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ABUNDANCE, UPTAKE, PRESENCE AND BIODEGRADATION OF MICROPLASTICS IN MALAYSIAN CONTEXT: A SYSTEMATIC LITERATURE REVIEW

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Abstract: A growing number of studies on microplastics can be found following the awareness of their impacts on the environment, especially wildlife. Realising the importance of gathering available information, a systematic literature review was conducted to collect and analyse information on microplastics in Malaysia. This review is based on the Reporting standards for Systematic Evidence Synthesis or ROSES. Two leading databases, namely Scopus and Web of Science, were used to gather related studies. Following the ROSES protocol, 27 studies were reviewed and classified into four themes which include: (1) composition and abundance of microplastics in the environment, (2) microplastics uptake by aquatic organisms, (3) the presence of microplastics in sea products and others and (4) biodegradation and biodeterioration of microplastics. Findings from the studies suggest that the abundance of microplastics in Malaysia is comparable to other parts of the world. Though concerning, the growing number of studies on various aspects of microplastics, including biodegradation potential, can be viewed as a positive sign of Malaysian knowledge and efforts to address the problem.

Keywords: Microplastics, plastic debris, biodegradation, systematic literature review, ROSES protocol.

Introduction

The National Oceanic and Atmospheric Administration U.S. Department of Commerce (NOAA) defines microplastics as plastic particles between 0.33 mm and 5 mm in size that can be harmful to the ocean and aquatic life (NOAA, 2021). Microplastics can be unintentionally placed in the environment when bigger plastics are degrading and breaking up into smaller pieces. Microplastics may also originate from many health and beauty products that consist of small plastic particles called microbeads that found their way to the ecosystems (Golwala *et al*., 2021; Zhang *et al*., 2021).

Microplastics in the ecosystems and their impacts on biotas are emerging areas of study globally, including Malaysia (Bakir *et al*., 2020; Fu *et al*., 2020). This is following the public concerns and awareness, although this is arguable as suggested by Catarino *et al.* (2021) that the concerns are not backed by scientific evidence where the impacts of microplastics to the biotas were usually found to be minimal and always appear harmless to human health. However, more studies have shown evidences on the presence and effects of microplastics in human, including in human placenta (Ragusa *et al*., 2021), and human peripheral lymphocytes (Çobanoğlu *et al*., 2021). While these negative impacts can be insignificant, the measures taken to control this issue should be supported as it can be irreversible due to the fact that microplastics are persistent and accumulate over time (He *et al*., 2021; Uurasjärvi *et al*., 2021).

Current studies on microplastics cover various aspects. Several studies are looking at the abundance and composition of microplastics in various ecosystems including marine areas (Carvalho *et al*., 2021; James *et al*., 2021), wetlands (Duan *et al*., 2021; Paduani, 2020; Qian *et al*., 2021), rivers (He *et al*., 2021; Li *et al*., 2021; Liu *et al*., 2021), and even terrestrial ecosystems although there are less prevalent (Khalid *et al*., 2020; Wong *et al*., 2020). These studies often compare types of microplastics found and relate them to the factors affecting the composition. In Malaysia, there are also a few studies that look at the abundance and composition of various microplastics in water samples and sediments. Few studies reported the highest quantity of microplastics in areas with high anthropogenic activities (Amin *et al*., 2020; Pariatamby *et al*., 2020).

Although microplastics can be found everywhere, this can be irrelevant if nothing is affected. This is why the studies on the impact of microplastics on various biotas are necessary and pursued by many (Amelia *et al*., 2020; Amin *et al*., 2020; Bakir *et al*., 2020; Fu *et al*., 2020). The most studied element of microplastics research in Malaysia is the uptake of microplastics by aquatic organisms. Although it is often studied, the types of organisms considered are limited to fish, clams, marine copepods and other zooplankton (Amelia *et al.*, 2020; Amin *et al.*, 2020; Pariatamby *et al*., 2020). The impacts of microplastics on human health have never been studied in Malaysia. The nearest to the topic is the studies on the presence of microplastics in various products consumed by humans and indirectly affecting them. These include studies on the presence of plastic particles in fish meals (Karbalaei *et al*., 2020), canned fish (Karami *et al.,* 2018*)* and commercial salts (Karami *et al*., 2017a). While many studies are looking at the negative aspects of microplastics in the environments, a few studies in Malaysia hope to tackle the issue by discussing the potential of plastic degradation using microorganisms isolated from plastic polluted ecosystems. In addition to this biodegradation potential of microorganisms, one study in Malaysia focuses on the development of biodegradable microbeads that can be a promising alternative to the current product (Govindasamy *et al*., 2019).

Studies on microplastics in Malaysia cover various aspects but are rarely compared to each other. It is believed that gathering all this available information is beneficial for better management of microplastics and plastic pollution issues in general. At the moment, no review study has been done on the studies of microplastics in Malaysia. The current paper attempts to fill this gap by conducting a systematic literature review on microplastic pollution in Malaysia.

In this study, following the SLR processes, we classify, select, and critically evaluate the previous studies to answer our formulated question. Our SLR is guided by the central research question – What do we know about microplastics in Malaysia and where can we go from here? This information will provide better understanding on the status of microplastic pollution, particularly in the marine ecosystem in Malaysia, and guide future efforts or policy design in controlling microplastic pollution. Understanding the current status of microplastic pollution in the country may also create awareness to the general public and improve responses. For the researchers specifically, this review informs specific areas that need further studies.

Methodology

Review Protocol

This study applies a review protocol developed by Haddaway *et al*. (2018), which is Systematic Evidence Synthesis or ROSES Reporting Standards. This review protocol was selected because of its original purpose to be used as a guide in reviewing environmental related studies, complementing more established review protocols such as QUOROM and PRISMA designed for medical studies review. Using this ROSES protocol, authors begin the review process by formulating the main research question before starting the systematic searching strategy. The systematic searching strategy includes identification, screening, and eligibility processes. Then, a quality appraisal follows before the data from the studies collected can be reviewed.

Formulation of Research Question

A few of the authors are familiar with the studies on marine debris. It has been realised that plastics had been a major component of marine debris around the world. However, the authors discovered that studies on marine debris are usually focused on the macro type that can be seen by the naked eyes. Meanwhile, studies on marine debris' impact usually found microplastics to be a major threat to the environment and wildlife. The authors believe there is a need to study microplastics further. This review study gathered information from available studies on microplastics and found the gap in current studies. The focus of the review is only on one country, Malaysia, which is of interest to the authors. The purposes mentioned guided the formulation of the research question of this review, that is, 'What do we know about microplastics in Malaysia and where can we go from here?'

Systematic Searching Strategy

Based on the ROSES protocol, the systematic searching strategy must include the identification, screening and eligibility processes. Figure 1 illustrates the processes followed by this study and number of articles after each of the steps were taken.

Identification

The identification process was done on the 1st of January 2021 to compile all previous studies published before the end of the year 2020. Two databases were used to assess available studies related to the topic, Scopus and Web of Science. The two databases were chosen as both are leading databases and are believed to be comprehensive and cover various disciplines including environmental related studies (Mohamed Shaffril *et al.*, 2020). One of the important tasks in the identification process is finding the keywords that help authors find all possible studies related to the topic of interest. The authors decided to use a search string that looks at title, abstract and keywords (TITLE-ABS-KEY in Scopus, and TOPIC in Web of Science). After some trials, the authors decided to use a simple string reported in Table 1. This is due to the low number of available studies when narrower keywords were used. It is also decided to keep the keywords as general as possible since the authors were looking at all studies related to microplastics and wanted to cover the widest

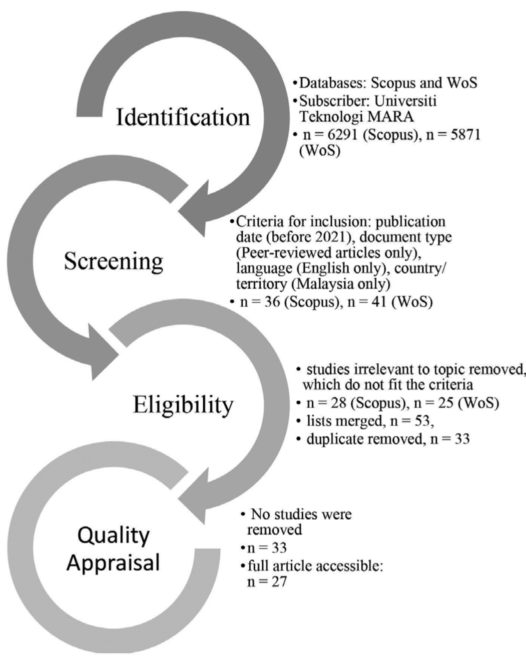

Figure 1: The flow diagram of the review protocol
(n represents the number of studies after each of the steps are taken)

possible topics. The identification process ends with 6291 results from the Scopus database and 5871 results from the Web of Science database (Table 1).

Screening

All the studies listed by the databases are then screened using the 'refine' function available in both databases that may include and exclude studies based on the criteria set by the users. This review study excludes all studies published after the year 2020. This study decided to include all other years because there is no study found before 2000. In terms of the document type, only peer-reviewed articles are included. Other articles including review articles, conference papers and books are excluded from the review. This is to have a particular standard on articles to be considered and the type of information the authors were looking for. Only articles using English as the medium were included to avoid mistakes or any confusion caused by the language barrier. The last criterion set by the authors was to exclude all studies outside Malaysia to keep to the objective of the paper. All the criteria of the studies that were included and excluded are listed in Table 2. Using the criteria, the number of articles recorded in Scopus was 36 and 41 in the Web of Science.

Eligibility

The authors continueed with the eligibility process after the screening process, where each of the retrieved articles was manually screened to ensure that they met the review criteria. This was done by thoroughly reading the article's title and abstract. When needed, further reading was done on the articles. In this process, few papers were excluded because they were irrelevant to the topic or/and not related to Malaysia. Following this process, only 29 articles were left in the Scopus and 26 articles left in the Web of Science. The lists of retrieved articles from both databases were then merged and duplicates were removed. In the end, only 33 articles were considered to be reviewed in this paper.

Quality Appraisal

Authors who are already familiar with the subject made a more rigorous assessment of the papers to ensure the quality of the literature to be included. Articles were classified between low, moderate, and high quality based on some criteria that focused on the method applied in their research. It was decided only to include articles that reach at least a moderate level. After this process, there was no need for articles to be omitted. However, only 27 articles were found with their full texts and thus further reviewed.

Table 1: Search string used to search for the literature

Database	Search String
Scopus (n=6291)	TITLE-ABS-KEY (microplastic* OR "micro plastic*" OR "micro debris" OR microdebris)
Web of Science (WoS) (n=5871)	TOPIC: (microplastic* OR "micro plastic*" OR "micro debris" OR microdebris)

Table 2: Criteria of literature to be included or excluded

Criteria	Inclusion	Exclusion
Publication date	Before 2000	After 2020
Document type	Article	Review paper, conference paper, proceedings, book chapters, etc.
Language	English	Other than English
Country	Malaysia	Outside Malaysia

Data Synthesis

In synthesising the data, the authors first prepared a table to extract data from all literature in an organized form. The table consists of columns for the title, aims, methodology, findings and conclusion. Each author made summaries of a few papers which are then collected and read again by all. Articles were then assessed and similar studies that look at certain aspects were grouped.

Results and Discussion

This study was able to find 27 full articles from the 33 articles that should be reviewed. Appendix 1 lists the 27 studies that are reviewed here while Appendix 2 lists the 6 unobtainable documents. From these 27 articles, this study found 4 similar topics that have been the focus of microplastic studies in Malaysia. These 4 topics were classified as themes that will be discussed in this paper. The oldest article found was published in 2009. Most of the studies were published after 2015 with 9 articles published in 2020. Figure 2 depicts the number of publications for each year.

Composition and Abundance of Microplastics in The Environment

Seven articles focused on the composition and abundance of microplastics in various marine ecosystems in Malaysia. Studies looked at the amount of different types of microplastics in water samples (Amin *et al*., 2020; Khalik *et al*., 2018; Pariatamby *et al*., 2020; Tee *et al*., 2020) and landfill, beach, and mangrove sediments (Fauziah *et al*., 2015; Pariatamby *et al*., 2020; Teuten *et al*., 2009). The study by Amin *et al*. (2020) analyses the presence of microplastics in the surface of the seawater and zooplankton in Terengganu coastal waters and found that the majority of microplastics were fibers which made up to 70% of the samples while fragments were 30%. The concentration of microplastics was highest from the station that was located near the beach compared to the other sampling sites. The most dominant kind of microplastics found in the surface water of Sungai Dungun, Terengganu, was also found to be fibers (Tee *et al*., 2020). The study by Tee *et al.* (2020) also reported the metal contents extracted from microplastics surfaces that include Pb, As, Mn, Zn, Cu, Fe, and Al. Another study which looked into the emergence of microplastics in the marine water found 1713 and 621 total particles at Kuala Nerus and Kuantan, respectively (Khalik *et al*., 2018). This research classified microplastics based on their physical properties. Three main shapes were classified into microplastics: filament, fragment, and irregular. In Kuala Nerus, black coloured particles were dominant (65.5 percent), while grey was the most common (48.7 percent) in Kuantan Port. Pariatamby *et al*. (2020) conducted another study at the Cherating

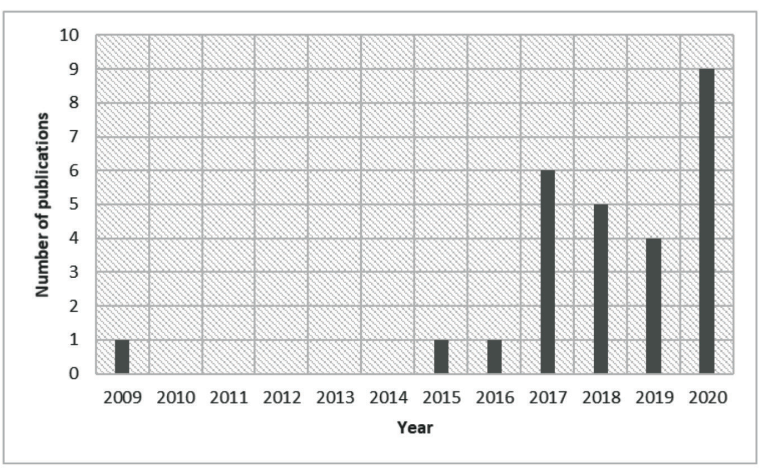

Figure 2: Number of publications for each year (2009-2020)

River and mangrove to investigate the occurrence of microplastics in surface water samples. In all surface water samples from the Cherating River and the Cherating mangroves, microplastics were present, with an average abundance of 0.0042 ± 0.0033 particles per m^3. The middle region was identified as the most polluted with an average quantity of 0.0070 ± 0.0033 particles per m^3. This came from intense fishing and tourism activities. Anthropogenic activities with the aid of strong wind increased the dissipation of floating microplastics in both areas. All these studies that looked at the composition and abundance of microplastics in water samples were usually done by filtering water through some membrane or sieve and materials trapped were analysed using microscopes.

Two other studies on the composition and abundance of microplastics, collected beach and mangrove sediments (Fauziah *et al*., 2015; Pariatamby *et al*., 2020). The study on microplastic abundance in mangrove forests (Pariatamby *et al*., 2020) showed a correlation (P, 0.05) between size and sediment depth. Finer microplastic particles usually accumulate more in the deeper layer than the surface layer. Lines that may come from the degradation of human-made fiber products were the most common microplastics found, then the next most frequent is pellet and film microplastics with sizes ranging from 5 mm to 1000 mm were most abundantly found in the deepest layer. A total of 2542 pieces (265.30 gm^{-2}) of small plastic debris from all six beaches sampled were found in the study that quantified plastic debris buried in various beach sediments across Malaysia (Fauziah *et al*., 2015). The majority of it was found in Kuala Terengganu beaches while plastic pellets were presented only in Batu Burok Beach and Seberang Takir Beach in Terengganu and Telur Likas Beach, Sabah. Pariatamby *et al*. (2020) and Fauziah *et al*. (2015) sampled sediments using two different methods. Sediments in Pariatamby *et al.* (2020) were sampled using the improved flotation method and microplastics were classified between line, pellet, and film, while sediments from another study by Fauziah *et al.* (2015) were sampled using a set of a nested sieve and classified into film, foam, fragment, line, and pellet. One study sampled landfill leachate as a source of endocrine-disrupting compounds obtained from plastics (Teuten *et al*., 2009). The study mathematically described the sorption of plastics and validated the model by experimental observations, concluding that bisphenol A (BPA) and nonylphenol (NP) concentrations are higher in landfill leachate than in wastewater effluent. Table 3 is a summary table of studies on microplastics in Malaysia that looks at the composition and abundance of microplastics in various ecosystems.

Microplastic Uptake by Aquatic Organisms

One of the most important reasons to study microplastics is their threat despite their small sizes. Many wildlife species are affected by either macro plastic entanglement or microplastic ingestion. Among the 27 microplastic studies reviewed here, most are listed under this theme. However, while many animals are affected, most studies in Malaysia focus on analysing the presence of microplastics in fish (Ibrahim *et al*., 2017; Karami *et al*., 2017c; Karami *et al*., 2017d; Karami *et al*., 2016; Karbalaei *et al*., 2019; Romano *et al.,* 2018; Sarijan *et al*., 2019) and only a few other studies on other aquatic organisms, including hard clams (Pariatamby et al., 2020), zooplankton (Amin *et al*., 2020) and marine copepods (Amelia *et al*., 2020). Table 4 lists the species studied to see microplastic uptake by aquatic organisms in Malaysia.

The amount of microplastic uptake in commercial marine fish in Malaysia is high when microplastics were examined from gills and viscera of 110 individual marine fish from 11 commercial fish species collected from the local market and the results showed that 9 out of 11 species contain plastic particles (Karbalaei *et al*., 2019). Of 56 plastic particles, 5.4% were pigments, 76.8% were found as plastic polymers and 17.8% were unidentified plastic particles. Local species *Eleutheronema tridatylum* and *Clarius gariepinus* were suggested as potential indicator species for other studies on ingested plastic particles as high numbers of ingested

Table 3: Summary table of studies under the theme of 'Composition and abundance of microplastics in the environment'

	Author/s	Sampling Area	Microplastic Classification	Amount of Microplastics
1	Amin *et al.*, 2020	Terengganu coast (surface water)	Fiber, fragment	3.3 particles L^{-1}
2	Hamid *et al.*, 2020	Carey Island, Selangor (mangrove sediment)	Line, pellet, film	936 -1227 particles kg^{-1} (dry weight)
3	Pariatamby *et al.*, 2020	Cherating River, Pahang (surface water)	Film, foam, fragment, line, pellet	0.0051 – 0.007 particles m^{-3}
4	Tee *et al.*, 2020	Sungai Dungun, Terengganu (surface water)	Fiber, foam, pellet	22.8 – 300.8 items m^{-3}
5	Khalik *et al.,* 2018	Kuantan, Pahang and Kuala Nerus, Terengganu (surface water)	Filament, fragment, irregular	0.13 – 0.69 pieces L^{-1}
6	Fauziah *et al.*, 2015	Port Dickson, Kuala Terengganu, Kota Kinabalu (beach sediment)	Film, foam, fragment, line, pellet	179 - 1164 items m^{-2}
7	Teuten *et al.*, 2009	Various locations including open dumps in Kuala Lumpur, Malaysia (landfill leachate)	Bisphenol A (BPA), nonylphenol (NP) and octylphenol (OP)	BPA (0.18 to 4300 mg L^{-1}) NP (0.18–98 mg L^{-1}) OP (0.03–3.4 mg L^{-1}).

Table 4: Summary table of species studied in Malaysia

	Author/s	Species studied
1	Amelia *et al.*, 2020	*Nitokra lacustris pacifica* (marine copepods)
2	Amin *et al.*, 2020	Various zooplankton (fish larvae, cyclopoid, shrimps, polychaete, calanoid and chaetognath)
3	Hamid *et al.*, 2020	*Meretrix lyrate* (hard clam)
4	Jaafar *et al.*, 2020 (METHOD)	Marine trawl fishes (*Drepane longimana, Drepane punctate, Gerres erythrourus, Caranx sexfasciatus, Eubleekeria splendens, Siganus guttatus, Pampus chinensis*)
5	Karbalaei *et al.*, 2019	11 commercial fish species (*Megalaspis cordyla, Epinephelus coioides, Rastrelliger kanagurta, Euthynnus affinis, Thunnus tonggol, Eleutheronema tridactylum, Clarias gariepinus, Colossoma macropomum, Nemipterus bipunctatus, Ctenopharyngodon idella, Selar boops*)
6	Sarijan *et al.*, 2019	6 commercial fish species (*Oreochromis mossambicus, Cyclocheilichthys apogon, Clarias gariepinus, Anabas testudineus, Pangasius hypophthalmus, Oxyeleotris marmorata*)
7	Romano *et al.*, 2018	*Barbodes gonionotus* fry (silver barp)
8	Ibrahim *et al.*, 2017	*Lates calcarifer* (wild and cage-cultured Asian sea bass)
9	Karami *et al.*, 2017b (METHOD)	*Clarias gariepinus* (African catfish)
10	Karami *et al.*, 2017c	4 species of common dried fish (*Rastrelliger kanagurta, Stolephorus waitei, Chelon subviridis, Johnius belangerii)*
11	Karami *et al.*, 2017d	Zebrafish (*Danio rerio*) larvae
12	Karami *et al.*, 2016	*Clarias gariepinus* (African catfish)

microplastics were detected in these species (Karami *et al*., 2017c). This study also found the presence of microplastics in the eviscerated fish flesh and dried fish organs. Out of the four dried fish species collected for investigation, a total of 61 plastic particles were isolated. About 56% of the particles were confirmed as microplastics, 21% were pigments, 6.55% were non-plastic particles (cellulose or actinolite) and 13.1% were not identified. This result shows that microplastics from the digestive system of aquatic organisms can translocate to their other tissues. Microplastics in wild and cage-cultured Asian sea bass, *Lates calcarifer* were found in abundance in another study conducted at Setiu Wetlands in Terengganu, Malaysia (Ibrahim *et al.,* 2017). The presence of the particles was higher in the wild species and nylon (PA) and polyvinyl alcohol (PVA) were the main types of polymer found in the gastrointestinal tract. A total of 4,498 microplastics were found in all samples with the wild *Lates calcarifer* showing the highest consumption of microplastic particles while the cage-cultured samples were the lowest. Ingestion of microplastics by commercial fish was also done to the species found in the Skudai River, Malaysia (Sarijan *et al*., 2019). The study shows that all species sampled had ingested microplastics. The most common microplastic colour eaten by fish is blue due to mistaking them for food.

Besides looking at the composition and amount of microplastics in fish, some studies look further into the impact of the plastic particles on the fish. Karami *et al*. (2016) had suggested that the uptake of microplastics in aquatic organisms does not affect the histology and morphology of the marine organisms. The author also stated that minimal threats were imposed to the aquatic organisms by the microplastics as they are believed to be inert. The African catfish gills, *Clarias gariepinus*, which were the study samples, show that the secondary lamellae had a normal structure with numerous mucous and basal cells, including the visible red blood cells in the capillary lumen. The structure of catfish sinusoids and hepatocytes in the liver also seemed normal (Karami *et al.*, 2016). Another study by Karami *et al.* (2017d) found that microplastics that are low-density polyethylene fragment uptake in zebrafish, *Danio rerio* larvae do not affect the cell morphology of the fish such as gill, liver, brain, and kidney. No morphological changes were detected from the microplastic uptake, showing no biomarker responses after the fish larvae were exposed to microplastic particles. Furthermore, another study involving silver barb, *Barbodes gonionotus* showed no effects of pristine polyvinyl chloride (PVC) fragments on the histology of the fish. The PVC fragments found in the intestinal part of the fish did not affect the internal organ as there was no microscopic ev idence (Romano *et al*., 2018).

The study on microplastic uptake by hard clam was conducted in the mangrove forest located at Pulau Carey, Selangor, on the west coast of Peninsular Malaysia. The study by Pariatamby *et al*. (2020) reported that microplastics had accumulated in the samples of hard clams, *Meretrix lyrate*. The microplastics entered the hard clam by the gill surface via ciliary movement. The consumed particles can stay in the clam for days or migrate into the cells. The largest microplastics found in the clam ranged from 5 mm to 20 mm, and the common type of the particles was line microplastics. Meanwhile, Amelia *et al*. (2020) analysed the absorption and egestion of polyhydroxyalkanoate microbeads in marine copepods (*Nitokra lacustris pacifica*). The fluorescence stained PHA microbeads were found in the tissue of the copepods, *Nitokra lacustris pacifica*. The proportion of PHA was > 70% in both filtered and unfiltered seawater treatments and the egestion time required 3 days to remove the microbeads from the body. The presence of microplastics has caused digestive constraints and caused a lower wet weight gain among the organisms. However, this higher ingestion rate may also lead to faster environmental consumption of microplastics over time.

The study of zooplankton microplastic ingestion in Terengganu coastal waters, southern South China Sea by Amin *et al.* (2020)

is another study on the uptake of microplastics by organisms. The study examines the presence of microplastics after the scientific digestion of zooplankton samples. About 70% of the samples were made up of fibers that constitute the majority of microplastics found. Microplastics were found in all of the zooplankton groups examined. The average size of microplastic particles was highest in shrimp and zoea, followed by fish larvae, polychaetes, calanoids, and chaetognaths, corresponding to their body sizes.

In order to detect the uptake of microplastics in aquatic organisms, many methods had been applied. Two studies discussed the weaknesses and the strengths of these various methods and suggested improvements to gain more accurate and comparable results (Jaafar *et al*., 2020; Karami *et al*., 2017b). For instance, Jaafar *et al*. (2020) studied the effectiveness of post-digestion methods in extracting microplastics from the gastrointestinal tract (GIT) and gills of fish. The efficiency of each method and protocol was assessed by comparing the relative removal of non-plastic materials from the GIT digestate and the gills of fish. They compared the presence of undigested materials on the filter, such as debris, shells, cartilage, organic matter, and coloration. It was found that sieving, a conventional method for isolating microplastics from samples, was 98.73% effective for GIT and 99.22% effective for gills. The study also suggested that density separation with $ZnCl_2$ solution improved the digestate removal of non-plastic materials and higher microplastic recoveries compared to other solutions.

Presence of Microplastics in Sea Products and Others

Microplastics in various organisms are known to be threatening to them, but the accumulation of microplastics by consuming these organisms is hardly studied. Owing to the cost-benefit aspect of the manufacture and use of plastic in recent years, the presence of these non-recycled plastic polymers in the terrestrial and marine environments has risen significantly. Animals in the terrestrial and marine environments eat these minuscule plastics and eventually, the microplastics are passed to all other trophic levels in the food chain. These plastic polymers pose a direct threat to aquatic life and indirectly impact the whole ecosystem by adsorbing other marine contaminants. Several studies on the presence of microplastics in sea products have been done in Malaysia (Karami *et al*., 2017a; Karami *et al*., 2018; Karbalaei *et al*., 2020). In addition, two other microplastic studies in Malaysia investigated the presence of microplastics in personal care and cosmetic products (Praveena *et al*., 2018; Suardy *et al*., 2020).

According to a report on the composition of microplastics in commercial Malaysian fish meals, 25% of the world's fish meal comes from fish processing waste, creating a possible microplastic pollution pathway since microplastics are found in the gastrointestinal tracts of many fish species (Karbalaei *et al*., 2020). In the study by Karbalaei *et al*. (2020), a total of 336 particles were isolated from three fish meal brands and 64.3% of the particles were confirmed as microplastics. The study advised that microplastic pollution can be high in fish meals and the evidence suggested that high levels of microplastics could also be affected to farmed organisms and that unintended environmental impacts need to be properly evaluated. In another study, 1g of fragments of various plastic types including LDPE, HDPE and PP were added to the abdominal cavity of dead sardines and sprats to replicate the actual wild state (Karami *et al*., 2018). These fish were subsequently exposed to several processes that are frequent in the production of canned fish. The samples were later analysed to determine the recovery rates of all the plastic polymers. Results showed that the recovery rates of polymers following the steaming process were more than 80.5% suggesting the excellent resistance of plastic polymers to chemicals and UV.

Another sea product that has been assessed in terms of the presence of microplastics is sea salt. The study was done by Karami *et al*. (2017a) that investigated microplastics in commercial salts from different countries. The study suggested that a low level of salt intake with anthropogenic particles has negligible health consequences. Although the results from the study did not show a significant load of microplastics larger than 149µm and are therefore negligible, the study suggested that the increasing trend of plastic use and disposal might lead to the accumulation of microplastics in the environment and necessitate the regular quantification of microplastics in various sea products (Karami *et al*., 2017a).

The use of microplastic components in the production of personal care and cosmetic products was investigated in two studies and emissions to the marine environment were estimated when the products were discarded (Praveena *et al*., 2018; Suardy *et al*., 2020). The study by Praveena *et al*. (2018) estimated the emission of microplastics into the environment based on the assumption that waste is discarded from wastewater treatment plants without sewage treatment and microplastics escape. A total of 0.199 trillion microplastic particles are estimated to be emitted annually into the environment. The study also suggested that microplastic pollution from personal care and cosmetic products would undeniably lead to the degradation of the marine environment by microplastics from the travelling and escaping of microplastics from drainage systems (Praveena *et al*., 2018). The analysis and characterization of microplastics from personal care and cosmetic products done by Suardy *et al*. (2020) reported that extracted microbeads from the products came in various colours and shapes and all six products sampled consist of polyethylene (PE) and polystyrene (PS) polymer.

Biodegradation and Biodeterioration of Microplastics

Most of the studies that have been discussed in three previous themes focus on the current status of microplastics in the environment, in organisms, and the sea and other products. Meanwhile, five studies found in Malaysia explore the potential in biodegradation and biodeterioration of microplastics from the environment. The potential from various species of bacteria has been studied including *Bacillus sp.* (Auta *et al*., 2017; Auta *et al*., 2018; Govindasamy *et al*., 2019), *Rhodococcus* sp. (Auta *et al*., 2018), and even isolated bacteria from the Antarctic including *Pseudomonas sp.* (Habib *et al.,* 2020). These studies isolated the colony of bacteria from various environments including mangrove ecosystems (Auta *et al*., 2017) and leachate samples from a landfill (Tarmizi *et al*., 2019). Auta *et al*. (2017) stated that bacteria isolated from mangrove sediment have the potential to degrade microplastics. Eight aerobic bacterial strains, representing the native bacterial community, were isolated in the study. The microbes that include *B. cereus* and *B. gottheilii* can grow on the media containing PE, PET, and PS and use the materials as their sole carbon source. The study suggests that their ability may be due to their adaptability to the plastic-infested area. Evident elongation and reduction were observed in both samples compared to the control. The observed shift and the formation of oxidation products, such as carbonyls, hydroxyls, esters, aromatics, and alcohols, reflected the changes in the chemical structure of the microplastics. The study also validates their findings using Scanning Electron Microscope (SEM) where microplastic surfaces were found rough and had multiple holes/pores, erosions, cracks and grooves after 40 days of incubation with isolates. This result presented proof of the degradation of the microplastics due to the activity of the microbes (Auta *et al*., 2017).

Another study by Auta *et al.* (2018) evaluated the growth response and degradation process of polypropylene (PP) by *Bacillus sp.* and *Rhodococcus sp*. and six different bacteria isolated from mangrove sediments in the study. Two of the bacteria isolates were found to be potential PP microplastic degraders. PP microplastics had a weight loss of 6.4% and 4.0% after 40 days of isolation with *Bacillus sp*. Stretch 27 as well as *Rhodococcus sp*. Stretch 36 respectively. This finding showed the ability of bacterial isolates to excrete unique enzymes that might potentially target microplastic UV-treated PP. This study covers the need to study properties of bacteria that contribute to the biodegradation of microplastics accumulating in the aquatic environment. Meanwhile, Tarmizi *et al.* (2019) studied the biodegradation process of microplastics in a batch culture system using a colony of leachate-derived bacteria in the Ayer Hitam landfill in Malaysia. The study determined that microplastics can be degraded in a batch culture system based on percentage weight loss, ammonia-nitrogen removal, changes in the chemical structure, and decomposition of microplastics after 14 days of the incubation period. The study recorded that PE has the highest dry weight loss (3.46%) in 14 days compared to other plastics. The study suggested that it was necessary to maximise incubation time in the biodegradation process.

Another study investigates the potential of isolated bacteria from the Antarctica for microplastics to degrade. The samples were obtained from Victoria Island, Antarctica, although the experiment was done in Malaysia (Habib *et al.,* 2020). It has been proposed that *Pseudomonas sp.* and *Rhodococcus sp*. are commonly found in the pristine or polluted soils of the Antarctic. It seems to be promising that these strains have the ability to use highly hydrophobic PP microplastics as their energy source. According to the researchers, for any single microorganism, with or without pre-treatment, the percentage of PP weight loss observed by ADL 15 within 40 days is the highest. The constant daily PP microplastic removal rate (K) from Antarctic bacterial isolates is calculated by first-order and half-life, t1/2. The half-life is estimated to approximate the time needed to reduce the microplastic PP by half. This study shows that *Pseudomonas sp.,* ADL15, which has a higher PP exposure tolerance than ADL36 (*Rhodococcus sp*.), has the fastest rate of removal of PP microplastics. The slower but steady increase in ADL 36 growth underpins the *Rhodococcus sp*. as K-strategist. It means that the species has the gene that evolves at a slower pace while maintaining a healthy atmosphere. The study suggested that plastic biodegradation is mainly affected by environmental factors such as pH. The impact of pH on microbe survival is profound. The study concluded that Antarctic soil bacteria might degrade polypropylene (PP) microplastics.

Beside studies that explore the potential of microorganisms to biodegrade plastic particles, there is also a study in Malaysia that looks at the development of biodegradable microbeads as a safer alternative to current microbeads used in health and beauty products. This study applied a double emulsion solvent evaporation technique (Govindasamy *et al*., 2019). The method extracts optimised microbeads developed by *Bacillus megaterium* UMTKB-1 and also copolymer developed using a dual emulsion solvent evaporation technique by *Massilia haematophila* UMTKB-2. The size of these biodegradable microbeads is found to be more consistent with human skin pores compared to the synthetic microbeads commercially available, showing a promising and more effective microbead (Govindasamy *et al*., 2019).

'What Do We Know About Microplastics in Malaysia and Where Can We Go from Here?'

Based on thematic analysis, this SLR study has grouped the 27 studies based on four themes. Each of the articles was classified under one theme except for two papers listed at least twice because the articles are looking at more than one aspect or theme. The articles from Amin *et al*. (2020) and Hamid *et al.* (2020) are both listed under two themes: (1) composition and abundance of microplastics in the environment, and (2) microplastic uptake by aquatic organisms.

Looking at all the studies; 10 out of the 27 articles were looking at the uptake of microplastics by aquatic organisms, especially fish. Fish species studied include *Eleutheronema tridactylum, Clarias gariepinus, Lates calcarifer, Clarias gariepinus, Barbodes gonionotus* and many others. Other organisms studied are hard clam, various zooplankton, and marine copepods. Many other organisms can be affected by microplastics but are yet to be studied in Malaysia. Besides different types of aquatic organisms, there is a gap in studying the uptake of microplastics in terrestrial animals. Further, there is also a need to study the pathway of microplastics from its uptake by these organisms through the food chain. The accumulation of microplastics in human health risk assessment is not found among studies in Malaysia but has been studied elsewhere (Senathirajah *et al*., 2021).

The other theme on microplastics that are mostly studied in Malaysia is the composition and abundance of microplastics in the environment. Among the ecosystems studied include surface water, beach, and mangrove. The composition of microplastics is mostly classified based on their shape or other physical properties. However, there are some differences in the types of microplastics listed in each of the studies. In addition, some studies focus on the relative composition and report the composition based on percentages. Some other studies look at the number of particles between different areas within the ecosystem. There is only one study that looks at the accumulation of hazardous material on microplastics surfaces. This is another gap that needs further study. In addition, it is suggested that most studies on microplastics in the marine ecosystem have been focusing on surface water. In contrast, many microplastics actually sink to the bottom of the ocean and affect bottom dwellers (Jacquin *et al*., 2019). Although the method to sample microplastics on the bottom of the sea or other ecosystems may be more complex, this should not be neglected to have a more unbiased and comprehensive study.

Moreover, there is also an emerging topic on microplastics related to the biodegradation and biodeterioration theme; that is the study on 'plastisphere' where microorganisms are using plastics as their new home. These microbial ecotoxicology studies explore the factors that contribute to the types of microorganisms found on plastic surfaces and the role of plastic debris as a material that carries pathogenic species (Ghiglione *et al*., 2016; Jacquin *et al*., 2019). There are already a few papers on biodegradation and biodeterioration of microplastics in Malaysia. Most of these studies isolate bacteria from the environment and introduce microplastics to the colonies in lab settings. A review study by Jacquin *et al*. (2019) suggested that this may provide a very different finding if the microplastics are directly sampled at sea. Further study on the species of bacteria on different types of microplastics has also been left out from the studies in Malaysia while many studies abroad have reported the differences in microbial assemblages found on non-biodegradable and biodegradable plastics (Jacquin *et al*., 2019), and different plastic types (Ashar *et al*., 2020).

From the systematic literature review, we feel that many of the topics on microplastics studied worldwide are also being studied in Malaysia. However, further studies can be explored in each of the topics or themes. There are also some limitations to what we have discussed in this review. There are 6 papers that are not found in this SLR which may provide a lot of valuable information that may be left out due to our access limitation. This SLR also only covers two databases which are Scopus and WoS and only includes peer-reviewed articles. We expect that there is much more information on microplastics available but are not discussed here.

Conclusion

Based on the 27 articles reviewed, this study would like to highlight some points that can be taken for future studies. Currently, the status of microplastics in Malaysia is not clearly known. The themes studied in Malaysia are found to be parallel to what are being studied worldwide. However, as discussed, many studies can be further carried out and in-depth studies can be done on each one of the themes. Studies on the abundance and composition of microplastics in Malaysia's coastal, marine and other aquatic ecosystems should be continued to cover wider areas and not neglecting studies on the impact of microplastics on various other environments including terrestrial ecosystem. Further research is also required in terms of the effects of microplastics on the health of human and other species. In addition to aquatic organisms, only a few studies have been conducted on mammals, human and other living organisms in Malaysia but have been done in other countries (Sarijan *et al*., 2019). The presence of microplastics in the food web or other trophic levels could be further researched as stated by Amin *et al*. (2020) that the abundance of microplastics in animals may differ in various localities and seasons. It is important to understand how the existence of microplastics can make other species vulnerable. Therefore, future studies should consider these gaps.

This systematic review has provided us with an overview of microplastics in Malaysia which is the main objective of this paper. As not much research involving microplastics has been conducted in Malaysia, this SLR can provide more information. This review provides general details of microplastics in the country and it is hoped that current management approach can be improved with new well-developed strategies for dealing with microplastic issues. The review provides some starting points to further study issues in microplastics. This review study concludes that there are many other areas related to microplastics to be explored, a lot of in-depth studies that can be done, while there is already a lot of information available to begin efforts in managing microplastic pollution in Malaysia.

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Appendix 1: Reviewed Articles

No.	Year	Author	Journal	Title
1	2009	Teuten *et al*.	Philosophical Transactions of the Royal Society B: Biological Sciences	Transport and release of chemicals from plastics to the environment and to wildlife.
2	2015	Fauziah *et al*.	Waste Management & Research	Plastic debris in the coastal environment: The invincible threat? Abundance of buried plastic debris on Malaysian beaches.
3	2016	Karami *et al*.	Environmental Research	Virgin microplastics cause toxicity and modulate the impacts of phenanthrene on biomarker responses in African catfish (*Clarias gariepinus*).
4	2017	Auta *et al*.	Environmental Pollution	Screening of *Bacillus* strains isolated from mangrove ecosystems in Peninsular Malaysia for microplastic degradation.
5	2017	Ibrahim *et al*.	Malaysian Journal of Analytical Sciences	Isolation and characterisation of microplastic abundance in *Lates calcarifer* from setiu wetlands, Malaysia.
6	2017	Karami *et al*.	Scientific Reports (Nature Research)	The presence of microplastics in commercial salts from different countries.
7	2017	Karami *et al*.	Science of the Total Environment	A high-performance protocol for extraction of microplastics in fish.
8	2017	Karami *et al*.	Scientific Reports (Nature Research)	Microplastics in eviscerated flesh and excised organs of dried fish.
9	2017	Karami *et al*.	Environmental Pollution	Biomarker responses in zebrafish (*Danio rerio*) larvae exposed to pristine low-density polyethylene fragments.
10	2018	Auta *et al*.	Marine Pollution Bulletin	Growth kinetics and biodeterioration of polypropylene microplastics by *Bacillus sp.* and *Rhodococcus sp.* isolated from mangrove sediment.
11	2018	Karami *et al*.	Science of the Total Environment	Microplastic and mesoplastic contamination in canned sardines and sprats.
12	2018	Khalik *et al*.	Marine Pollution Bulletin	Microplastics analysis in Malaysian marine waters: A field study of Kuala Nerus and Kuantan.
13	2018	Praveena *et al*.	Marine Pollution Bulletin	Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An evidence from Malaysia.
14	2018	Romano *et al*.	Environmental Pollution	Effects of pristine polyvinyl chloride fragments on whole body histology and protease activity in silver barb *Barbodes gonionotus* fry.

15	2019	Govindasamy *et al*.	Data in Brief	Dataset on controlled production of polyhydroxyalkanoate-based microbead using double emulsion solvent evaporation technique.
16	2019	Karbalaei *et al*.	Marine Pollution Bulletin	Abundance and characteristics of microplastics in commercial marine fish from Malaysia.
17	2019	Sarijan *et al*.	Environment Asia	Ingestion of microplastics by commercial fish in Skudai river, Malaysia.
18	2019	Tarmizi *et al*.	International Journal of Engineering and Advanced Technology	Micro-plastic characteristics and removal of ammonia-nitrogen in batch culture.
19	2020	Amelia *et al*.	Journal of Sustainability Science and Management	Uptake and egestion of polyhydroxyalkanoate microbeads in the marine copepod *Nitokra lacustris pacifica*
20	2020	Amin *et al*.	Marine Pollution Bulletin	Microplastic ingestion by zooplankton in Terengganu coastal waters, southern South China Sea.
21	2020	Habib *et al*.	Polymers	Biodeterioration of untreated polypropylene microplastic particles by antarctic bacteria.
22	2020	Hamid *et al*.	Journal of Engineering and Technological Sciences	Microplastics abundance and uptake by M*eretrix lyrata* (Hard clam) in mangrove forest.
23	2020	Jaafar *et al*.	Chemosphere	Improving the efficiency of post-digestion method in extracting microplastics from gastrointestinal tract and gills of fish.
24	2020	Karbalaei *et al*.	Marine Pollution Bulletin	Analysis and inorganic composition of microplastics in commercial Malaysian fish meals.
25	2020	Pariatamby *et al*.	Journal of Engineering and Technological Sciences	Status of microplastic pollution in aquatic ecosystem with a case study on cherating river, Malaysia.
26	2020	Suardy *et al*.	Sains Malaysiana	Analysis and characterization of microplastic from personal care products and surface water in Bangi, Selangor.
27	2020	Tee *et al*.	Sains Malaysiana	Microplastic abundance, distribution, and composition in Sungai Dungun, Terengganu, Malaysia.

Appendix 2: Unobtainable Documents

No.	Year	Author	Journal	Title
1	2017	Matsuguma *et al.*	Archives of Environmental Contamination and Toxicology	Microplastics in Sediment Cores from Asia and Africa as Indicators of Temporal Trends in Plastic Pollution
2	2018	Malik *et al.*	Journal of Material Cycles and Waste Management	Potential recyclable materials derived from riverine litter at log boom Sungai Batu in Kuala Lumpur
3	2019	Kamaruddin *et al.*	International Journal of Integrated Engineering	Glass transition behavior of poly methyl methacrylate microplastics under various intermediates ratio
4	2020	Hamza *et al.*	Journal of Green Engineering	Microplastic occurrence in seaturtle nesting beach sediments from Terengganu, Malaysia
5	2020	Praveena *et al.*	Environmental Science and Pollution Research	Microplastic emissions from household washing machines: preliminary findings from Greater Kuala Lumpur (Malaysia)
6	2020	Razali *et al.*	Journal of Sustainability Science and Management	Effect of thermo-photocatalytic process using zinc oxide on degradation of macro/micro-plastic in aqueous environment