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THE EFFECT OF MICROPLASTICS ON COMMERCIALLY VALUED AQUACULTURE SPECIES: A REVIEW.

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Thanks to all of you.

ABBREVIATIONS

AHR	Aromatic hydrocarbon resin
CP	Cellophane
FRM	Spherical polymer microplastics
GSE	General search equation
MP(s)	Microplastic(s)
NA	Not available (data)
PE	Polyethylene
PET	Polyethylene terephthalate
PMC	Pubmed central
PP	Polypropylene
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analysis
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PU	Polyurethane
PVC	Polyvinyl chloride
SPSE	Specific search equation
WOS	Web of Science

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ABSTRACT

Microplastics are globally ubiquitous heterogeneously distributed, reaching and accumulating from the most overpopulated regions on earth and its coasts to pristine locations and ocean depths. A microplastic is a particle, fragment, fibre, pellet or sphere composed of plastic material, with a linear dimension between 1µm-5mm. Among many others, aquaculture is considered a direct source of microplastics entering the environment and consequently the organisms produced, as most of the facilities and gear used are made of different plastic materials. The aim of this study is to carry out a systematic review of the available information on the effect of microplastics on commercially valued aquaculture species (algae, echinoderms, crustaceans, molluscs and fish); as well as the possible correlations between their presence and the potential risk to human health from their consumption. The results obtained are very diverse, as they depend on the polymer type, its size, concentration, exposure time, format (fibres, fragments, pellets, microbeads, etc.), the analysis method and protocol used, as well as the species analysed and even on the moment of its life cycle (embryos, juveniles or adults). In conclusion, with the continuous increase of microplastics in the environment, systematic research to asses the impact of microplastics on commercially valued aquaculture species and their possible effect on human health.

Keywords: Microplastic, pollution, effects, aquaculture species, food safety, human health.

RESUMEN

Los microplásticos están extendidos heterogéneamente por todo el mundo, se acumulan a largo plazo contaminando desde las regiones más superpobladas de la tierra y sus costas hasta lugares prístinos y profundidades oceánicas. Un microplástico es una partícula, fragmento, fibra, pellet o esfera compuesta por material plástico, con una dimensión lineal entre 1μm–5mm. Entre otras, la acuicultura es considerada una fuente directa de entrada de microplásticos al medio y en consecuencia a los organismos producidos, ya que la mayoría de las instalaciones y del equipamiento empleado está constituido por diferentes materiales plásticos. El objetivo de este estudio es realizar una revisión sistemática que analice la información disponible acerca del efecto de los microplásticos en las especies acuícolas de interés comercial (algas, equinodermos, crustáceos, moluscos y peces) y las posibles correlaciones entre su presencia así como el posible riesgo para la salud humana por su consumo. Los resultados obtenidos son muy diversos, ya que dependen del tipo de polímero, su tamaño, concentración, tiempo de exposición, formato (fibras, fragmentos, pellets, microperlas, etc.); del método y protocolo de análisis utilizado; y también depende de la especie analizada e incluso del momento de su ciclo vital (larvas, juveniles o adultos). En conclusión, con el continuo aumento de los microplásticos en el medio ambiente, es necesario realizar una investigación sistemática para evaluar el impacto de los microplásticos en las especies acuícolas de valor comercial y su posible efecto en la salud humana.

Palabras clave: Microplástico, contaminación, efecto, especies acuícolas, seguridad alimentaria, salud humana.

1. INTRODUCTION

1.1. Microplastics, scientific background

Plastic is a material with a unique long chain-like molecular chemical structure made up of repeating identical homopolymer units or different copolymer sub-units in various sequences derived from fossil oil or gas feedstocks. Nowadays, plastic's versatility and low production costs make it the most widely used material today. Its malleability makes possible for it to be resistant manufactured to degradation, flexible, rigid, elastic and durable objects; which can be given numerous applications such as foams, fibres, films, different size beads and flakes, pieces and complete objects (Andrady & Neal, 2009; GESAMP, 2015; Napper & Thompson, 2020; Mofijur et al., 2021).

Having its origins approximately 170 years ago with parkesina, the forerunner of today's celluloid by Alexander Parkes, plastics are relatively new materials. Later on in 1907, Leo Baekeland discovered bakelite, the first truly synthetic mass-produced plastic by 1940 (Andrady & Neal, 2009; Teuten et al., 2009; Jambeck et al., 2015). Since then, different plastic variations have been developed and the annual worldwide demand and consequent production of plastic has been increasing reaching 368 million tons from which only 29.1 million tons were collected post-consumer waste in 2019 (Drzyzga & Prieto, 2019; Plastics Europe, 2020). Roughly 30 years after the start of mass production, the presence of small plastic fragments in the open ocean were reported for the first time (Carpenter & Smith, 1972; Laist, 1987).

There is a wide variety of classifications for plastics depending on the criteria that differentiate them, e.g. according to their chemical composition, shape, size, presence or absence of additives or colourants etc. (Napper & Thompson, 2020).

In relation to their chemical composition, there is a vast assortment of different polymers but the global market demand distribution is dominated by: polyethylene (PE) 29.8%, poly-propylene (PP) 19.4%, polyvinyl chloride (PVC) 10%, polyurethane (PUR) 7.9%, polyethylene terephthalate (PET) 7.9%, polystyrene (PS) 6.2%, and others 18.8% (Plastics Europe, 2020).

The size-based classification of plastics is widely used, GESAMP (2015) and Mofijur et al. (2021) reviewed the available literature differentiating into mega-, macro-, meso-, micro-, and nano-size ranges (Table 1).

Table 1. Size-based classification of the plastic particles (own elaboration, extracted from GESAMP (2015) and Mofijur et al. (2021).

Particle	Size
Megaplastic	> 1 m
Macroplastic	25 mm - 1 m
Mesoplastic	5 - 25 mm
Microplastic	1μm - 5 mm
Nanoplastic	< 1 μm

Determining the size range that each term encompasses was an improvement, since there was a great inconsistency and consequent problem originated from the difficulty of establishing a uniform standard classification (GESAMP, 2015; Zhou et al., 2020).

The term microplastic (MP) was coined for the first time in a manuscript by Ryan & Moloney (1990), and Thompson et al. (2004) describing the long-term pollutant accumulation of fragments particles, fibres or granules. It referred to the presence of plastic particles not detectable to the naked eye, but only through the use of a microscope in samples taken from the marine environment to analyse their litter content, without formally proposing a size range. In the course of research, the size range of the MPs was defined as plastic particles with a linear dimension up to 5 mm (Gregory & Andrady, 2003; Betts, 2008; Moore, 2008; Fendall & Sewell, 2009; NOAA Marine Debris Program, 2009). And later on, with the definition of nanoplastic, the MP size range was finally accepted between 1μm - 5 mm (GESAMP, 2015; Zhou et al., 2020; Mofijur et al., 2021).

An observation should be made, regarding the differentiation between MPs, they can be generally grouped into two categories: primary and secondary MPs. The primary MPs are those plastics that are directly produced for the original purpose of being micro-sized, which are within the threshold of the definition of microplastic. They are commonly known as pellets, micro-beads or virgin microplastics, and are included in numerous cosmetic and pharmaceutical products that pass through water sewage treatment plants reaching the marine environment; and also as plastic powders used in industrial processes such as air blasting technologies due to its cutting and abrasion powers (Andrady, 2011; Cole et al., 2011; Hernandez et al., 2017; Zhou et al., 2020; Mofijur et al., 2021).

The secondary MPs have their origin from fragmentation and degradation of larger plastics already present in the environment into smaller size, by continuous exposure to the action of natural processes, such as UV radiation (photo-degradation, oxidation), the action of the waves, wind or the friction with sediment causing disintegration, leaching and release of the particles into the environment (Derraik, 2002; Browne et al., 2007; Cole et al., 2011). But there are other less perceptible pathways for secondary MPs to enter the marine environment. Secondary MPs can be generated from the wearing of pneumatic tires, released from the use and washing of synthetic fabrics in the laundry and textile industry, released from tea-bags and from the paint flaking off the bottom of marine structures or vessels (Andrady, 2011; Cole et al., 2011; GESAMP, 2015; Napper & Thompson, 2016; Boucher & Friot, 2017; Hernandez et al., 2019; Thiele et al., 2021).

This classification can help to indicate potential sources and identify mitigation measures to reduce their input to the environment. Thompson (2006) estimated that around 10% of the plastics produced end up in the marine environment, either directly if discarded immediately after use, which are the majority of primary MPs; or indirectly, as the plastic debris degrades over time, producing previously so-called secondary microplastics, and these are transported by wind, rain, water sewages, river runoffs, drift, dust etc. into the sea (Krause & Bräger, 2006; Barnes et al., 2009; Cole et al., 2011; Ryan et al., 2009; Andrady, 2011). This results in a heterogeneous global distribution of plastic debris, which needs to be further investigated, reaching and accumulating from the most overpopulated regions on earth and its coasts to pristine locations and ocean depths (Moore, 2008; Martinez et al., 2009; Barnes et al., 2009; Zhou et al., 2020).

In addition, there are other sources of plastic entering the marine environment from, industries that develop on the coast or directly in the sea, such as tourism, fisheries, shipping, or aquaculture, among others (Bayo et al., 2019; Dowarah & Devipriya, 2019; Chen et al., 2021).

Aquaculture is considered one of the activities that will contribute to solving the human protein source crisis, and in developing countries it is considered a key industry due to the role that it plays in improving the economy, hunger, malnutrition and other social and political problems. Analysing the evolution of the sector, the total fish production has experienced an annual growth throughout the world, except in Europe, which has gradually decreased since 1980, although in recent decades it seems to be recovering (FAO, 2020; Zhou et al., 2020)..

Currently, aquaculture represents 46% of total production, including fisheries, and contributes to providing 52% of the total production of fish for human consumption. The major production country is China, who by its own, was capable of producing 35% of the total in 2018. In addition, China has become the first country whose total aquaculture production surpassed the total of fishing captures, the world's largest fishery, and the largest exporter of related products (Cao et al., 2015; FAO, 2020; Zhou et al., 2020).

Since most of the aquaculture facilities are built with different plastic materials due to their characteristics, it cannot be denied that the aquaculture sector is a direct source of plastic input into the environment. It cannot be separated from any part of the farming process, the complete facilities in the different stages of development (hatchery, nursery, pre-fattening and fattening) contain plastic elements, some examples are: nets, ropes, mooring buoys, feeders, water circulation systems, aerators, among others. MPs can even been found in the feed itself, microplastics can be found (Castelvetro et al., 2020; Zhou et al., 2020; Mofijur et al., 2021; Thiele et al., 2021).

In addition, MPs have also been detected in commercial aquaculture animals. Due to their small size, MPs are bioavailable even to filter feeding species in the food web. Uptake may occur through active ingestion by being mixing with prey/feed, or through already contaminated prey/feed, sediment and/or water. Both routes have already been observed in laboratory experiments (Bern, 1990; Besseling et al., 2014; Farrell & Nelson, 2013; Frias et al., 2014; Watts et al., 2014).

Ingestion of MPs can cause ulcers, stress, satiation, abrasion, oxidative stress, decreased growth rate and alter the reproductive fish success (Pedà et al., 2016). MPs may also incorporate contaminants or harmful bacteria attached to their surfaces that can be harmful or cause disease in the trophic chain from which bioaccumulation is possible(Teuten et al., 2009; Cole et al., 2011). However, the effect of MPs can vary between polymer type, the retention time, the possible presence of additives, etc., and depending on the organism studied i.e. algae (macro- and microalgae), echinoderms, crustaceans, molluscs and fishes.

In the last decade, a great deal of research has been carried out on microplastic contamination of aquaculture products. However, to my knowledge this is the first study that has compiled all available information over the last 20 years on the effects of microplastics on aquaculture species of commercial interest (algae, echinoderms, crustaceans, molluscs and fish). The analysis of such research will provide an overview of the current problem and set a precedent for where future research can be directed.

2. OBJECTIVES

The main aim of this review was to gather available evidence on the effect of microplastics (MPs) on commercially valued aquaculture species (marine and freshwater, produced in open and closed systems).

Towards this end, the following specific objectives were proposed:

- Examine the effects of MPs on the growth of cultivated species.
- Revise the concentration of MPs found in commercially valuable aquaculture species.
- Review existing studies to confirm or reject whether the proportion of MPs found in aquaculture species poses a greater risk to human health than in fisheries.
- Analyse how the aquaculture industry is a direct source or pathway for introducing MPs into aquatic ecosystems and the food chain.

3. MATERIAL & METHODS

3.1. Study search design

The documentary analysis method used to elaborate the hereby Master's thesis has been the classical method of systematic review, the purpose of which is to obtain the "state of the art" on the subject of study through rigorous and objective multiple searches. Providing the most complete and updated unbiased collection of documents by analysing several reliable sources of information such as the consulted databases: Web of Science (WOS), Pubmed and Pubmed Central (PMC).

The study search design used to compile all the knowledge referring to the present topic was the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) methodology. This method has been shown to be successful in various areas of science, including aquaculture and marine science, and it can be used as justification for future research to be carried out, since it allows new conclusions, proposals and detection of possible new challenges.

In order to elaborate the search equations, a series of keywords related to the previously established study objectives were included, and linked by the combined use of Boolean operators such as AND and OR. In addition, the quotation mark symbol (" ") was used to retrieve or maintain adjacent terms in searches. They allow expansion or limitation in the performed searches according to particular needs, building search equations of a general or more specific type focus, guaranteeing the maximum coverage of the reviewed topic.

The equations in the searches performed are shown in Table 2. First of all, the general search equation (GSE) aims to provide introductory information, while the specific elaborated search equations (SPSE) focus on gathering specific information in order to narrow the previous searches as much as possible to the specific topic.

Table 2. General search equations used in the above cited databases.

Code	Name	Search equation
(GSE)	General search equation	((microplastic OR "plastic particle" OR microbead OR microfibre) AND (pollution OR litter OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry"))
(SPSE - 1)	Specific search equation 1	((microplastic OR "plastic particle" OR microbead OR microfibre) AND (pollution OR litter OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND ("food chain" OR "commercially valued species"))
(SPSE - 2)	Specific search equation 2	((microplastic OR "plastic particle" OR microbead OR microfibre*) AND (pollution OR litter OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND (effect OR ingestion OR growth OR reproduction OR survival OR development OR "antibiotic resistance"))

(SPSE - 3)	Specific search equation 3	((microplastic OR "plastic particle" OR microbead OR microfibre) AND (pollution OR litter OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND ("food safety" OR "human health"))
(SPSE - 4)	Specific search equation 4	((microplastic OR "plastic particle" OR microbead OR microfibre) AND (pollution OR litter OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND ("food chain" OR "commercially valued species") AND (effect OR ingestion OR growth OR reproduction OR survival OR development OR "antibiotic resistance") AND ("food safety" OR "human health"))

3.2. Study selection criteria

For the correct selection and filtering of the articles obtained, a series of inclusion and exclusion selection criteria were defined. Applying them limits the initial number of articles obtained to only those articles of relevance that could contribute to answering and reaching the proposed questions and objectives, respectively.

The selection criteria were:

- Selection only of original publications in scientific journals, books and conference abstracts, verified and reliable, excluding review articles, as they do not provide new data on the topics reviewed.
- Publications written in English.
- Publications from January 1, 2000 until June 1, 2021.
- Publications linking the presence of microplastics with the development of commercially valued aquaculture species, and their relationship with human diseases.

To further refine the data, manual curation was applied to discard redundant findings, and unrelated to the purpose of the searches; either because they exceeded the filters applied or did not fall under the previously stated objectives. Also, articles of interest that were not previously assigned by the systematic searches performed were included.

4. RESULTS & DISCUSSION

This section summarizes the findings obtained with the multiple bibliographic searches performed. The data extracted and synthesized are presented in the form of a table, responding to and covering the objectives set out in this Master's thesis.

The term "entry" is referred to: research articles, previous reviews related to the topic, conference proceedings, as well as book chapters or any other type of format for the presentation of scientific and peer-reviewed information.

4.1. Bibliometric analysis

A total of 1.566 "raw" entries were identified at the start of the search process, ending with 1.522 records once the study selection criteria filters were applied. Figure 1 graphically illustrates the number of results obtained for each search equation, before and after applying the above mentioned criteria. And, Table 3 summarizes the cumulative total number of entries identified by database searching, with the PMC being the one with the highest number of records. As can be seen in both, Figure 1 and Table 2, the number of hits after the screening was not much lower than those obtained in the first instance. This can be explained by the fact that, for the most part, the initial results meet the requirements set later on.

A more detailed description of the number of results obtained for each of the search equations carried out in each of the databases consulted and the total cumulative number of hits obtained can be found in Tables 1-5 (Annex 1).

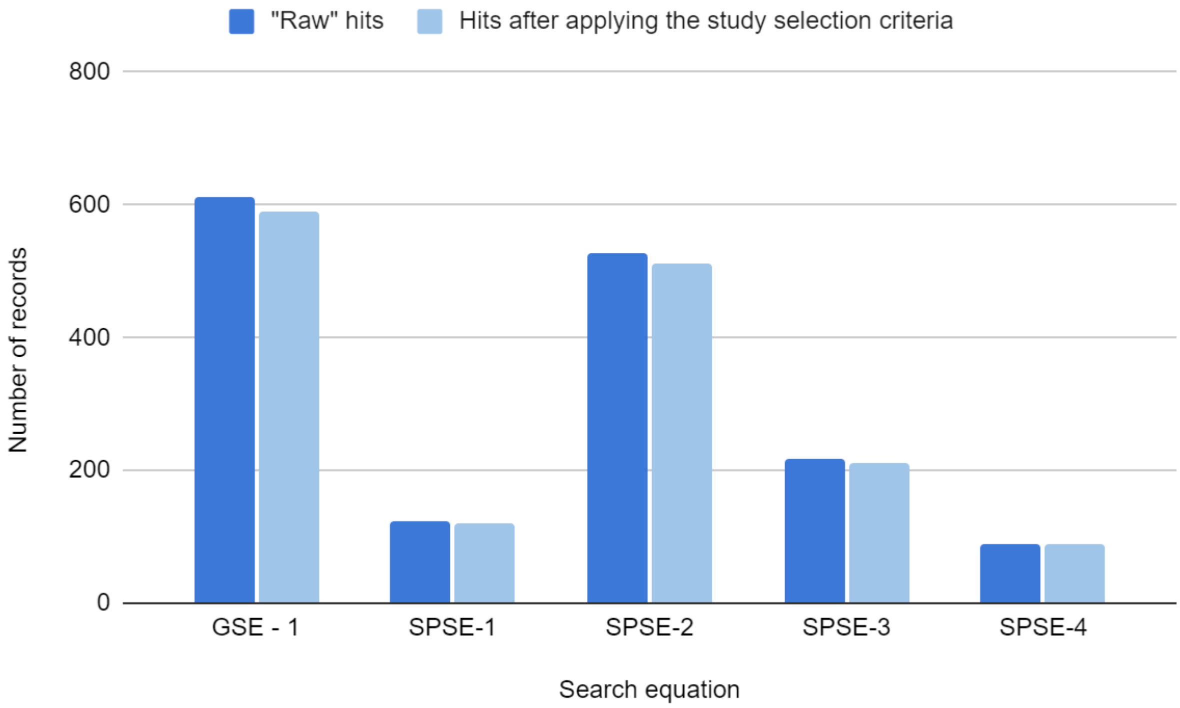

Figure 1. Number of records obtained for each search equation before and after applying the study selection criteria. General search equation (GSE) and the specific equations from 1 to 4 (SPSEs).

Table 3. Number of "raw" records per database and the number of records after applying the study selection criteria per database.

	PubMed	PMC	WOS	# Total records
"Raw" hits	254	935	376	**1.566**
After filtering	247	897	374	**1.522**

To further refine the data, duplicates results between search equations were checked out to see the actual number of results. Figure 2 shows the Venn diagram comparing the results of the general search equation (GSE) and the specific equations (SPSEs). As expected, a total of 78 records were duplicated in all the equations, and this is due to the fact that the SPSEs complement the GSE by making the most specific searches as mentioned above. Furthermore, a large part of the hits obtained were common between GSE and SPSE-2; and GSE, SPSE-2 and SPSE-3, 241 and 108 entries respectively. Also, 46 documents were found only in GSE, 3 in SPSE-2 and 1 in SPSE-4.

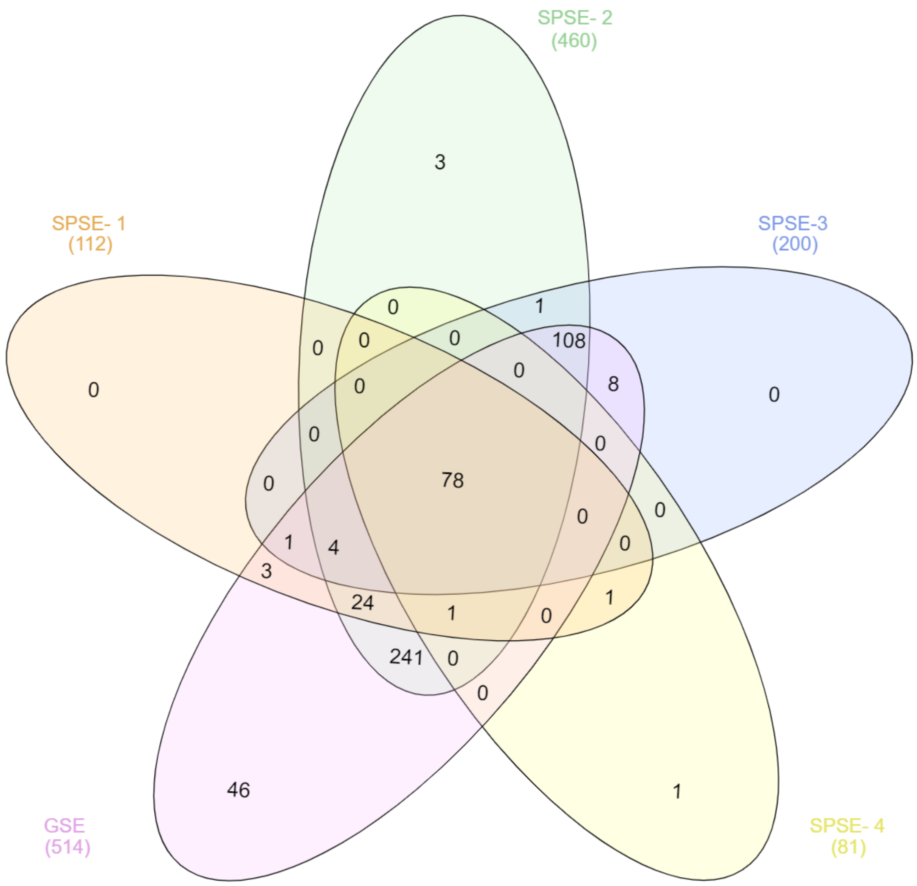

Figure 2. Venn diagram of the different search equations for duplicate identification. General search equation (GSE) and the specific equations from 1 to 4 (SPSEs).

Excluding the duplicates, the real number of results obtained for the search equations was 520 records. Then, manual curation was carried out and those entries that were not relevant to the present review were excluded, leaving a total of 121 publications assessed to be included for the detailed analysis in the present study.

These 121 articles were classified according to different parameters of interest: 1) the taxonomic group on which they are investigating in relation to the effect of MPs, and 2) the environment and the source of the studied organisms.

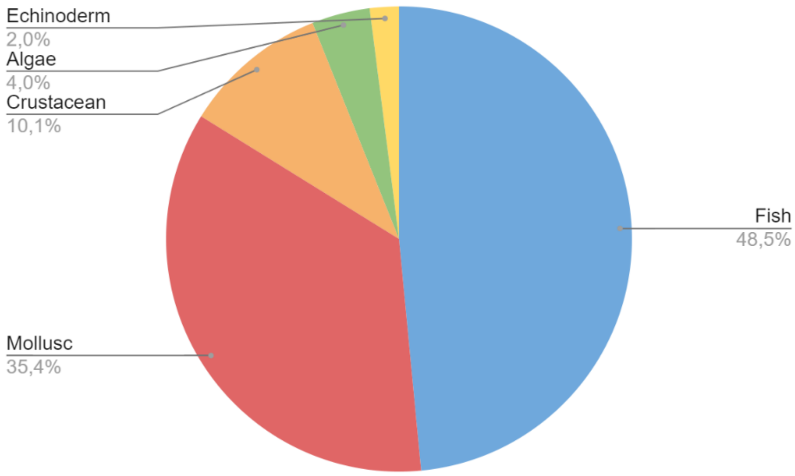

Figure 3. Percentage of the taxonomic group of organisms addressed.

Figure 3 shows the percentage of the taxonomic group of organisms addressed in the reviewed articles. The most represented group is fish, with the highest percentage of articles (74%), followed by molluscs with 51%, and crustacean with 16%, while algae and echinoderms only represent 4 and 2%·, respectively. This is consistent with the most exploited groups in aquaculture. The case of algae is singular, because although its aquaculture production is high, its market is smaller compared to the rest, and this is one of the reasons why there are fewer related studies to algae (FAO, 2020).

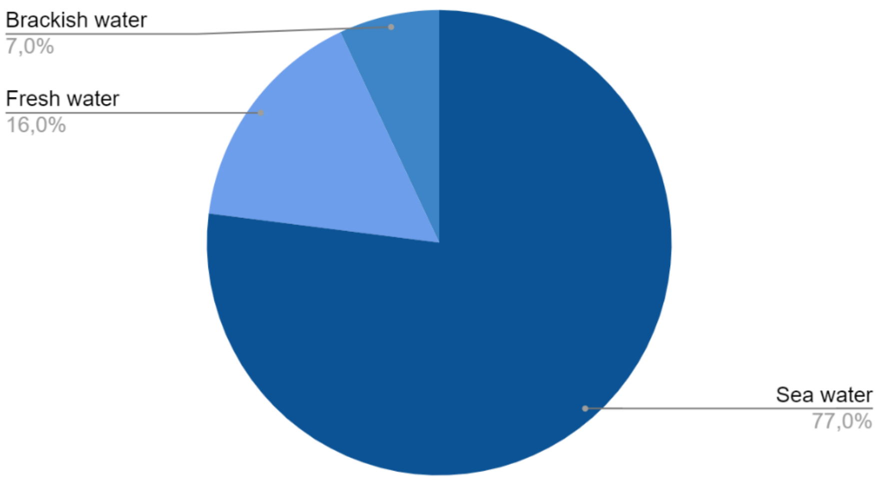

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Figure 4. Percentage in relation to the environment in the reviewed articles.

Figure 4 represents the percentage in relation to the environment in the reviewed articles. The dominance of seawater was observed, which concentrates 77% of the investigations carried out, while only 16% and 7% are dedicated to freshwater and brackish water respectively.

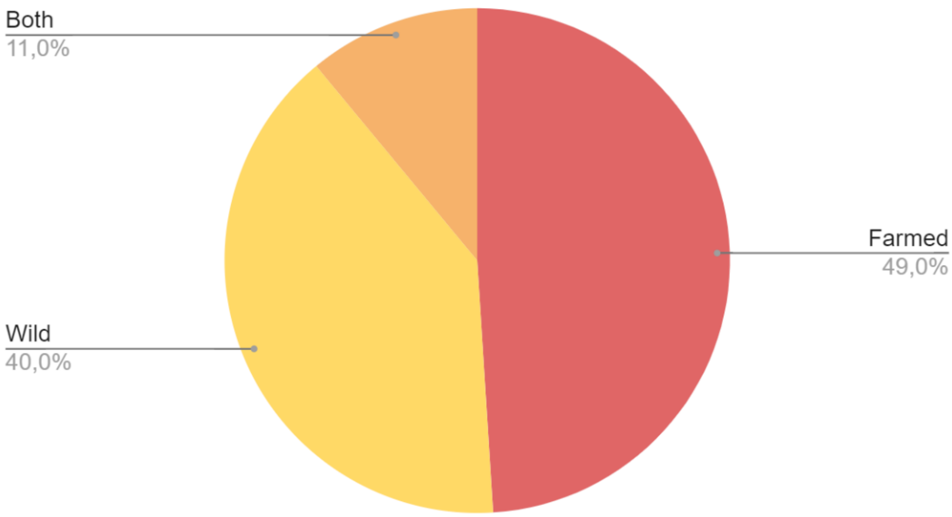

Figure 5. Percentage in relation to the source of the organisms studied in the reviewed articles.

Figure 5 illustrates the percentage of publications in relation to the source of the organisms studied. Analysing organisms collected from the wild or from aquaculture entities. The results obtained indicate that the effects of MPs on aquaculture and wild organisms have been studied almost equally, 49% and 40% respectively; and a minority of 11% compares both organisms in the same study.

It should be noted that the percentages illustrated in Figures 3-5 do not correspond to the number of reviewed publications studying the effect of microplastics on each taxonomic group. This is due to there are articles in which more than one taxon group is studied.

The present study has focused on the review of research carried out on aquaculture species, or where wild and farmed organisms have been compared. Therefore, 72 is the final number of publications included in this review.

A flow chart representing the information gathered and the screening process applied is shown in Figure 6.

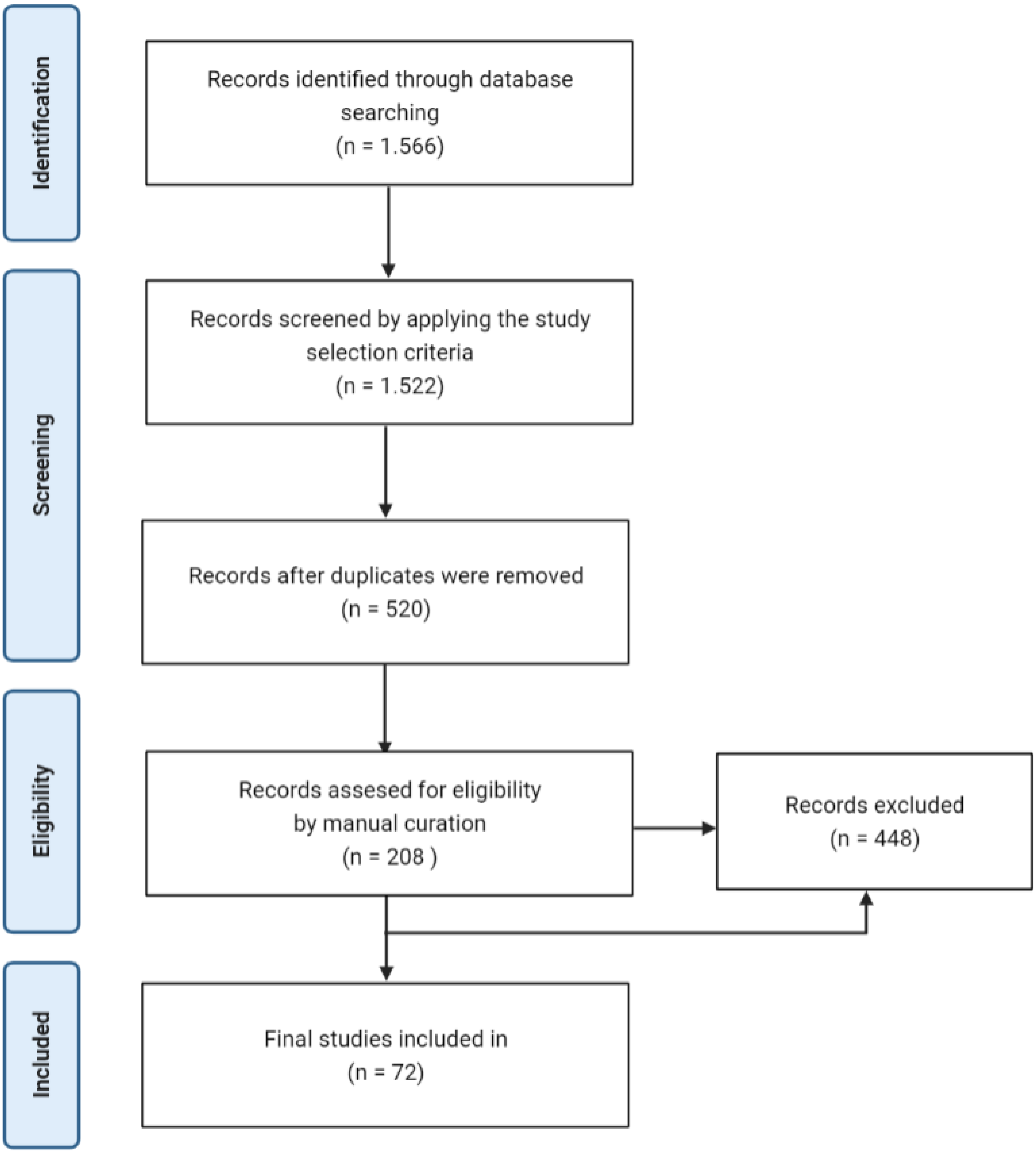

Figure 6. PRISMA flow chart for search and record screening process.

4.2. Annual publications evolution over time

Figure 7 shows the total annual production of scientific articles published in combination in the databases consulted after excluding duplicates and during the search period, containing information related to the general categories: microplastics, pollution, aquaculture, food chain, effect and food safety.

It can be appreciated that this is a topic of recent interest to the scientific community; the first article published was in 2006, and 83.5% of the publications occurred from 2018 until 2021. The average number of publications was 2.5 articles per year from 2006 until 2013. From 2014 onwards, the number of publications per year has been increasing progressively over time, until 2018, from which practically doubles itself. Thus, the highest number of publications recorded so far has been in 2020, reaching 172 publications. And the present year, a total of 109 studies have been published so far.

This exponential increase in publications is due to the growing interest of the scientific community in identifying sources of environmental pollution and their effects on life; and this has been exacerbated in the case of microplastics and aquaculture by a great deal of pressure from a society that is increasingly aware of the current environmental problems, is concerned about how its actions impact on the environment, and is interested in the quality of the food it eats.

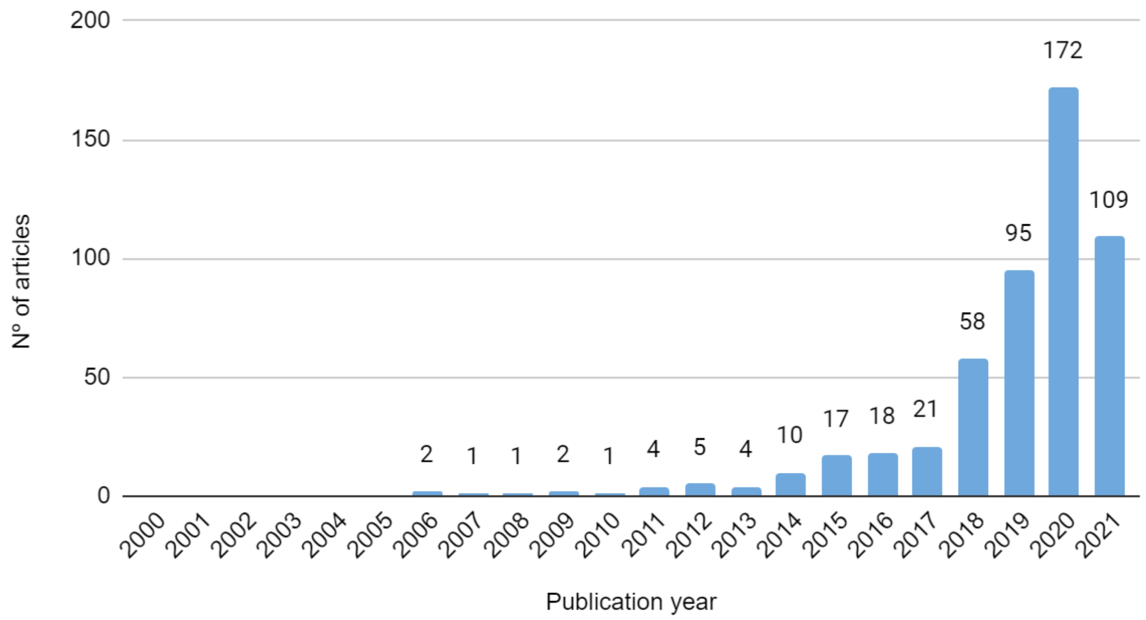

Figure 7. Number of publications per year of the results obtained after excluding duplicates from January 1, 2000 to June 1, 2021.

4.3. Microplastics effect on commercially valued aquaculture species

Tables from 4 to 8 compile the results of the articles reviewed on the effect of MPs on the farmed organisms studied or comparing wild and farm conditions, grouped according to taxonomic group in five categories: algae (macro and micro algae), echinoderms, crustaceans, molluscs and fish.

The impacts of MPs on cultivated species, the environment and human health are relatively recent areas of research, and much of the consequences of exposure to these materials are currently still unknown.

Effects can be classified as physical or chemical. Physical effects are those that depend on the size and shape of the particle, and chemical effects are those related to their composition, the presence of additives or other contaminants such as heavy metals, adhered to their surface (GESAMP, 2015).

Prior to the discussion, it should be noted that the results have been compared with caution, considering that the investigations used different sampling protocols, analytical and polymer identification methods, experimental conditions (duration, parameters and water quality etc.), in relation to the MPs (different concentrations, sizes, formats etc.); and that the studies have been carried out on different species. Therefore, it is difficult to compare the effect of MPs contamination and its impacts among different organisms without bias.

Table 4. Effects of microplastics exposure to algae based on several effect criteria. Dry weight (d.w), not available data (NA).

Taxonomic group		Species	Environment	Polymer type	Size	Tested concentration	Extracted concentration	Effect	Reference
ALGAE	Macroalgae	*Pyropia spp.*	Seawater	PET (fibers)	1.13 mm	NA	1.8 ± 0.7 items /gr d.w.	- Adhesion to the surface.	(Q. Li et al., 2020)
ALGAE	Macroalgae	*Pyropia yezoensis*	Seawater	PE,Rayon, PP (fibers, foams, films)	< 2 mm	NA	1.53 ± 0.72 items/gr d.w.	- Adhesion to the surface.	(Feng et al., 2020)
ALGAE	Microalgae	*Scenedesmus obliquus*	Freshwater	PS	0.07 μm	44-1100 mg/L	NA	- Lower chlorophyll content. - Growth inhibition.	(Besseling et al., 2014)
ALGAE	Microalgae	*Chlorella sp.*	Freshwater	PS	0.02 μm	0.08-0.58 mg/L	NA	- Decrease in photosynthetic capacity.	(Bhattacharya et al., 2010)
ALGAE	Microalgae	*Scenedesmus sp.*	Fresh/Seawater	PS	0.02 μm	0.08-0.58 mg/L	NA	- Decrease in photosynthetic capacity.	
ALGAE	Microalgae	*Raphidocelis subcapitata*	Freshwater	PE	63-75 μm	130 mg/L	NA	- Increase in growth.	(Canniff & Hoang, 2018)
ALGAE	Microalgae	*Pseudokirchneriella subcapitata*	Freshwater	PS	0.05 μm 0.1 μm	0.1-1 mg/L 0.1-0.8 mg/L	NA	- Growth inhibition.	(Casado et al., 2013)
ALGAE	Microalgae	*Chlorella pyrenoidosa*	Freshwater	PS	0.1-1μm	10-100 mg/L	NA	- Growth inhibition. - Morphological malformations.	(Mao et al., 2018)
ALGAE	Microalgae	*Skeletonema costatum*	Seawater	PVC	1μm 1 mm	0-2000 mg/L	NA	- Decrease in photosynthetic capacity. - Lower chlorophyll content.	(Zhang et al., 2017)

Table 5. Effects of microplastics exposure to echinoderms based on several effect criteria. Individual (ind.), not available data (NA).

Taxonomic group	Species	Environment	Polymer type	Size	Tested concentration	Extracted concentration	Effect	Reference
ECHINODERMS	*Apostichopus japonicus*	Seawater	CP, PET and polyester (fibers)	20-50 µm	NA	0-30 items/individual	- Accumulation in the gut and body wall.	(Mohsen et al., 2018, 2019)
	Holothuria cinerascens	Seawater	CP, PET and polyester (fibers)	20-50 µm	NA	0-24 items/ind.	- Accumulation in the gut and body wall.	(Iwalaye et al., 2020)

Table 6. Effects of microplastics exposure to crustaceans based on several effect criteria. Individual (ind.), not available data (NA).

Taxonomic group	Species	Environment	Polymer type	Size	Tested concentration	Extracted concentration	Effect	Reference
CRUSTACEANS	*Cherax quadricarinatus*	Freshwater	PS (spheres)	200 nm	0, 0.5 and 5 mg/L	NA	- Accumulation in the gut and hepatopancreas. - Altered lipid metabolism: - fatty acids. +cholesterol. - Lower expression levels of fatty acid genes.	(Chen et al., 2020)
	Litopenaeus vannamei	Seawater	PE PTFE PP PS PVC	6 -18 μm 1-8 μm 1.77-18 μm 100-200 μm 13 μm	1 mg/L	NA	- Altered haemolymph proteome profiles. - Altered gut bacterial composition and functionality: +risk of putative opportunistic pathogens. -production of putative beneficial bacteria.	(Duan et al., 2020)
	Artemia franciscana	Salt ponds, salt marshes or Hypersaline ecosystems	FRM (spheres)	1-5 μm	0, 0.4, 0.8 and 1.6mg/L	NA	- Accumulation in the gut. - Fertility reduction (reproductive success).	(Peixoto et al., 2019)
	Artemia parthenogenetica	Salt ponds, salt marshes or Hypersaline ecosystems	PS (spheres)	10 μm	10, 10^2, 10^3 and 10^4 particles/mL	1.23 items/ind. up to 14 days	- Accumulation in the gut. - Reduced ingestion. - Deformed and disorderly arranged intestinal epithelia. - Altered lipid metabolism.	(Wang et al., 2019)
	Artemia salina	Salt ponds, salt marshes or Hypersaline ecosystems	PS (spheres)	5 μm	1, 25, 50, 75 and 100 mg/L	NA	- Accumulation in the gut. - Growth reduction. - Mortality in chronic treatments from 25 to 100 mg/L concentration. - Deformed and disorderly arranged intestinal epithelia.	(Suman et al., 2020)

Table 7. Effects of microplastics exposure to molluscs based on several effect criteria. Dry weight (d.w), wet weight (w.w.), not available data (NA).

Taxonomic group	Species	Environment	Polymer type	Size	Tested concentration	Extracted concentration	Effect	Reference
MOLLUSCS	*Mytilus galloprovincialis*	Seawater	PS	3, 45 µm	1-500 items/mL	NA	- Altered multixenobiotic resistance system activity. - Accumulation in the haemolymph	(Franzellitti et al., 2019)
	Magallana gigas	Seawater	PS (spheres)	100, 250, 500µm	30 items per size	19.4± 1.1% 19.4± 2% 12.9± 2%	- Egestion of 63.9± 3%, 17± 2.2% and 3.7± 0.9%. - Retention of 15.4± 2%	(Graham et al., 2019)
	Mytilus edulis	Seawater	NA (fibres, fragments, sheets, spheres)	0.05-5 mm	2000 items/L	9.2 items/g (max.)	- Adhesion to soft tissues. - Accumulation in the intestine, foot, stomach, gills, muscle, mantle, gonads and viscera. - Egestion after depuration.	(Kolandhasamy et al., 2018)
		Seawater	NA (beads)	100nm 2 µm	0.42 28.2 282 µg/L	NA	- Higher intake with 100 nm particles. - Physical malformations.	(Rist et al., 2019)
	Choromytilus chorus	Seawater	PS (spheres)	8.1-12 µm	0 100 1000 items/L	NA	- No significant differences among treatments. - No accumulation	(Opitz et al., 2021)
	Crassostrea gigas	Seawater	PS (beads)	6 µm	10^4, 10^5 and 10^6 items/L	NA	- Accumulated in the intestines, digestive tubules. - Reduced lysosomal membrane activity. - Increased mortality.	(Thomas et al., 2020)
		Seawater	CP, PET, PE, AHR, Polyester (fibres, fragments)	<0.2 mm	NA	4.53 items/g w.w. 35.6±11.3 items/g, d.w.	- Accumulation of MPs in the gills, mantle, muscle and digestive glands. - Accumulation of Cr, Cd, Pb and Cu.	(Zhu et al., 2020)

Table 8. Effects of microplastics exposure to fish based on several effect criteria. Individual (ind.), not available data (NA).

Taxonomic group	Species	Environment	Polymer type	Size	Tested concentration	Extracted concentration	Effect	Reference
FISH	*Dicentrarchus labrax*	Seawater	NA (spheres)	1-5 µm	0.26-0.69 mg/L	NA	- Accumulation in the liver, gills, muscles and brain. - Oxidative stress in gills and liver. - Lipid oxidative damage in gills. - Biomagnification in the gills and liver. - Hypoxia.	(Barboza et al., 2018)
	Mugil cephalus	Seawater	PP,PE (fibers)	<2mm	NA	0.2 items/ind.	- Lower ingestion in farmed than wild mullets.	(Cheung et al., 2018)
	Oreochromis niloticus	Freshwater	PET PES PE (fragments)	NA	NA	0.2 items/g	- Accumulation in the gills, gut and flesh.	(Garcia et al., 2021)
	Lates calcarifer	Seawater	PS (spheres)	97µm	100 items/L	NA	- Altered fish behaviour, lower swimming speed and erratic movements.	(Guven et al., 2018)
	Clarias gariepinus	Freshwater	PVC (particles)	95.41 ± 4.23 µm	0.50% 1.5% 3%	NA	- Higher oxidative stress: - Reduced haemoglobin values. - Lower neutrophil counts. - Altered glutathione peroxidase activity in the brain and gill. - Inhibited superoxide dismutase activity in the brain and gills - Reduced catalase activity in the brain. - Increased lipid peroxidation levels in the brain.	(Iheanacho & Odo, 2020)
	Oncorhynchus mykiss	Freshwater	PE (spheres)	10-300 µm	80,000-850,000 items/ind.	0 items	- Intake occurred but no accumulation.	(Kim et al., 2020)

	Oreochroms mossambcus	Freshwater	PP PE (fibres, fragments)	<1mm	NA	6.14± 3.80 items/ind.	- Accumulation in the gastrointestinal tract	(Li et al., 2021)
	Micropterus salmoides					39.64± 23.38 items/ind.		
	Monopterus albus		PE PP (fibres, films)	0.1-0.5 1-5 mm	0.13± 0.06 4.6± 1.5 items/kg	2.4± 0.8 items/ind.	- Accumulation in the gut and edible parts.	(Lv et al., 2019)
	Fundulus heteroclitus	Seawater	PE (spheres)	250-300 425-500 710-850 µm	0.3 1.3 5.35 mg/L	40 35 15 items/ind	- Accumulation in the gastrointestinal tract. - Excretion with faeces.	(Ohkubo et al., 2020)
	Pagrus major							
	Chanos chanos	Freshwater	NA (fibers, films, fragments, granules)	NA	NA	9.58± 3.3 8.8±2.7 items/g	- Accumulation in the gastrointestinal tract. - Growth reduction.	(Priscilla & Patria, 2019)

4.3.1. Algae

Little is known about the MPs pollution status in algae, and although they are the main primary producers in the marine ecosystem, their effects and toxicity have rarely been determined.

Macroalgae play an important role in the ecological stability of marine ecosystems, contributing to the retention and distribution of sediment in coastal areas, and constituting habitats in which diverse organisms are associated (Taylor & Cole, 1994; Reed et al., 2016; Gao et al., 2018). Some species of seaweed are consumed by humans and in some cultures are an important element of their diets (Feng et al., 2019).

Demand for macroalgae far outstrips supply, so intensive macroalgae cultivation is taking in Asian countries. China is the world's largest producer of seaweed, with a long-term mariculture of nori seaweed (*Pyropia yezoensis)* located in the Haizhou Bay (Feng et al., 2020).

In this concern, Feng et al., (2020) and Li et al., (2020) both studied the content of MPs present in nori seaweed and reported external adsorption on the whole-thallus of the macroalgae but no internal uptake. Likewise, Li et al., (2020) studied the commercial culture of *P. yezoensis,* where 95.8% of the samples analysed contained MPs, about 1.8 ± 0.7 items /gr in dry weight, with a mean size of 1.13mm, and being the predominant polymeric form was fibres, followed by films and pellets.

In addition, the spatial-temporal distribution of MPs was tested in the China bay. For this purpose, a comparison was carried out between *P. yezoensis* samples analysed during the culture season, and other macroalgae species (*Ulva prolifera, U. pertusa, Sargassum horneri, Cladophora sp.* and *Undaria pinnatifida*) that naturally grew in the culture facilities during the non-culturing season (Feng et al., 2020). According to Li et al., (2020), they showed that macroalgae have different MP uptake capacity, with nori algae having the highest adhesion (1.53 ± 0.72 items/gr dry weight). It is suggested that this may be related to the characteristics of each species (morphology, stem composition, etc.).

In both studies, 11 different polymer compositions were detected, the main ones being polyethylene (PE), polyethylene terephthalate (PET) fibres, polypropylene (PP), polystyrene (PS), rayon and cellophane (CP), among others. This great diversity in composition suggests that the sources of MPs present in the algae analysed are varied, and that in this case they are also promoted by the intensive production that occurs in the area (Feng et al., 2020; Q. Li et al., 2020). The plastic materials that make up the cultivation facilities (net curtains, ropes and buoyant balls among others) can also constitute a direct source of MPs that enter the marine environment, thought the cultivated macroalgae and finally to humans via food web.

For microalgae, Prata et al. (2019) reviewed the available data and concluded that the effects and toxicity of MPs are not yet well understood. Current experimental results do not provide consensus as they depend on the species, the polymer type (shape, size, composition, surface static charge and additives), concentration and exposure time among other factors.

It should be noted that some of the included studies also used nanoplastics in their experiments. Bhattacharya et al. (2010), Zhang et al. (2017) and Mao et al. (2018) conclude that the presence of plastic materials causes a decrease in photosynthetic capacity in the species analysed, which may be related to a lower chlorophyll content (Zhang et al., 2017). A lower chlorophyll concentration was also detected in *Scenedesmus obliquu*s and *Tetraselmis chuii* (Besseling et al., 2014; Prata et al., 2018).

MPs have also been reported to inhibit the growth of several microalgae species (Bergami et al., 2017; Besseling et al., 2014; Casado et al., 2013; Mao et al., 2018). In contrast to *Raphidocelis subcapitata* in which PE MPs were used as substrate and growth was increased (Canniff & Hoang, 2018). Also, in the case of *Chlorella pyrenoidosa,* Mao et al. (2018) showed that MPs were a direct cause of the presence of physical malformations on its morphology, such as: unclear pyrenoid, plasma detached from the cell wall, deformed thylakoids and cell wall thickening.

It is worth to mention that some of these authors point out that certain effects of the presence of MPs in the microalgae studied appear to be temporary in nature, i.e., vulnerability to MPs is developed during an initial period and later there is a recovery period due to the microalgae's ability to adapt to these materials (Zhang et al., 2017; Mao et al., 2018).

4.3.2. Echinoderms

Most of the studies on MPs in echinoderms have been carried out on holothurians, in particular with the species *Holothuria cinerascens* and *Apostichopus japonicus* (Mohsen et al., 2018, 2019; Iwalaye et al., 2020). In addition to their role in marine ecosystems, these organisms are of great interest and economic value in some Asian countries due to their consumption, so aquaculture production is carried out (Choo, 2008; Yang et al., 2015)

Sea cucumbers are non-selective feeders, they feed by extracting organic matter and organisms from the sediment they inhabit, predisposing them to the ingestion of MPs (Yang et al., 2015).

Mohsen et al. (2018, 2019) studied the presence of MPs in the intestine and in the coelomic fluid of *A. japonicus* and its relationship with the presence of heavy metals. MPs were detected in all samples analysed from different aquaculture facilities. In both studies the polymer types were mainly fibres of cellophane, polyester and polyethylene terephthalate.

Both Iwalaye et al. (2020) and Mohsen et al. (2018) reported similar MPs concentrations in *H. cinerascens* and *A. japonicus*, respectively, an average of 0-24 and 0-30 items/intestine, and of 0-19 items/individual after filtering the coelomic fluid. The length of the MPs ingested was 55 µm in the gut and 20 µm in the coelomic fluid, a larger size than the gut. This supports the idea that the microplastics might be passed by diffusion into the coelom through the walls of the respiratory trees, but this hypothesis needs further investigation.

Mohsen et al. (2019) analysed the interaction of heavy metals with MPs in *A. japonicus* as in their previous work (Mohsen et al., 2018). The eight heavy metals analysed were detected associated with all isolated MPs at a concentration higher than the corresponding in the sediment. They showed that *A. japonicus* like other sea cucumber farmed species (Ahmed et al., 2017) is a macro-concentrator of cadmium and a micro-concentrator of zinc and arsenic, present in 100 and 12% of the samples analysed, respectively. Both zinc and cadmium were found to accumulate in the body wall, which is of interest to human health as this is the part of the body that is consumed as food.

There was no correlation between the concentration of MPs and the weight of the specimens of *A. japonicus* analysed. Also, there was no significant correlation between heavy metal associated MPs and assimilation in the body wall of *A. japonicus*. However, there was a correlation with the concentration of MPs in the sediment in which they live; the higher the amount in the environment, the higher the concentration inside of the body wall (Mohsen et al., 2018, 2019).

4.3.3. Crustaceans

Most of the available literature reviews available, reported the concentration of MPs in aquaculture crustaceans but few studies described its effects. The selected articles reviewed in this study mainly focuses on *Artemia spp*., commonly named or brine shrimp. This is due to its as live feed for larviculture of molluscs, crustaceans and fish at aquaculture industries; so it is of interesting to know the impact of these materials on them. In addition, other few publications dealt with economically important aquaculture species such as *Cherax quadricarinatus* and *Litopenaeus vannamei*, which are used as a source of high quality protein for human consumption.

Brine shrimp is a non-selective and obligate phagotrophic filter-feeder that continually ingests suspended particles of suitable size, regardless of their nature, making it particularly vulnerable to ingest MPs. Several studies have been carried out analysing the uptake and effects of different concentrations of MPs on various species of *Artemia spp.* (Peixoto et al., 2019; Suman et al., 2020; Wang et al., 2019). In all three studies, it was found that brine shrimp ingest these materials depending on exposure concentration, exposure times and availability of food. Furthermore, a large part of the amount ingested (up to 97% for *Artemia parthenogenetica*) can be egested as pellets in the faeces, and accumulation of MPs in the digestive tract of the organisms was recorded.

Wang et al., (2019) and Suman et al., (2020) reported growth reduction in brine shrimp, in contrast, Peixoto et al., (2019) reported no significant detrimental effects on growth. Similarly, disparate results were obtained for mortality rates between *A. parthenogenetica* and *A. franciscana*, where exposure to polystyrene MPs only induced mortality in *A. salina.* Also both, Wang et al., (2019) and Suman et al., (2020)noted deformed and disorderly arranged intestinal epithelia after the MPs treatments in brine shrimp *Artemia*.

The results present by Peixoto et al. (2019) also determined that the reproductive success of *A. franciscana* was strongly negatively impacted in a MP dose-dependent manner. And the intestinal histological analyses from Wang et al., (2019) showed a greater abundance of lipid droplets was present among epithelia after 24 h of exposure at a concentration of 10 particles/mL. This may be indicative of a possible disturbance of lipid metabolism, as has been observed in other crustaceans such as the crab *C. quadricarinatus* (Chen et al., 2020).

The effect of MPs at water concentrations 0, 0.5 and 5 mg/l were analysed in *C. quadricarinatus* (Chen et al., 2020). The greatest differences were detected with the highest concentration treatment (5 mg/L). The 200 nm polystyrene microspheres significantly inhibited the growth of juvenile red claw crayfish and accumulated in the intestines and hepatopancreas. Compared to the control group, survival rate was unchanged while lipid metabolism in the hepatopancreas was greatly altered. Lipid levels in the hepatopancreas and haemoglobin decreased, while cholesterol increased significantly. This might have been caused by an insufficient intake of exogenous fat from the consumption of MPs instead of feed. In addition, lower gene expression levels were recorded for the fatty acid metabolism, indicating that the fatty acid utilization ability of hepatopancreas cells was inhibited (Chen et al., 2020).

Duan et al., (2020) investigated the toxicological effects of MPs exposure in *L. vannamei* using an integrated approach of its microbiome, proteomics and metabolomics. Variations in the composition and functioning of the gut microbiota were observed. Compared to the control group, the abundance of *Bacteroidetes* and *Proteobacteria* increased and *Firmicutes* decreased for the different polymers tested. Also, concluded that exposure to MPs could negatively affect the development of beneficial bacteria and increase the risk of developing diseases due to opportunistic pathogens of intestinal metabolism. In terms of hemolymphatic metabolism, exposure of *L. vannamei* to the five types of MPs resulted in disparate effects, some of which are: PVC affected immune homeostasis, PTFE induced the immune response by initiating cellular apoptosis as a defence against polymer stress. Both, PVC and PS increased oxidative stress, and PE, PS and PVC altered the pathogen-associated molecular patterns.

4.3.4. Molluscs

In relation to molluscs, the publications reviewed focus on monitoring the concentration of MPs and their effects on the organisms at the physiological level (Kolandhasamy et al., 2018; Franzellitti et al., 2019; Rist et al., 2019; Thomas et al., 2020; Zhu et al., 2020; Opitz et al., 2021). As well as on the capacity of egestion with faeces and rejection with pseudofaeces of MPs during the depuration process (Davidson & Dudas, 2016; Cho et al., 2018; Kolandhasamy et al., 2018; Rist et al., 2018; Birnstiel et al., 2019; Graham et al., 2019). Thus assessing whether the consumption of aquaculture-produced molluscs poses a potential risk for the entry of MPs into humans.

Due to the large consumption of molluscs worldwide, the most studied organisms were bivalves, specifically mussels and oysters. These are characterised by being filter feeders, ingesting food by filtering large volumes of seawater. This has been shown as a major pathway for MPs and other pollutants associated with them to enter the organisms (Brennecke et al., 2015).

In oysters, the differences between the results obtained may be due to the size of the particles, the concentrations to which individuals are exposed or the sampling point, among other factors. All the publications reviewed state that there was an uptake of MPs from the environment, which is supposed to be due to two main causes: being mistaken for food, as they are of similar size, or being accidentally ingested with the water (Rist et al., 2019). Also, in the experiments in which the specimens were subjected to the purification process, the MP content was significantly reduced, and most of it was only 24 hours into the process. However, a variable percentage of MPs is always retained, which the specimens are not able to remove with the pseudofaeces (Graham et al., 2019).

Some authors reported the accumulation of MPs in multiple organs and soft tissues in *Crassostrea gigas* (Thomas et al., 2020; Zhu et al., 2020) and *Mytilus edulis* (Kolandhasamy et al., 2018). Zhu et al. (2020) detected the presence of trace metals (Cr, Cd, Pb and Cu) at significantly elevated concentrations (30.48, 4.41, 0.39 and 181.04 μg/g dry weight, respectively), and showed that their concentration in oysters increases proportionally to that of the MPs as they are adsorbed on its surface. In contrast, Opitz et al. (2021) in their research on *Choromytilus chorus*, did not observe accumulation or any other significant effects. It is suspected that due to the reduced experimental period (40 days) the mussels may have enough energy to cope with the additional costs of MPs concentrations treatments. If being prolonged, they suggest that a reduction in energy budget will occur and an increase of energy needed for feeding activities and digestive processes may be observed; showing in that case significant effects.

Similarly, exposure to MP in both oysters and mussels did not result in increased mortality; with the exception of the laboratory experiments carried out on *M. edulis* larvae, where physical malformations in embryo growth (Rist et al., 2019) and a increase in mortality rate of *C. gigas* (Thomas et al., 2020) were observed.

In addition, Franzellitti et al. (2019) with larvae and adults of *M. galloprovincialis* pointed out the accumulation of particles in haemolymph and the alteration of the multixenobiotic resistance system. Thomas et al. (2020) found in *C. gigas* a reduction of the activity of lysosomal membranes, which in both cases leads to the weakening of the specimens, as there are defence mechanisms that act against the presence of foreign agents.

4.3.5. Fish

In the case of fish, the research reviewed analyses the impact of exposure to MPs on several cultured species in both marine and freshwater environments. As in the other aquatic cultured organisms examined previously, ingestion and accumulation of MPs occur, although in some cases there is no accumulation, as it has been shown that all or part of MPs are eliminated in faeces. This was reported in studies carried out in trout (*Oncorhynchus mykiss*), mummichog (*Fundulus heteroclinus*) and red seabream (*Pargus major*) (Kim et al., 2020; Ohkubo et al., 2020). On the other hand, in the case of Cheung et al. (2018), found, lower intake of MPs in farmed flathead grey mullet (*Mugil cephalus*) compared to wild ones, which could be due to the filtration systems present in aquaculture facilities that would result from the input of MPs.

The accumulation of MPs occurred in areas that are not normally ingested as food by humans, such as the digestive tract, gills and other internal organs. However, a small minority of these particles are translocated by various possible routes such as through the intestine epithelia and are retained in fish fillets destined for human consumption (Barboza et al., 2018; Priscilla & Patria, 2019; Lv et al., 2020; Ohkubo et al., 2020; Garcia et al., 2021; Li et al., 2021).

In terms of external morphological changes, a significant reduction in growth was observed in *Chanos chanos* (Priscilla & Patria, 2019), as well as, Guven et al. (2018) where *Lates calcarifer* specimens saw their behaviour altered with erratic swimming and reduced speed after exposure.

It should also be noted that in some species such as sea bass (*Dicentrarchus labrax)* and catfish (*Clarias gariepinus)*, showed increased oxidative stress and reduced lipid metabolism leading to lipid oxidative damage after exposition to MPs (Barboza et al., 2018; Iheanacho & Odo, 2020).

Finally, in addition to respiration and confusion with feed, another possible route of entry of MPs into fish is through the feed itself. Specifically, through fishmeal, one of its main components. Fishmeal is fish powder obtained from milled dried whole fish or fish parts from wild-caught fish or waste from the aquaculture industry (FAO, 1986; Shepherd & Jackson, 2013).

The presence of MPs in fishmeal has been reported in several studies (Castelvetro et al., 2020; Zhou et al., 2020; Mofijur et al., 2021; Thiele et al., 2021). However, there is still no optimal analytical method to calculate its concentration in fishmeal, due to the high protein content and the small lipid and mineral fraction, because they interfere with analysis (Castelvetro et al., 2020). In the test carried out by Thiele et al. (2021) on the main wild caught species used for fishmeal production, an average of 0.72 microplastics/individual was found, and when analysing commercial brands of fishmeal, a concentration of 123.9 ± 16.5 polyethylene microplastics per kg of fishmeal was obtained. Suggesting that the increase in concentration is due to possible augmentation during the fishmeal production process. In addition, it goes so far as to estimate the number of MPs released into the environment via the feed alone at 300 million MPs (< 1 mm).

5. CONCLUSIONS

In summary, from the present bibliographic review, the following final statements can be drawn:

- The lack of consensus on determining size ranges for the classification of plastics and microplastics in particular, can lead to confusion and make difficult to collect and interpret significant data.
- Among the different taxonomic groups, aquaculture fish are the most studied followed by molluscs, crustaceans, algae and echinoderms in the last instance.
- Microplastics ingestion have occurred in all organisms analysed, but their impacts and toxicity are not yet well understood and current experimental results offer no consensus.
- Microplastics effects and concentrations can vary greatly depending on the polymer type, its size, concentration, exposure time, format (fibres, fragments, pellets, microbeads, etc.), as well as on the method and protocol of analysis used. Furthermore, their effects depend on the species analysed and the time of their life cycle (larva, juveniles or adults).
- Many studies reported microplastics accumulation mostly in non edible parts (except bivalve molluscs). While only a minimal part is being translocated into the flesh. This observation suggests that microplastics in itself may not increase the health risk from the consumption of aquaculture species. Nevertheless, future research should focus on clarifying the different possible routes of entry of microplastics into organisms.
- In the view of the continuing increase of microplastics in the environment, urgent and systematic research is needed to asses the impact of microplastics on commercially valued aquaculture species an their possible effect on human health.
- Although the aquaculture industry is considered a source or pathway for introducing microplastics into aquatic environments. With currently available data, organisms produced in aquaculture facilities do not present a higher concentration than wild specimens sampled in nearby areas. Therefore, aquaculture products do not pose a higher risk to human health than in fisheries.
- Despite the difficulty of finding a material comparable to plastic, it would be interesting to examine alternative materials used in mariculture gears to not contribute to microplastic pollution in the marine environment.

6. ANNEX I

Table 1: Summary of the search results obtained with the general search equation (GSE).

(GSE)	((microplastic OR "plastic particle" OR microbead OR microfibre) AND (litter OR pollution OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry"))	
Database	“raw” hits	After filtering
Pubmed	135	130
PMC	293	277
WOS	183	184
TOTAL	611	591

Table 2: Summary results of the searches carried out with the specific search equation 1 (SPSE-1).

(SPSE-1)	((microplastic OR "plastic particle" OR microbead* OR microfibre*) AND (litter OR pollution OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND (“food chain” OR “commercially valued species”))	
Database	“raw” hits	After filtering
Pubmed	12	12
PMC	97	93
WOS	14	14
TOTAL	123	119

Table 3: Summary results of the searches carried out with the specific search equation 2 (SPSE-2).

(SPSE-2)	((microplastic OR "plastic particle" OR microbead* OR microfibre*) AND (litter OR pollution OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND (effect OR ingestion OR growth OR reproduction OR survival OR development OR "antibiotic resistance"))	
Database	“raw” hits	After filtering
Pubmed	93	91
PMC	290	280
WOS	144	142
TOTAL	527	513

Table 4: Summary results of the searches carried out with the specific search equation 3 (SPSE-3).

(SPSE-3)	((microplastic OR "plastic particle" OR microbead* OR microfibre*) AND (litter OR pollution OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND (“food safety” OR “human health”))	
Database	“raw” hits	After filtering
Pubmed	12	12
PMC	174	169
WOS	31	30
TOTAL	217	211

Table 5: Summary results of the searches carried out with the specific search equation 4 (SPSE-4).

(SPSE-4)	((microplastic OR "plastic particle" OR microbead* OR microfibre*) AND (litter OR pollution OR debris OR waste OR toxic) AND (aquaculture OR "aquaculture industry") AND (“food chain” OR “commercially valued species”) AND (effect OR ingestion OR growth OR reproduction OR survival OR development OR "antibiotic resistance") AND (“food safety” OR “human health”))	
Database	“raw” hits	After filtering
Pubmed	2	2
PMC	81	78
WOS	4	4
TOTAL	88	88

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