Marine Pollution Bulletin 175 (2022) 113269

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Ingestion of polyethylene microspheres occur only in presence of prey in the jellyfish *Aurelia aurita*

Vanesa Romero-Kutzner [*,1], Javier Tarí [1], Alicia Herrera, Ico Martínez, Daniel Bondyale-Juez, May Gómez

Marine Ecophysiology Group (EOMAR), Iu-ECOAQUA, Universidad de Las Palmas de Gran Canaria, 35017 Campus Universitario de Tafira, Canary Islands, Spain

ARTICLE INFO

Keywords:
Jellyfish
Plastic contamination
Microplastic ingestion
Time of presence
Retention time
Microplastic egestion

ABSTRACT

Microplastic ingestion was studied in *A. aurita*, a bloom-forming, circumglobal medusa. Here, we determined whether factors such as the concentration of polyethylene microspheres (75–90 μm) or the absence/presence of prey affect the ingestion, duration of microspheres in the gastrovascular cavity (time of presence), and retention time. The presence of polyethylene microspheres' was determined by exposing medusae during 480 min to three different treatments (5000, 10,000, 20,000 particles L^{-1}), and was checked every 10 min to ascertain whether they had incorporated any. Preliminary results show that microsphere ingestion occurred only in the presence of prey (~294 *Artemia* nauplii L^{-1}). The time of presence of microbeads in *A. aurita* increased (103, 177, and 227 min), with increasing microplastic concentration, and the microbeads were egested within 150 min.

This study initiates the understanding of the potential implications that arise of the encounter between jellyfish and microplastic agglomerates, and with perspectives for future research.

Microplastics (MP) have been accumulating in oceans worldwide over the last four decades (Carpenter et al., 1972). Nowadays, MP pollution poses an urgent global environmental problem. According to Pabortsava and Lampitt (2020), in the Atlantic Ocean alone, 11.6–21.1 million tons of 32–651 μm size-class plastics are suspended in the top 200 m. The discharge of MPs from land to the sea is enormous; for example in the Bay of Bengal (India), approximately 1–3 billion pieces are released daily (Napper et al., 2021). Considering this, and the continuous plastic fragmentation in the environment, an increase in MP contamination and impacts on marine biota are expected in the future (Andrady, 2011; Visbeck, 2018).

MPs are ingested by numerous marine organisms (Ugwu et al., 2021; Cole et al., 2011; Haegerbaeumer et al., 2019; Taha et al., 2021). Ingestion of MPs by zooplankton is considered to be the main entry of MPs into marine food webs (Cole et al., 2019; Laurenceau-Cornec et al., 2015; Setälä et al., 2014). Even though MP ingestion and their effects on zooplankton are increasingly studied (Botterell et al., 2019; Wright et al., 2013), there is still much to investigate, especially their relationship with gelatinous zooplankton (GZP), which are underrepresented in the microplastic literature (Iliff et al., 2020).

GZP include ctenophores or 'comb jellies', chordates such as salps, and jellyfish. Jellyfish are referred to as members of the Phylum Cnidaria with a pelagic phase, primarily scyphozoans. These fragile animals are considered key members of ocean ecosystems due to their trophic interactions (Boero et al., 2008; Richardson et al., 2009). Their delicate bodies are easily damaged, which is one reason why research on these organisms has been avoided in the past (Raskoff et al., 2003).

It has been recently found that jellyfish do ingest plastics in their natural environment. Plastic particles have been found during the examination of wild samples in the laboratory (Albano et al., 2021; Iliff et al., 2020; Macali et al., 2018; Rapp et al., 2021; Sun et al., 2017; Zheng et al., 2020) and pictures of ingested particles in jellyfish have been taken in the field (Macali et al., 2018; Rapp et al., 2021). Further, Zheng et al. (2020) observed that from various wild zooplankton and ichthyoplankton taxa, medusae had the highest level of ingestion (0.056–0.117 MP ind^{-1} or 0.78 MP m^{-3}). When bloom-forming *Pelagia noctiluca* were collected near the shore in the Canary Islands (Gran Canaria), 97% of the sample size showed the presence of micro debris (Rapp et al., 2021).

Macali et al. (2018) suggested that jellyfish can wrongly recognise plastic as food. This behaviour has already been observed in other marine organisms (Cole et al., 2013; Lusher et al., 2013). Medusae are

* Corresponding author.
E-mail address: vanesa.romero.kutzner@gmail.com (V. Romero-Kutzner).
[1] First and second authors have contributed equally to this work; therefore, they must be considered indistinctly as first authors.

https://doi.org/10.1016/j.marpolbul.2021.113269
Received 25 March 2021; Received in revised form 9 December 2021; Accepted 13 December 2021

tactile and avid planktivores, their clearance rate (for zooplankton) being between 6.94 × 10^{-6}-1.90 × 10^{-7} m^3 s^{-1} (Båmstedt, 1990; Båmstedt et al., 1994). However, the ingestion and egestion of MPs by jellyfish in the natural environment is unknown. Exposure experiments under controlled conditions are needed to investigate the ingestion, residence time, egestion, and the potential impact of MPs on marine biota (Rodríguez-Torres et al., 2020; Sun et al., 2017). Additionally, commercial spherical polymers, such as polyethylene (PE), polypropylene (PP), and polystyrene (PS), set a baseline and enable comparison, within and between species (Rodríguez-Torres et al., 2020).

Most jellyfish research is focussed on the circumglobal medusa *Aurelia* sp., also called the moon jellyfish or true jellyfish. This genus, although usually considered harmless to humans, can be problematic when they occur in blooms (Baxter et al., 2011; Mariottini and Pane, 2010; Matsumura et al., 2005). Sucharitakul et al. (2020) observed that cultured *A. aurita* presents a limited ingestion rate and a rapid egestion of PS microspheres. However, this study was carried out in the absence of food. Costa et al. (2020a, 2020b) found evidence of ingestion of PE microspheres in *A. aurita* ephyrae in the absence and presence of prey. They found that direct MP ingestion (3.8 × 10^3–1.8 × 10^9 particles L^{-1}) causes immobility and affects pulsation rates in *A. aurita* ephyrae (Costa et al., 2020a), but indirect MP ingestion through contaminated prey did not evidence any impact, on the immobility or behaviour of *A. aurita* ephyrae (Costa et al., 2020b). In juvenile *A. aurita* (Sucharitakul et al., 2020), in the absence of prey, neither respiration nor histology was affected due to MP ingestion. However, despite the growing interest in how MPs impact jellyfish, the ability of jellyfish to retain MP should not be ignored for multiple reasons.

First, ingestion and residence time of MPs may be utilized as indicators for ecological risk assessment (Sun et al., 2017). According to Sun et al. (2017), the residence time of MPs should be examined in future research, which would also enable validation of jellyfish as an innovative bioindicator for plastic pollution (Macali and Bergami, 2020). Second, and not less important, GZP trophic interactions are extensive (Fig. 1). Even humans are listed as predators. Jellyfish are a traditional food in Asia, widely consumed in countries like China, Japan, Thailand, and Malaysia (Raposo et al., 2018). Human health could be impacted if contaminated jellyfish are ingested. According to the GZP food web (Fig. 1), jellyfish MP ingestion could also influence processes such as bioaccumulation, biomagnification through trophic transfer (Cole et al., 2011; Hasegawa and Nakaoka, 2021), and seafloor gelatinous carcasses deposition (jelly-falls) (Albano et al., 2021; Macali and Bergami, 2020; Sweetman and Chapman, 2015) leading to a potential increase of MP availability to benthic scavengers.

Based on this, in this work for the first time, ingestion of MPs in the presence and absence of prey was investigated in juvenile *A. aurita* medusa. The objective of the present study is to investigate the presence of MPs in *A. aurita*'s gastrovascular cavity over time (presence time), and the duration of MP retention in the gastrovascular cavity (retention time), considering the effect of prey.

Here we used polyethylene (PE) microspheres (Cospheric fluorescent green polyethylene microspheres, 1.025 g cm^{-3}, 75–90 μm). PE polymer has the highest global production rates and is the most common type of marine litter in the ocean and on beaches (Andrady, 2017; Beiras et al., 2018; Burns and Boxall, 2018; Erni-Cassola et al., 2019; Hidalgo-Ruz et al., 2012). PE exposure experiments were carried out with three concentrations (low, 5000 MP L^{-1}; medium 10,000 MP L^{-1}; and high, 20,000 MP L^{-1}). These MP concentrations are within the range commonly used for exposure tests (Costa et al., 2020a; Rodríguez-Torres et al., 2020; Setälä et al., 2014). However, due to the limited number of plankton Kreisels (four), on an experimental day, only one MP concentration treatment was performed, resulting in three replicates and one control. We hypothesised that plastic ingestion of *A. aurita* increases with higher MP availability and in the presence of food.

For this purpose, four 1.7 L plankton Kreisel tanks specially designed for this study were used, and one *A. aurita* individual (1–2 cm) was placed in each tank. In the control group, we wanted to pursue the observation of medusae behaviour in the experimental plankton Kreisels as a reference.

The presence or absence of the microspheres was followed with ultraviolet light during MPs exposure in the plankton Kreisels in darkness A microscope was not used to enable the observation of MP ingestion over time. Hart (1991) followed the ingestion of echinoderm larvae on polystyrene microspheres (10 and 20 μm) in a cylindrical glass observation chamber. In this study, the presence or absence of microplastic under the described conditions was simple to follow with the naked eye in the ingestion experiments. Further, it was possible to quantify the number of ingested particles under the egestion experiment conditions. A short video showing the presence of PE microspheres in the gastrovascular cavity of *A. aurita* has been included as Supplementary

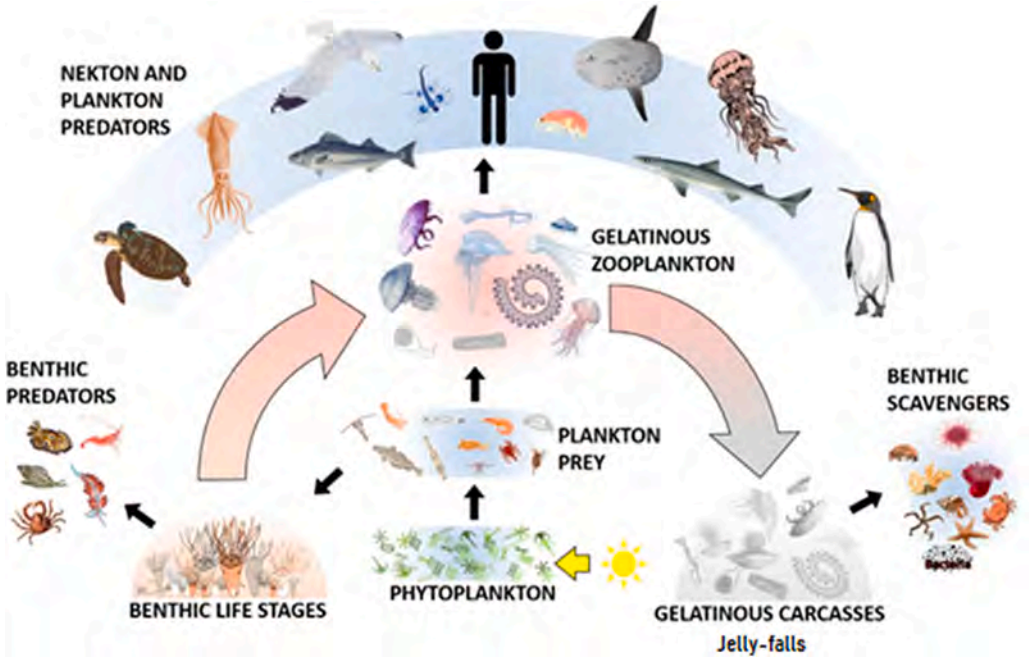

Fig. 1. Simplified scheme compiling the trophic interactions described for gelatinous zooplankton. Coloured arrows represent possible transitions from gelatinous zooplankton as it can be metagenesis or Jelly-falls. Black arrows symbolise predation flows. The members of the represented groups are based on various works (Ates, 2017; Choy et al., 2017; Pauly et al., 2009; Riascos et al., 2012; Takao et al., 2014). Mutual predations and additional interactions between group members have been omitted. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

material.

Before exposing medusae to MPs, a PE stock suspension containing distilled water with an aqueous solution of hydrophobic particles (Tween) was prepared. The MPs in the stock solution were verified by manual counting of 10 μL aliquots, using a stereo microscope with a Bogorov counting chamber. The resulting concentration of the stock solution was 322 ± 21 MP in 10 μL^{-1}. MPs were then added to the plankton Kreisel tanks so that the resulting concentrations were 5,000 ± 326 microspheres L^{-1}, 10,000 ± 652, and 20,000 ± 1034 MPs L^{-1}, respectively.

Firstly, MPs ingestion in the absence of prey was followed. The experimental design is illustrated in the Supplementary material. Thus, every 10 min for 480 min, whether the medusa had plastic inside the gastrovascular cavity was checked with ultraviolet light. It has been previously observed that accumulations of microbeads occur only in the gastrovascular cavity of *A. aurita* (Sucharitakul et al., 2020). Therefore, a microsphere was considered ingested only if it was found in the gastrovascular cavity. If plastic was observed, the duration of its presence (time of presence) was determined. The same procedure was applied for the next part of this first experiment, *A. aurita* MP exposure in the presence of prey. Now 500 48 h-*Artemia* nauplii (~294 per L^{-1}) were added to each MP exposure concentration. For this purpose, aliquots from the *Artemia* culture were counted (by adding Lugol's iodine solution), in the same way as PE microspheres.

In a second experiment, we studied the retention time of the MPs from the gastrovascular cavity and whether this time varies with concentration, as well as the variability of the number of ingested microspheres. For this, *A. aurita* was exposed to MP (5000 MPs L^{-1}; 10,000 MPs L^{-1}; 20,000 MPs L^{-1}) and fed with 48 h-*Artemia* nauplii (~294 L^{-1}) for 30 min, to give medusa enough time to eat. After this 30 min medusae were placed separately into three tanks filled exclusively with seawater. Again, with ultraviolet light, it was checked every 10 min to see whether they had microspheres inside until all the MPs were expelled.

Finally, statistical analysis and graphs were performed with the software R Core Team (2020) and its integrated development environment Rstudio (version 1.1.463). However, given the small sample size, our results should be considered preliminary and qualitative. The normality of the data was verified by the Shapiro-Wilk test, and the homogeneity of variances was analysed with the Bartlett test. Since both normality and homogeneity of variances were fulfilled, no transformation was necessary and an ANOVA test was applied to determine statistical differences between MP treatments.

Despite the MP exposure concentrations (5000 MP L^{-1}; 10,000 MP L^{-1}; 20,000 MP L^{-1}), no plastic ingestion was observed in the absence of prey (Table 1). Microplastics stuck only to the external surface of the jellyfish. In contrast, in the presence of prey, *A. aurita* did ingest MPs (Table 1). On average, microspheres could be observed in the gastrovascular cavity after 34 min. The time of presence of PE in the gastrovascular cavity increases with the increasing concentration of microspheres (Table 1).

Table 1
Results obtained from the experiment 1 (ingestion experiment) and experiment 2 (egestion experiment). Numbers are expressed as an average with standard deviation.

		Experiment 1	Experiment 2	
Treatment	**Ingestion**	**Time of presence (min)**	**Retention time (min)**	**Average microspheres**
5.000 microspheres/L	✗	-	-	-
5.000 microspheres /L + nauplii	✓	103.33 ± 136.67	150 ± 60	1 ± 1
10.000 microspheres/L	✗	-	-	-
10.000 microspheres /L + nauplii	✓	176.67 ± 16.67	166.67 ± 33.33	2
20.000 microspheres /L	✗	-	-	-
20.000 microspheres /L + nauplii	✓	226.67 ± 96.67	123.33 ± 33.33	3 ± 2

The time of plastic presence was 103.33 (5000 microspheres L^{-1}), 176.67 (10,000 microspheres L^{-1}) and, 226.67 min (20,000 microspheres L^{-1}), respectively. However, no significant differences were found between the time of presence and the three MP concentration treatments (low, 5000 MP L^{-1}; medium 10,000 MP L^{-1}; and high, 20,000 MP L^{-1}) (p-value = 0.307). The percentage of time jellyfish had ingested plastic was up to 47% (Fig. 2) for the highest plastic concentration experiment (20,000 microspheres L^{-1}), 37% in the medium plastic concentration treatment (10,000 microspheres L^{-1}), and only 22% in the lowest plastic concentration treatment (5000 microspheres L^{-1}) during 480 min (100%). Our hypothesis that the ingestion of microplastic increases with the presence of prey can be accepted, as in the absence of prey, they did not ingest the microspheres.

No significant differences were found between the different concentrations of PE microspheres (5000 MP L^{-1}; 10,000 MP L^{-1}; 20,000 MP L^{-1}) and the retention time (p-value = 0.441), nor was an appreciable upward trend observed as in the previous experiment (Table 1). Therefore, it seems that the retention time is independent of the environmental plastic concentration. The retention time was 150 (5000 microspheres L^{-1}), 166.67 (10,000 microspheres L^{-1}) and, 123.33 min (20,000 microspheres L^{-1}), respectively (Table 1). However, the fastest retention time was detected in jellyfish number 2 (20,000 microspheres L^{-1}) which egested one particle after 40 min (Table 2). The longest retention time was 160 min (5000 and 10,000 microspheres L^{-1} of PE microspheres treatment). The average number of microspheres in the gastrovascular cavity was 1 for 5000 microspheres L^{-1}, 2 for 10,000 microspheres L^{-1} and, 3 for 20,000 microspheres L^{-1} (Table 1).

In Table 2, we can observe the number of microspheres ingested by each jellyfish at each concentration. Whole numbers (0–4) correspond to the microspheres present in the gastrovascular cavity. The microspheres were considered expelled if they were not present in the gastrovascular cavity or the manubrium. We could observe that *A. aurita* can integrate particles into the gastrovascular cavity, then expel them to the manubrium and incorporate these same particles again into the gastrovascular cavity (Table 2).

In our study, we observed that *A. aurita* ingestion of PE microspheres in the laboratory occurs only when prey is present (Table 1). Neither the average time of presence nor the retention time is affected by the concentration of microspheres in the environment, however, the number of microspheres ingested increased at higher concentrations (Table 1). Other MP exposure studies, such as Cole and Galloway (2015) did advocate that high MP abundance or concentration led to increased ingestions. However, in the natural environment, jellyfish could be ingesting plastic in absence of food, as recently evidenced with commercial PS microspheres in *A. aurita* (Sucharitakul et al., 2020). Possibly, *A. aurita* can distinguish MPs from the prey, due to the chemoreceptors present in their oral arms (Archdale et al., 2002). All polymers have different surface characteristics, and varying degrees of crystallinity (Santana-Viera et al., 2021), which could additionally affect ingestion rates, time of presence, and retention time.

Other zooplankton prefer to ingest aged microplastics compared to pristine plastic, suggesting that microplastics that developed biofilms in the marine environment may generate a chemosensory response (Lobelle and Cunliffe, 2011; Vroom et al., 2017). Algae, eggs, and substances like petroleum are frequently present in PE and PP polymers due to their positive buoyancy (Muthukumar et al., 2011). Additionally, deposition of different species on the polymer surface can facilitate the formation of carbonyl residues, which can be substrates for non specific microbial populations (Acosta-Coley and Olivero-Verbel, 2015). Pellets with a virgin surface also occur in the natural environment, as PE and PP pellets were the most abundant plastics onshore in Cartegena (Colombia) (Acosta-Coley and Olivero-Verbel, 2015). Plastic ingestion of commercial beads could potentially reflect *A. aurita* ingestion rates of virgin pellets in the natural environment. However, to date in the

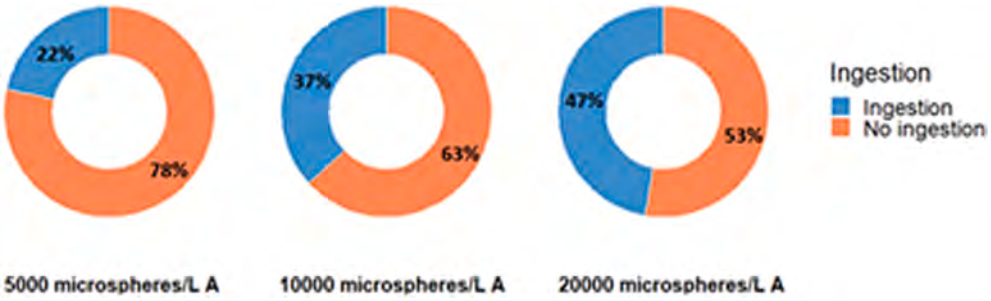

Fig. 2. Ingestion of polyethylene microspheres in presence of prey. Percentage of the microplastic presence time in the gastrovascular cavity is shown. The experimental duration of *A. aurita* exposure to microplastics was 480 min (100%).

Table 2
PE microspheres (μspheres) egestion experiment. Data reflect the number of particles in the gastric cavity. In the case of 0, microplastic were absent in the gastrovascular cavity, but still present in the manubrium. The PE μspheres were expelled if they were not present in the gastric cavity nor the manubrium.

Time (min)	5000 μspheres L^{-1}			10,000 μspheres L^{-1}			20,000 μspheres L^{-1}		
	Jellyfish 1	Jellyfish 2	Jellyfish 3	Jellyfish 1	Jellyfish 2	Jellyfish 3	Jellyfish 1	Jellyfish 2	Jellyfish 3
0	1	1	2	1	1	1	3	1	4
10	0	1	2	0	0	1	2	0	4
20	0	1	2	2	0	1	3	1	3
30	1	1	0	2	2	1	2	0	3
40	1	1	0	0	0	1	3		3
50	1	1	1		0	1	3		3
60	1	0	0		1	0	3		3
70	0		0		1	0	3		3
80			1		0	1	3		3
90			2			1	3		1
100			2			2	3		1
110			1			2	3		1
120			1			2	2		0
130			1			1	1		
140			1			1	0		
150			1			1			
160			0			0			

natural environment fibres and fragments are the most common plastic found in medusae (Albano et al., 2021; Iliff et al., 2020; Rapp et al., 2021; Sun et al., 2017). Many fragments are irregular in form and can present sharp edges, causing potential internal abrasion when ingested (Wright et al., 2013). Even the size range of MP particles ingested by the jellyfish could be wide, as recently proved by Brandon et al. (2020), who found that every examined salp had ingested mini-MPs (5–333 μm), regardless of the oceanic region, species, or life-history stage.

As medusae (and GZP) are tactile zooplanktivores it is hard to compare ingestion and retention time with visual planktivores, such as fish, or filtering planktivores, like copepods. In the ingestion experiments in the presence of prey, microspheres started to appear in the gastrovascular pouches after 20 min (see Supplementary material), irrespective of the treatment (5000 MP L^{-1}; 10,000 MP L^{-1}; 20,000 MP L^{-1}). Hansson (2006) also observed more food accumulated in the gastrovascular cavities than in the oral arms after 20 min of feeding. Subsequently, the time of presence of microspheres in the gastrovascular cavity was longer with increasing plastic concentration (Table 1). Sucharitakul et al. (2020) found PS particles starting to appear in the gastrovascular cavity within 1–2 h of exposure, the maximum number of microbeads occurring at 16 h of exposure (2000 microspheres L^{-1}). A potential explanation for this is that *A. aurita* can catch their prey with their entire body surface (Heeger and Möller, 1987). The feeding behaviour of *A. aurita* is briefly explained by Archdale and Anraku (2005). Nevertheless, not much is known about the transport kinetics of the captured prey in jellyfish (Hansson, 2006).

In this study, we observed short retention times 0.7–2.7 h (Table 2). Sucharitakul et al. (2020) observed that *A. aurita* egested microbeads within 8 h of consumption from the gastrovascular cavity, with a retention time of 4 h in the manubrium. In our study, there is no evidence that *A. aurita* digests (disintegrate) PE microspheres. Neither did Sucharitakul et al. (2020) observe the digestion of PS microspheres in *A. aurita*. The MPs exposure time prior to the egestion experiment of both studies is different. In our study, *A. aurita* were exposed to PE for 30 min and were then detected at time point 0 of the egestion experiment in the gastrovascular cavity. Sucharitakul et al. (2020) exposed *A. aurita* for 1 h, and PS could be observed only in the tentacles and oral arms. In our study, many PE did not reach the cavities and were expelled directly from the manubrium. We also observed that some of the microspheres that had reached the gastrovascular cavities returned to the manubrium after a few minutes, and from there they could either return to the cavities or be expelled (Table 2). To our knowledge, this behaviour has not been reported before. It is known that *Aurelia aurita* prefer natural food items over artificial ones and can expel artificial items shortly after capture (Archdale et al., 2002). The retention time of MPs in wild jellyfish is not known, but MPs can be retained longer in wild zooplankton than in experimental ones (Egbeocha et al., 2018).

The number of microspheres in the gastrovascular pouches increased with increasing plastic concentration. We observed a range of 1–3 microspheres per individual (Table 2). Iliff et al. (2020) found that the amount of microplastic in wild benthonic jellyfish ranged from 1.1 to 1.8 per individual, like our results. *Pelagia noctiluca* collected from the natural environment, presented a maximum abundance of 8 plastic items in the bell (Rapp et al., 2021) (63% of the micro debris found in the gastrovascular cavity were blue, and 14% transparent). Sucharitakul et al. (2020) found 2 PS microspheres (mean value) in the gastrovascular cavity (ingestion experiment and egestion experiment).

In our study, MPs also stuck to the body in the absence of food (not

quantified), especially when the concentration was increased. Mucus cells are potentially responsible for trapping these plastic particles, as they occur all over *A. auritas*'s body surface (Heeger and Möller, 1987). The number of particles attached to the outer body surface was also higher than those found in the gastric pouch, in the study of Sucharitakul et al. (2020).

The idea of removing nanoparticles from contaminated water using jellyfish mucus is not new (Patwa et al., 2015). In fact, GoJelly 'a gelatinous solution to plastic pollution', is a EU Horizon 2020 funded project, and has received the most public attention for its aim of developing jellyfish mucus as a filter for microplastics (Rothe, 2020). Preliminary results indicate that plastic removal rates vary with species (Freeman et al., 2020). Despite this, *A. aurita* is among the easiest jellyfish to culture and according to our results, may be a suitable species for such studies.

Besides, some scientists have pointed out that jellyfish plastic ingestion can contribute to plastic deposition on the seafloor (Albano et al., 2021; Macali and Bergami, 2020). The body shape of jellyfish, or GZP in general, facilitates rapid sinking through the water column. The sinking speed of GZP varies within taxa and water temperature. Lebrato et al. (2013) estimated that scyphozoan biomass like *A. aurita* has a sinking speed of 1000 m d^{-1}. The sinking speed of MPs is related mostly to particle density. MPs density can increase in seawater due to the absorption of contaminants and biofouling (Fred-Ahmadu et al., 2020; Morét-Ferguson et al., 2010). Particles with a density lower than seawater float at the sea surface; with jellyfish blooms, these could be transported to deeper layers. Further, jellyfish blooms are often short-lived and mass mortality could easily lead to seafloor plastic depositions. Jelly-falls of *Aurelia* sp. have been found in the Mediterranean (Marques et al., 2021), Red Sea (Alamaru et al., 2009), the Arabian Sea (Billett et al., 2006), and the Pacific Ocean (Miyake et al., 2002).

In addition, scyphozoan polyps have been found attached to macroplastics in the canyon of Xisha Trough (China), affecting the deep-sea benthic-pelagic coupling process (Song et al., 2021). Scyphozoans have a metagenic life cycle and if polyps, a benthic life stage, absorb pollutants from this artificial plastic substrate, medusae could be affected through transgenerational effects (Zhou et al., 2020).

To date, plastic concentration in the ocean is hard to quantify due to the variations it undergoes from one area to another. Surface plastic depends on oceanic currents and tends to accumulate mainly in the subtropical gyres (Cózar et al., 2014). It has been recently demonstrated that dissolved organic carbon leaching from plastics stimulates microbial activity (Romera-Castillo et al., 2018). Likewise, jellyfish blooms have been observed in the regions of plastic accumulation (Ziveri, 2013). The role of bacteria during jellyfish blooms has also been widely investigated (Condon et al., 2011; Guy-Haim et al., 2020; Riemann et al., 2006; Tinta et al., 2012). Encounters of jellyfish blooms and plastic aggregations may potentially magnify their impact on bacterial activity, leading to major consequences for marine biota and cycles.

Further studies are needed to understand the ingestion and impacts of microplastics on medusae and their combined effect on marine ecosystems. Medusae are voracious predators of zooplankton in marine ecosystems and prey should be included in future studies. While bloom-forming medusae could be crucial in ocean plastic pollution research due to their abundance and trophic interactions (Fig. 1), little is known about the role of MPs in trophic fluxes (Rodrigues et al., 2021).

In conclusion, to allow extrapolation of laboratory-based results to the environment, conditions must be equated (Rodrigues et al., 2021). In addition, in the Decade of Ocean Science new knowledge should be generated, encouraging actions towards a more integrated ocean observation system (Visbeck, 2018). In this sense, future jellyfish microplastic ingestion studies should be more realistic, include cumulative stressors (Rudd, 2014), and predict future scenarios to strengthen the overall evidence base for ocean governance.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.113269.

CRediT authorship contribution statement

V. Romero-Kutzner: conceptualization, methodology, data analysis, writing original draft; **J. Tarí**: investigation, methodology, data analysis. **A. Herrera**: conceptualization, methodology, writing-review, and edit, supervision; **I. Martínez**: conceptualization, methodology, writing-review, and edit; **D.R. Bondyale-Juez**: conceptualization, writing-review, and edit; **M. Gomez**: validation, writing-review and edit, funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was partially supported by the PERSEO project (ProID201710051), granted to M. Gómez, and funded by Canary Island Government and ERDF funds. V. Romero Kutzner was supported by the Canary Island Government (TESIS 20 150 10011).

References

Acosta-Coley, I., Olivero-Verbel, J., 2015. Microplastic resin pellets on an urban tropical beach in Colombia. Environ. Monit. Assess. 1877 (187), 1–14. https://doi.org/10.1007/S10661-015-4602-7, 2015.

Alamaru, A., Bronstein, O., Dishon, G., Loya, Y., 2009. Opportunistic feeding by the fungiid coral Fungia scruposa on the moon jellyfish Aurelia aurita, 2009 Coral Reefs 284 (28). https://doi.org/10.1007/S00338-009-0507-7, 865–865.

Albano, M., Panarello, G., Di Paola, D., D'Angelo, G., Granata, A., Savoca, S., Capillo, G., 2021. The mauve stinger Pelagia noctiluca (Cnidaria, Scyphozoa) plastics contamination, the strait of Messina case. Int. J. Environ. Stud. 1–6 https://doi.org/10.1080/00207233.2021.1893489.

Andrady, A.L., 2017. The plastic in microplastics: a review. Mar. Pollut. Bull. 119, 12–22. https://doi.org/10.1016/J.MARPOLBUL.2017.01.082.

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605. https://doi.org/10.1016/J.MARPOLBUL.2011.05.030.

Archdale, M.V., Anraku, K., 2005. Feeding behavior in scyphozoa, crustacea and cephalopoda. Chem. Senses 30, i303–i304. https://doi.org/10.1093/CHEMSE/BJH235.

Ates, R.M.L., 2017. Benthic scavengers and predators of jellyfish, material for a review. Plankt. Benthos Res. 12, 71–77. https://doi.org/10.3800/PBR.12.71.

Båmstedt, U., 1990. Trophodynamics of the scyphomedusae Aurelia aurita. Predation rate in relation to abundance, size and type of prey organism. J. Plankton Res. 12, 215–229. https://doi.org/10.1093/PLANKT/12.1.215.

Båmstedt, U., Martinussen, M.B., Matsakis, S., 1994. Trophodynamics of the two scyphozoan jellyfishes, Aurelia aurita and Cyanea capillata, in western Norway. ICES J. Mar. Sci. 51, 369–382. https://doi.org/10.1006/JMSC.1994.1039.

Baxter, E.J., Sturt, M.M., Ruane, N.M., Doyle, T.K., McAllen, R., Harman, L., Rodger, H. D., 2011. Gill damage to Atlantic Salmon (Salmo salar) caused by the common jellyfish (Aurelia aurita) under experimental challenge. PLoS One 6, e18529. https://doi.org/10.1371/JOURNAL.PONE.0018529.

Beiras, R., Bellas, J., Cachot, J., Cormier, B., Cousin, X., Engwall, M., Gambardella, C., Garaventa, F., Keiter, S., Le Bihanic, F., López-Ibáñez, S., Piazza, V., Rial, D., Tato, T., Vidal-Liñán, L., 2018. Ingestion and contact with polyethylene microplastics does not cause acute toxicity on marine zooplankton. J. Hazard. Mater. 360, 452–460. https://doi.org/10.1016/J.JHAZMAT.2018.07.101.

Billett, D.S.M., Bett, B.J., Jacobs, C.L., Rouse, I.P., Wigham, B.D., 2006. Mass deposition of jellyfish in the deep Arabian Sea. Limnol. Oceanogr. 51, 2077–2083. https://doi.org/10.4319/LO.2006.51.5.2077.

Boero, F., Bouillon, J., Gravili, C., Miglietta, M., Parsons, T., Piraino, S., 2008. Gelatinous plankton: irregularities rule the world (sometimes). Mar. Ecol. Prog. Ser. 356, 299–310. https://doi.org/10.3354/meps07368.

Botterell, Z.L.R., Beaumont, N., Dorrington, T., Steinke, M., ThoMPon, R.C., Lindeque, P. K., 2019. Bioavailability and effects of microplastics on marine zooplankton: a review. Environ. Pollut. 245, 98–110. https://doi.org/10.1016/J.ENVPOL.2018.10.065.

Brandon, J.A., Freibott, A., Sala, L.M., 2020. Patterns of suspended and salp-ingested microplastic debris in the North Pacific investigated with epifluorescence microscopy. Limnol. Oceanogr. Lett. 5, 46–53. https://doi.org/10.1002/LOL2.10127.

Burns, E.E., Boxall, A.B.A., 2018. Microplastics in the aquatic environment: evidence for or against adverse impacts and major knowledge gaps. Environ. Toxicol. Chem. 37, 2776–2796. https://doi.org/10.1002/ETC.4268.

Carpenter, E.J., Anderson, S.J., Harvey, G.R., Miklas, H.P., Peck, B.B., 1972. Polystyrene spherules in coastal waters. Science 178 (4062), 749–750. https://doi.org/10.1126/science.178.4062.749.

Choy, C.A., Haddock, S.H.D., Robison, B.H., 2017. Deep pelagic food web structure as revealed by in situ feeding observations. Proceedings. Biol. Sci. 284 https://doi.org/10.1098/rspb.2017.2116.

Cole, M., Coppock, R., Lindeque, P.K., Altin, D., Reed, S., Pond, D.W., Sørensen, L., Galloway, T.S., Booth, A.M., 2019. Effects of nylon microplastic on feeding, lipid accumulation, and moulting in a Coldwater copepod. Environ. Sci. Technol. 53, 7075–7082. https://doi.org/10.1021/ACS.EST.9B01853.

Cole, M., Galloway, T.S., 2015. Ingestion of nanoplastics and microplastics by Pacific oyster larvae. Environ. Sci. Technol. 49 (24), 14625–14632.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., Galloway, T. S., 2013. Microplastic ingestion by zooplankton. Environ. Sci. Technol. 47, 6646–6655. https://doi.org/10.1021/ES400663F.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: a review. Mar. Pollut. Bull. 62, 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025.

Condon, R.H., Steinberg, D.K., del Giorgio, P.A., Bouvier, T.C., Bronk, D.A., Graham, W. M., Ducklow, H.W., 2011. Jellyfish blooms result in a major microbial respiratory sink of carbon in marine systems. Proc. Natl. Acad. Sci. 108, 10225–10230. https://doi.org/10.1073/PNAS.1015782108.

Costa, E., Gambardella, C., Piazza, V., Vassalli, M., Sbrana, F., Lavorano, S., Garaventa, F., Faimali, M., 2020a. Microplastics ingestion in the ephyra stage of Aurelia sp. Triggers acute and behavioral responses. Ecotoxicol. Environ. Saf. 189, 109983 https://doi.org/10.1016/j.ecoenv.2019.109983.

Costa, E., Piazza, V., Lavorano, S., Faimali, M., Garaventa, F., Gambardella, C., 2020b. Trophic transfer of microplastics from copepods to jellyfish in the marine environment. Front. Environ. Sci. 158. https://doi.org/10.3389/FENVS.2020.571732.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Duarte, C.M., 2014. Plastic debris in the open ocean. Proc. Nat. Acad. Sci. 111 (28), 10239–10244.

Egbeocha, C.O., Malek, S., Emenike, C.U., Milow, P., 2018. Feasting on microplastics: ingestion by and effects on marine organisms. Aquat. Biol. 27, 93–106.

Erni-Cassola, G., Zadjelovic, V., Gibson, M.I., Christie-Oleza, J.A., 2019. Distribution of plastic polymer types in the marine environment; a meta-analysis. J. Hazard. Mater. 369, 691–698. https://doi.org/10.1016/J.JHAZMAT.2019.02.067.

Fred-Ahmadu, O.H., Bhagwat, G., Oluyoye, I., Benson, N.U., Ayejuyo, O.O., Palanisami, T., 2020. Interaction of chemical contaminants with microplastics: principles and perspectives. Sci. Total Environ. 706, 135978 https://doi.org/10.1016/J.SCITOTENV.2019.135978.

Freeman, S., Booth, A.M., Sabbah, I., Tiller, R., Dierking, J., Klun, K., Rotter, A., Ben-David, E., Javidpour, J., Angel, D.L., 2020. Between source and sea: the role of wastewater treatment in reducing marine microplastics. J. Environ. Manag. https://doi.org/10.1016/j.jenvman.2020.110642.

Guy-Haim, T., Rubin-Blum, M., Rahav, E., Belkin, N., Silverman, J., Sisma-Ventura, G., 2020. The effects of decomposing invasive jellyfish on biogeochemical fluxes and microbial dynamics in an ultra-oligotrophic sea. Biogeosciences 17, 5489–5511. https://doi.org/10.5194/BG-17-5489-2020.

Haegerbaeumer, A., Mueller, M.-T., Fueser, H., Traunspurger, W., 2019. Impacts of micro- and Nano-sized plastic particles on benthic invertebrates: a literature review and gap analysis. Front. Environ. Sci. 17. https://doi.org/10.3389/FENVS.2019.00017.

Hansson, L.J., 2006. A method for in situ estimation of prey selectivity and predation rate in large plankton, exemplified with the jellyfish Aurelia aurita (L.). J. Exp. Mar. Bio. Ecol. 328, 113–126. https://doi.org/10.1016/j.jembe.2005.07.002.

Hart, M.W., 1991. Particle captures and the method of suspension feeding by echinoderm larvae. Biol. Bull. 180 (1), 12–27.

Hasegawa, T., Nakaoka, M., 2021. Trophic transfer of microplastics from mysids to fish greatly exceeds direct ingestion from the water column. https://doi.org/10.1016/j.envpol.2021.116468.

Heeger, T., Möller, H., 1987. Ultrastructural observations on prey capture and digestion in the scyphomedusa Aurelia aurita. Mar. Biol. 96, 391–400. https://doi.org/10.1007/BF00412523.

Hidalgo-Ruz, V., Gutow, L., ThoMPon, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ. Sci. Technol. 46, 3060–3075. https://doi.org/10.1021/ES2031505.

Iliff, S.M., Wilczek, E.R., Harris, R.J., Bouldin, R., Stoner, E.W., 2020. Evidence of microplastics from benthic jellyfish (Cassiopea xamachana) in Florida estuaries. Mar. Pollut. Bull. 159, 111521 https://doi.org/10.1016/j.marpolbul.2020.111521.

Laurenceau-Cornec, E.C., Trull, T.W., Davies, D.M., Bray, S.G., Doran, J., Planchon, F., Carlotti, F., Jouandet, M.P., Cavagna, A.J., Waite, A.M., Blain, S., 2015. The relative importance of phytoplankton aggregates and zooplankton fecal pellets to carbon export: insights from free-drifting sediment trap deployments in naturally iron-fertilised waters near the Kerguelen plateau. Biogeosciences 12, 1007–1027. https://doi.org/10.5194/BG-12-1007-2015.

Lebrato, M., Molinero, J.C., Cartes, J.E., Lloris, D., Mélin, F., Beni-Casadella, L., 2013. Sinking jelly-carbon unveils potential environmental variability along a continental margin. PLoS One 8. https://doi.org/10.1371/journal.pone.0082070.

Lobelle, D., Cunliffe, M., 2011. Early microbial biofilm formation on marine plastic debris. Mar. Pollut. Bull. 62 (1), 197–200.

Lusher, A.L., McHugh, M., ThoMPon, R.C., 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Mar. Pollut. Bull. 67, 94–99. https://doi.org/10.1016/J.MARPOLBUL.2012.11.028.

Macali, A., Bergami, E., 2020. Jellyfish as innovative bioindicator for plastic pollution. Ecol. Indic. 115, 106375 https://doi.org/10.1016/j.ecolind.2020.106375.

Macali, A., Semenov, A., Venuti, V., Crupi, V., D'Amico, F., Rossi, B., Corsi, I., Bergami, E., 2018. Episodic records of jellyfish ingestion of plastic items reveal a novel pathway for trophic transference of marine litter. Sci. Rep. 8, 1–5. https://doi.org/10.1038/s41598-018-24427-7.

Mariottini, G.L., Pane, L., 2010. Mediterranean jellyfish venoms: a review on scyphomedusae. Mar. Drugs 8, 1122–1152. https://doi.org/10.3390/md8041122.

Marques, R., Rufino, M., Darnaude, A.M., Carcaillet, F., Meffre, M., Bonnet, D., 2021. Jellyfish degradation in a shallow coastal Mediterranean lagoon. Estuar. Coast. Shelf Sci. 261, 107527 https://doi.org/10.1016/J.ECSS.2021.107527.

Matsumura, K., Kamiya, K., Yamashita, K., Hayashi, F., Watanabe, I., Murao, Y., Miyasaka, H., Kamimura, N., Nogami, M., 2005. Genetic polymorphism of the adult medusae invading an electric power station and wild polyps of Aurelia aurita in Wakasa Bay, Japan. J. Mar. Biol. Assoc. U. K. 85, 563–568. https://doi.org/10.1017/S0025315405011483.

Miyake, H., Lindsay, D.J., Hunt, J.C., Hamatsu, T., 2002. Scyphomedusa Aurelia limbata (Brandt, 1838) found in deep waters off Kushiro, Hokkaido, Northern Japan. Plankton Biology and Ecology 49 (1), 44–46.

Morét-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C. M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Mar. Pollut. Bull. 60, 1873–1878. https://doi.org/10.1016/J.MARPOLBUL.2010.07.020.

Muthukumar, T., Aravinthan, A., Lakshmi, K., Venkatesan, R., Vedaprakash, L., Doble, M., 2011. Fouling and stability of polymers and composites in marine environment. Int. Biodeterior. Biodegradation 65 (2), 276–284.

Napper, I.E., Baroth, A., Barrett, A.C., Bhola, S., Chowdhury, G.W., Davies, B.F.R., Duncan, E.M., Kumar, S., Nelms, S.E., Hasan Niloy, M.N., Nishat, B., Maddalene, T., ThoMPon, R.C., Koldewey, H., 2021. The abundance and characteristics of microplastics in surface water in the transboundary Ganges River. Environ. Pollut. 274, 116348 https://doi.org/10.1016/J.ENVPOL.2020.116348.

Pabortsava, K., Lampitt, R.S., 2020. High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. Nat. Commun. 11, 1–11. https://doi.org/10.1038/s41467-020-17932-9.

Patwa, A., Thiéry, A., Lombard, F., Lilley, M.K.S., Boisset, C., Bramard, J.F., Bottero, J.Y., Barthélémy, P., 2015. Accumulation of nanoparticles in "jellyfish" mucus: a bio-inspired route to decontamination of nano-waste. Sci. Rep. 5, 1–8. https://doi.org/10.1038/srep11387.

Pauly, D., Graham, W., Libralato, S., Morissette, L., Deng Palomares, M.L., 2009. Jellyfish in ecosystems, online databases, and ecosystem models. Hydrobiologia 616, 67–85. https://doi.org/10.1007/s10750-008-9583-x.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Raposo, A., Coimbra, A., Amaral, L., Gonçalves, A., Morais, Z., 2018. Eating jellyfish: safety, chemical and sensory properties. Wiley Online Libr. 98, 3973–3981. https://doi.org/10.1002/jsfa.8921.

Rapp, J., Herrera, A., Bondyale-Juez, D.R., González-Pleiter, M., Reinold, S., Asensio, M., Martínez, I., Gómez, M., 2021. Microplastic ingestion in jellyfish Pelagia noctiluca (Forsskal, 1775) in the North Atlantic Ocean. Mar. Pollut. Bull. 166, 112266 https://doi.org/10.1016/J.MARPOLBUL.2021.112266.

Raskoff, K.A., Sommer, F.A., Hamner, W.M., Cross, K.M., Raskoff, K.A., Sommer, F.A., Hamner, W.M., 2003. Collection and culture techniques for gelatinous zooplankton. Biol. Bull. 204 (1), 68–80.

Riascos, J., Vergara, M., Fajardo, J., Villegas, V., Pacheco, A.S., 2012. The role of hyperiid parasites as a trophic link between jellyfish and fishes. J. Fish Biol. 81 (5), 1686–1695. https://doi.org/10.1111/j.1095-8649.2012.03427.x.

Richardson, A., Bakun, A., Hays, G.C., Gibbons, M.J., 2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends Ecol. Evol. 24 (6), 312–322.

Riemann, L., Titelman, J., Båmstedt, U., 2006. Links between jellyfish and microbes in a jellyfish dominated fjord. Mar. Ecol. Prog. Ser. 325, 29–42. https://doi.org/10.3354/MEPS325029.

Rodrigues, S.M., Elliott, M., Almeida, C.M.R., Ramos, S., 2021. Microplastics and plankton: knowledge from laboratory and field studies to distinguish contamination from pollution. J. Hazard. Mater. 417, 126057 https://doi.org/10.1016/J.JHAZMAT.2021.126057.

Rodríguez-Torres, R., Almeda, R., Kristiansen, M., Rist, S., Winding, M.S., Nielsen, T.G., 2020. Ingestion and impact of microplastics on arctic calanus copepods. Aquat. Toxicol. 228, 105631 https://doi.org/10.1016/J.AQUATOX.2020.105631.

Romera-Castillo, C., Pinto, M., Langer, T.M., Álvarez-Salgado, X.A., Herndl, G.J., 2018. Dissolved organic carbon leaching from plastics stimulates microbial activity in the ocean. Nat. Commun. 9, 1–7. https://doi.org/10.1038/s41467-018-03798-5.

Rothe, D., 2020. Jellyfish encounters: science, technology and security in the Anthropocene Ocean. Crit. Stud. Secur. 8, 145–159. https://doi.org/10.1080/21624887.2020.1815478.

Rudd, M.A., 2014. Scientists' perspectives on global ocean research priorities. Front. Mar. Sci. 1 https://doi.org/10.3389/FMARS.2014.00036/FULL.

Santana-Viera, S., Montesdeoca-Esponda, S., Guedes-Alonso, R., Sosa-Ferrera, Z., Santana-Rodríguez, J.J., 2021. Organic pollutants adsorbed on microplastics: analytical methodologies and occurrence in oceans. Trends Environ. Anal. Chem. 29, e00114 https://doi.org/10.1016/J.TEAC.2021.E00114.

Setälä, O., Fleming-Lehtinen, V., Lehtiniemi, M., 2014. Ingestion and transfer of microplastics in the planktonic food web. Environ. Pollut. 185, 77–83. https://doi.org/10.1016/J.ENVPOL.2013.10.013.

Song, X., Lyu, M., Zhang, X., Ruthensteiner, B., Ahn, I.-Y., Pastorino, G., Wang, Y., Gu, Y., Ta, K., Sun, J., Liu, X., Han, J., Ke, C., Peng, X., 2021. Large plastic debris DuMP: new

biodiversity hot spots emerging on the Deep-Sea floor. Environ. Sci. Technol. Lett. 8, 148–154. https://doi.org/10.1021/ACS.ESTLETT.0C00967.

Sucharitakul, P., Pitt, K.A., Welsh, D.T., 2020. Limited ingestion, rapid egestion and no detectable impacts of microbeads on the moon jellyfishAurelia aurita. Mar. Pollut. Bull. 156, 111208 https://doi.org/10.1016/j.marpolbul.2020.111208.

Sun, X., Li, Q., Zhu, M., Liang, J., Zheng, S., Zhao, Y., 2017. Ingestion of microplastics by natural zooplankton groups in the northern South China Sea. Mar. Pollut. Bull. 115, 217–224. https://doi.org/10.1016/j.marpolbul.2016.12.004.

Sweetman, A.K., Chapman, A., 2015. First assessment of flux rates of jellyfish carcasses (jelly-falls) to the benthos reveals the importance of gelatinous material for biological C-cycling in jellyfish-dominated ecosystems. Front. Mar. Sci. 2 https://doi.org/10.3389/fmars.2015.00047.

Taha, Z.D., Md Amin, R., Anuar, S.T., Nasser, A.A.A., Sohaimi, E.S., 2021. Microplastics in seawater and zooplankton: a case study from Terengganu estuary and offshore watersMalaysia. Sci. Total Environ. 786, 147466 https://doi.org/10.1016/J.SCITOTENV.2021.147466.

Takao, M., Okawachi, H., Uye, S.I., Okawachi, H., 2014. Natural predators of polyps of Aurelia aurita s.L. (Cnidaria: scyphozoa: Semaeostomeae) and their predation rates. Plankt. Benthos Res. 9, 105–113. https://doi.org/10.3800/pbr.9.105.

Tinta, T., Kogovšek, T., Malej, A., Turk, V., 2012. Jellyfish modulate bacterial dynamic and community structure. PLoS One 7, e39274. https://doi.org/10.1371/JOURNAL.PONE.0039274.

Ugwu, K., Herrera, A., Gómez, M., 2021. Microplastics in marine biota: a review. Mar. Pollut. Bull. 169, 112540.

Archdale, M.V., Yamanouchi, T., Anraku, K., 2002. Feeding behavior of Aurelia aurita towards artemia and artificial pellets. Jap. J. Tast. smell Res. 9, 747–750. https://doi.org/10.1016/0022-0981(88)90246-8.

Visbeck, M., 2018. Ocean science research is key for a sustainable future. Nat. Commun. 91 (9), 1–4. https://doi.org/10.1038/s41467-018-03158-3, 2018.

Vroom, R.J.E., Koelmans, A.A., Besseling, E., Halsband, C., 2017. Aging of microplastics promotes their ingestion by marine zooplankton. Environ. Pollut. 231, 987–996. https://doi.org/10.1016/J.ENVPOL.2017.08.088.

Wright, S.L., ThoMPon, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178, 483–492. https://doi.org/10.1016/J.ENVPOL.2013.02.031.

Zheng, S., Zhao, Y., Liangwei, W., Liang, J., Liu, T., Zhu, M., Li, Q., Sun, X., 2020. Characteristics of microplastics ingested by zooplankton from the Bohai SeaChina. Sci. Total Environ. 713, 136357 https://doi.org/10.1016/J.SCITOTENV.2019.136357.

Zhou, R., Lu, G., Yan, Z., Jiang, R., Bao, X., Lu, P., 2020. A review of the influences of microplastics on toxicity and transgenerational effects of pharmaceutical and personal care products in aquatic environment. Sci. Total Environ. 732, 139222 https://doi.org/10.1016/J.SCITOTENV.2020.139222.

Ziveri, P., 2013. Plastic debris and jellyfish swarms spotted in Mediterranean. UAB MedSeA (MEDiterranean Sea Acidification in a changing climate) Project note.