ao-singapore-plastics/.