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Evaluating the performance of the 'Seabin' – a fixed point mechanical litter removal device for sheltered waters

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Abstract

Mechanical interventions are increasingly suggested as a means of removing plastic litter from aquatic environments; their performance is rarely evaluated, but such information is critical to inform policy interventions such as those required to facilitate UNEA 5.2. The Seabin, a fixed-point device designed to remove floating litter in sheltered waters was examined in an urban tidal marina (Southwest UK). It captured on average 58 litter items/day; chiefly plastic pellets, polystyrene balls and plastic fragments. It also captured one marine organism for every 3.6 items of litter, or 13 organisms/day, half of which were dead upon retrieval. The rate of litter capture was inferior to manual cleaning conducted with nets from pontoons or vessels. Hence, in this location the Seabin was of minimal benefit in terms of marine litter removal and resulted in mortality of marine organisms. The presence of such devices could also precipitate false optimism and reliance on technological solutions, rather than systemic changes in our production, use, and disposal of plastics.

Key words

Plastic pollution, Marine Litter, Mechanical cleaning device, Seabin, Techno-optimism; Policy intervention

1. Introduction

Plastic litter is recognised as a major threat to the environment resulting in ecological, economic and social harm. Commonly reported biological impacts include entanglement (Laist, 1997; Campani *et al.*, 2013; Provencher *et al.*, 2014; Duncan *et al.*, 2017), ingestion (Denuncio *et al.*, 2011; Wilcox *et al*., 2015; Nicolau *et al.*, 2016; Ryan, 2016), and providing a vector for non-native organisms (Zettler *et al.,* 2013; Rech *et al*., 2018) and contaminants (Caruso, 2019). Furthermore, the economic value of the marine environment is dictated by its quality. The occurrence of litter can reduce the environmental value and thus economic benefit or increase costs associated with maintenance. The presence of marine litter can also deter tourists, reducing revenue and consequently weakening coastal economies (Krelling *et al*., 2017). Litter on beaches has further been shown to reduce or undermine the restorative effect or well-being associated with visiting places like beauty spots (Beaumont *et al.*, 2019). Consequently, mechanical solutions designed to tackle marine litter are increasingly being promoted and deployed as part of the solution. However, few of these devices have been evaluated in terms of their efficacy; such data is urgently needed in order to guide interventions to potentially stem the flow of plastic to the natural environment.

Mass production of plastics commenced in the 1950s (Barnes *et al.*, 2009; Thompson *et al.*, 2009) having become an integral part of modern society. As of 2020, global production of plastic is estimated at 370 million metric tonnes a year (Plastics Europe, 2020). In turn, due to inadequate waste disposal infrastructure (Sheavly and Register, 2007; Kershaw *et al.,* 2011; Vegter *et al.*, 2014; Leeuwen and Koop, 2017), a 'throw away' ethos around the use of plastics, and a lack of consideration for end-of-life disposal at the design stage, it has become increasingly prevalent as litter in the natural environment (Rillig, 2012; Geyer, *et al*., 2017; de Souza *et al.*, 2018; Bolontz *et al.,* 2019).

Marine litter originates from a wide range of sources both terrestrial and marine, and manifests in diverse shapes and sizes from microscopic fragments to macro and mega waste such as fishing nets and boat hulls. The presence of plastic litter in the marine environment exists not only in coastal waters (Ogi *et al.,* 1999; Moore *et al.*, 2002) but extends to the open oceans (Eriksen *et al.*, 2014) and the seafloor (Moore, 2008; Woodall *et al.*, 2014; Courtene-Jones *et al.*, 2017; Villarrubia-Gómez *et al*., 2018).

A substantial portion of marine litter is thought to originate from coastal populations, particularly during wind and rainfall events (Coe and Rogers, 2012), which can act as transport mechanisms. This is partly attributable to the buoyant properties of plastic which enable litter to be dispersed over large distances due to wind and surface currents, and its durability which permits its persistence either in a whole or fragmented form (Derraik, 2002; Kukulka *et al.*, 2012; Reisser *et al.*, 2013; Eriksen *et al.*, 2014; Zbyszewski *et al*., 2014; Wright and Kelly, 2017). For example, an increased abundance of marine litter has been shown to correlate with intense precipitation events (Moore *et al.*, 2002; Carson *et al.*, 2013; Cheung *et al.*, 2016; Axelsson and Sebille *et al.*, 2017) and seasonal rains (Araujo and Costa, 2007; Shimizu *et al.*, 2008; Lima *et al*., 2014; Cheung *et al.*, 2016). While a study conducted on sub-arctic islands reported accumulation rates of plastic litter stranded on beaches to be primarily dependant on wind (Eriksson *et al.*, 2013).

Managing the flow of litter to marine waters is becoming increasingly pertinent. It has been estimated that in the UK alone local authorities spend an average ~£6000 per km per year (Mouat *et al*., 2010) on cleaning ports, harbours and areas of touristic importance; generating a growing interest in the use of mechanical devices to facilitate clean up. Various legislative and mechanical solutions for marine litter are being implemented globally, however, the design and use of these cleaning devices remains in its infancy (Kasparavičiūtė *et al.*, 2018; Gong and Trajano, 2019).
One example is a 100 m long barrier-like system developed by The Ocean Clean-up to capture floating waste in the open oceans (The Ocean Cleanup, 2019). Other devices include 'trash traps' installed in rivers to capture urban litter (NOAA, 2017), and 'Trash wheels' installed in estuarine systems, utilising conveyor belts to transport and remove litter from aquatic environments (National Geographic, 2017). Further devices include Aqua-drones, autonomous vehicles that actively collect floating litter in sheltered environments such as marinas and ports (European Commission, 2018).

Another example is the Seabin which was developed by the Australian company Seabin Pty Ltd., founded in 2015, with the goal of developing a localised solution to marine litter in urban marine areas. Clean-ups of harbours and marinas are generally conducted for two reasons; aesthetically, the marina users do not want to see floating litter and, when stationary, blockage of cooling water intake by litter could lead to costly damage to the vessel. To date more than 860 Seabins have been installed globally and are reported to have captured over 3,250,000 kg of litter. The Seabin is a "trash skimmer" created for calm sheltered environments, such as marinas, ports, and yacht clubs. The device is designed to intercept floating litter from the micro to macro range as well as contaminated organic material (Seabinproject, 2022). The Seabin is designed to continuously suck water inwards using a submersible pump which is filtered through a ~2 x 5 mm triangular mesh bag, displacing 25 L hr^{-1} (Seabinproject, 2022). The cleaned water is then pumped back into the surrounding area leaving the litter in the catch bag (Seabin project, 2022), see Figure 1.

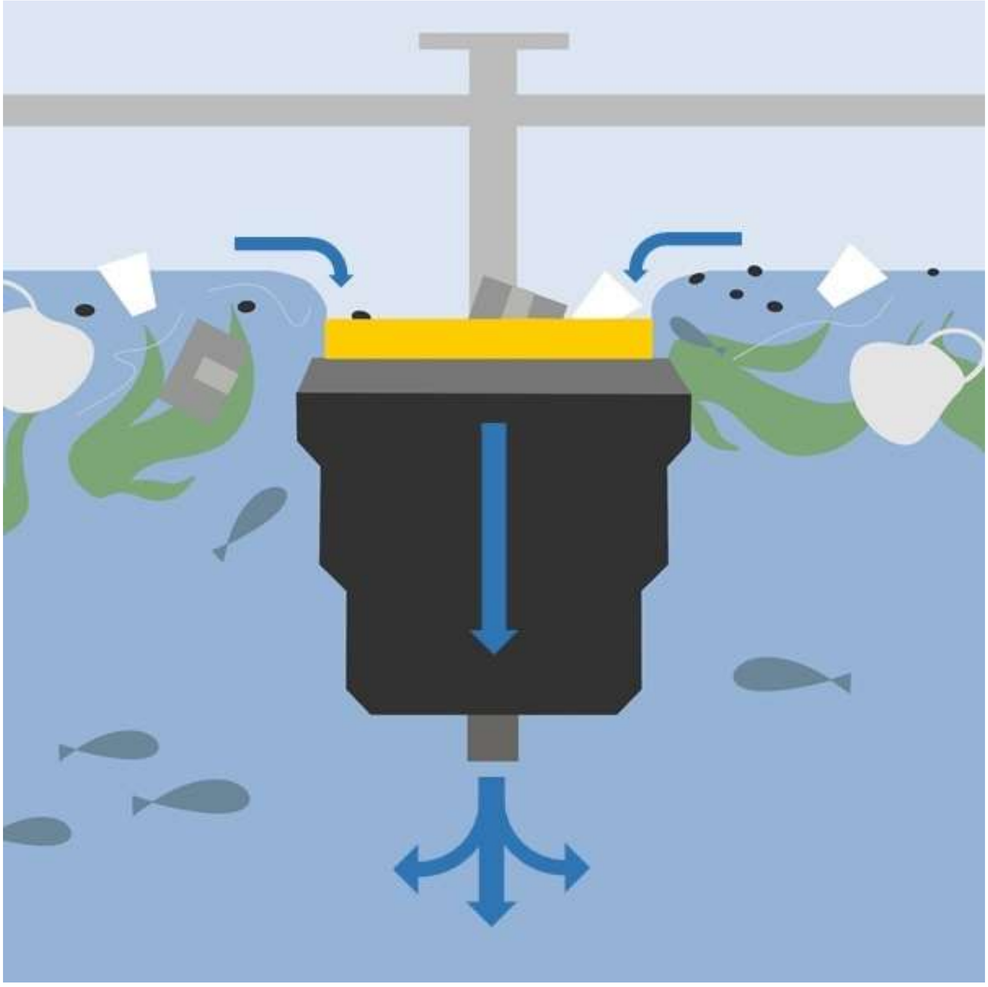

Figure 1. Illustration of Seabin and mechanism. Image: Authors own.

Given their increasing use and lack of formal evaluation, the focus of this study was to evaluate the performance of a Seabin which was purchased by, and evaluated on behalf of Plymouth City Council, the unitary authority for the region in which the Seabin was installed.

1.1 Aims and objectives.

Sampling was conducted around four principal aims. The first to establish whether Seabins are selective in the type and size of litter they capture, indicating the overall suitability of the device in environments they are designed to operate. The second to establish if litter retention decreases with the period of deployment, for example as a consequence of clogging or satiation of the device, and the third to examine if the performance of Seabins are affected by weather conditions. Finally, the study evaluated the extent to which the deployment site, Queen Anne's Battery marina, was cleaner due to the presence of a Seabin, establishing if the devices presence alleviates the need for other cleaning approaches and associated resources.

2. Methods:

2.1. Study Site

The Seabin was installed at 50.364233 and -4.131958 at Queen Anne's Battery marina between 21st April and 26th June 2021, see Figure 2. Queen Anne's Battery marina sits within Plymouth Sound (Southwest UK) which is influenced by a semi-diurnal tide and temperate tidal ecosystems as well as heavy marine traffic and commercial and recreational boating activity (Langston *et al.*, 2003) being a site of six marinas and western Europe's largest naval base. The Seabin was placed in an area where floating marine litter congregated and in a location that did not interfere with the marinas boating activities. A seaward facing wall and pontoon either side of the device protected it against strong wave action.

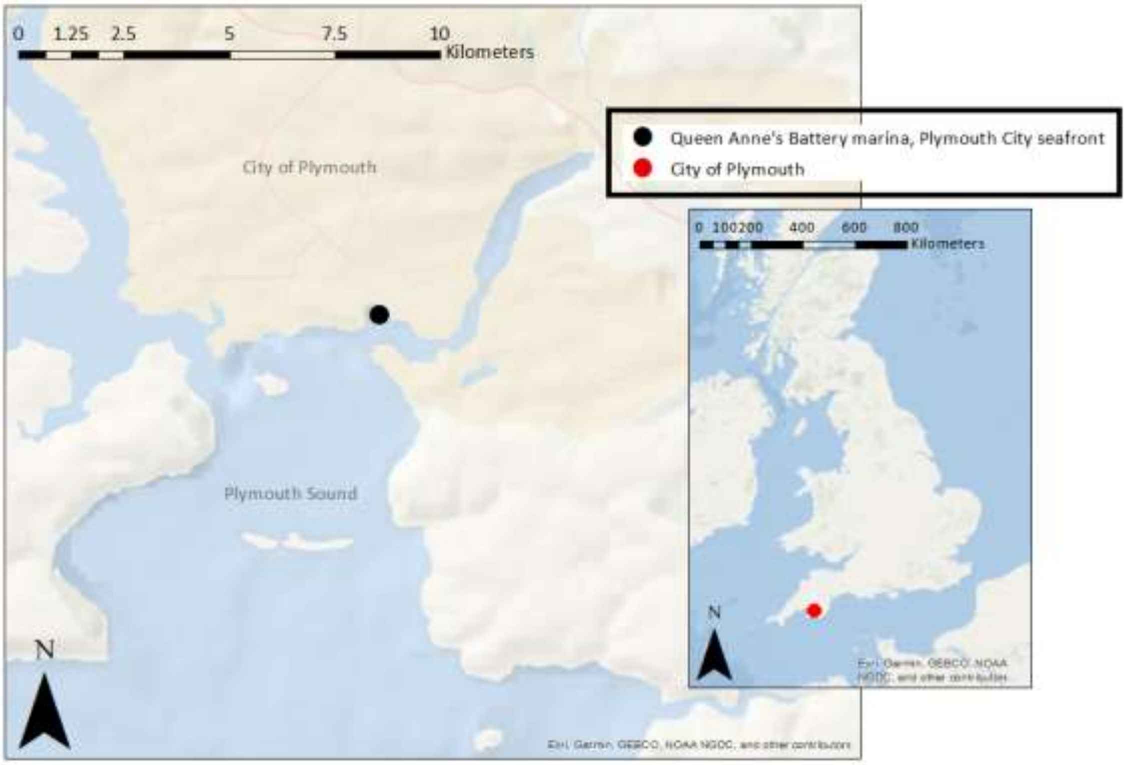

Figure 2. Map showing the location of Queen Anne's Battery Marina within Plymouth Sound and the UK.

2.2. Seabin selectivity and performance during variable weather conditions

In order to establish if the Seabin was selective in the litter it was capturing, data on litter size and composition retained by the device was collected over various durations of operation; 6, 24, 48, and 72 hours. Litter collected by the Seabin was compared with the litter size and composition present in the surrounding marina, determined by manual surface trawls. To ensure manual cleaning did not reduce the availability of litter to the Seabin, following each manual trawl, a period of at least 24 hours (two tidal exchanges, ~5 m on a spring tide and ~2 on a neap tide) was allowed prior to any collection of data from the Seabin.

For each operational period, data was collected on five replicate occasions. After each deployment, the contents of the catch bag were emptied, thoroughly rinsed, and sorted by hand. Litter was measured using a ruler or tape measure to the nearest millimetre across the longest length. Litter items with high flexibility were straightened to maximum length without additional tensional force.

Abundance of each litter item was recorded and categorized according to the OSPAR guidelines for monitoring marine litter (OSPAR, 2020). All litter was then placed in a drying oven for a minimum of 48 hours to allow dry mass to be recorded to the nearest 0.01g.

The size and composition of litter present in the surrounding marina was also examined across five manual trawls, conducted using a 330µm mesh handheld plankton net (26 cm ø) which was towed at a constant speed along an adjacent pontoon for 5 minutes. This was conducted at regular intervals during the 8-week installation of the Seabin. The location for the manual trawls was chosen in order to ensure litter accumulation and litter composition in this area was comparable to the location of the Seabin.

Early in the study, it was observed that marine organisms were also being captured by the device, therefore any organisms found in the catch bag at the time of collection were identified where possible to family level and their abundance and any fatalities were recorded. All organisms collected by the Seabin were returned to the marina. Organic matter collected by the Seabin was weighed, wet weight (w.w.), and also returned to the marina. The Seabin catchment bag was rinsed thoroughly with seawater from a high-pressure hose between each deployment.

Hydrological data and meteorological conditions were also recorded daily. Wind speed (mph), rainfall (mm), and temperature (°C) was sourced via Bears by the Sea weather station (located in Plymouth 6.5 km from the Seabin). Wind speeds were categorised according to the Beaufort scale, and rainfall according to the America Meteorological Society. Tide data was harnessed from Tide Times UK recorded at Devonport, 3.5 km from the Seabin.

A pilot deployment using the same device at the same location was conducted between the 4th of April and 25th of July 2019, and used to qualitatively compare data on litter retention between different years giving generality to the results. During the pilot deployment the device was emptied at uniform intervals (24 hours, Monday – Friday).

2.3. The influence of Seabin devices on floating marine litter vs. other cleaning approaches

Between September to November 2020 four independent Seabin users (UK), were asked a series of questions regarding their experience of the device. The questions were centred around the topics of; the extent of the litter problem in their marina, the selection of the Seabin over other cleaning devices or approaches, placement choice, operational regimes (emptying and cleaning), litter retention, and operational issues (if any).

Similarly, staff at four marinas in Plymouth were asked a series of questions regarding their cleaning operations in order to draw further comparisons between mechanical devices and conventional manual cleaning approaches. The questions focused on the method, frequency and extent of cleaning operations, the size, composition, and extent of litter retained, and the cost of such operations. An approximate cost of these manual cleans were assessed and based upon the frequency, duration and litter retention (assuming a standard salary rate, depreciation, and age of vessels used and estimates of litter removed if accurate record not kept) compared with the Seabin.

Lastly, an estimate was made as to the number of Seabin devices that would be required to keep Queen Anne's Battery marina 'free' from floating litter, based upon litter density in the marina and the litter removal rate recorded by the Seabin.

2.4. Data Analysis

Statistical analysis was performed with R Studio (version 3.6.2) (R Core Team 2021) and Minitab (V18). Levene's test was conducted to test for homogeneity of variances. Raw data that was shown to be non-homogenous was transformed by square root and subsequently logged transformed if still shown to be non-homogenous. A one-way analysis of variance (ANOVA) followed by a Tukey's HSD was used to test the difference between; mass of litter captured per operation period, abundance of items captured per operation period, abundance of litter by material type, abundance of litter by item type, and organism mortality per operation period. The statistical conclusion was determined according to the comparison of p-value under 95 % of confidence intervals (p=0.05). Data that failed the homogeneity assumptions, were analysed for differences using the nonparametric Kruskal-Wallis test. The mass of plastic and non-plastic materials collected from the Seabin, as well as the mass of plastic and non-plastic materials collected during the manual trawls were compared using a T-Test. Prior to analysis, data were tested for the assumptions of normality and homogeneity of variance using Shapiro-Wilk test and Levene's test, respectively. Data that failed the above assumptions were compared using the Mann-Whitney U test.

The interaction of wind speed, rainfall, air temperature, and tidal state on the retention of marine litter by the Seabin were examined in Minitab (V.18) using a linear regression between the dependant variable (marine litter) and independent variable (meteorological and hydrological parameters).

3.0. Results

3.1. Seabin selectivity and performance during variable weather conditions

Litter retained by the Seabin was found to be varied in composition and size. A total of 1828 items or 0.18 kg was retained during 750 hours of operation in 2021, equivalent to 58 items or 0.0059 kg d^{-1} per 24 hours.

A Kruskal-Wallis rank sum test showed a significant difference in abundance between various types of litter collected by the Seabin ($H_{(65.049)}$=28, p= <0.01). The most abundant items were consistently; polystyrene balls (n=701), biobeads (n=524), and plastic pieces between 0 and 2.5 cm (n=192), See Figure 3.

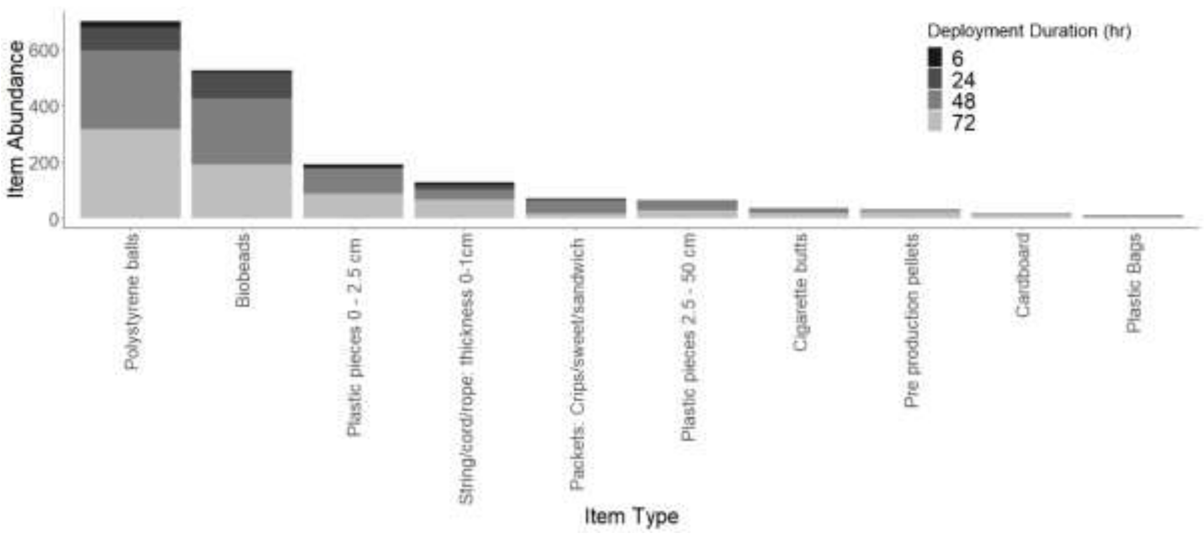

Figure 3. Total abundance of the top 10 most frequently collected items by the Seabin, by operation duration.

A significantly greater abundance of plastics accounting for 98.5 % and 99.5 % of all items, compared to paper, cardboard, wood and metal, were collected by both the Seabin (One-way ANOVA, $F_{3,12}$=30.12, p=<0.05; Fig. 4A) and the manual trawls (One-way ANOVA, $F_{2,12}$=118.6, p=<0.01; Fig. 4B). Likewise, a Mann-Whitney U Test showed there to be a significant difference between the mass of plastic compared to non-plastic items collected by both the Seabin (W = 51.5, p=<0.001) and manual trawls (t = -2.4932, df = 7.8259, p=< 0.05). Plastic accounted for 94 % of the mass of items within the Seabin and 82 % of the mass of items collected during manual trawls.

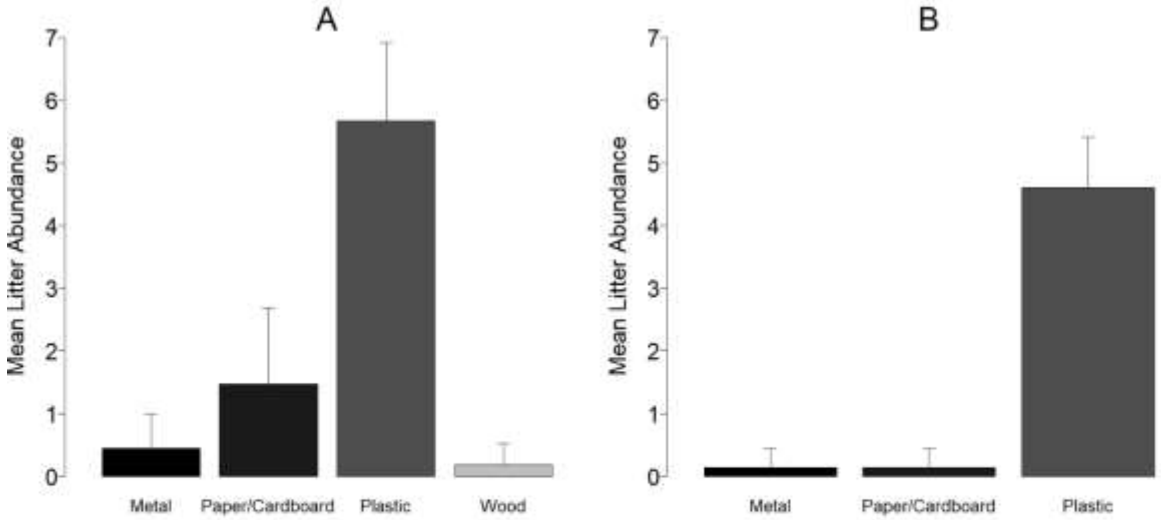

Figure 4: Abundance of items of different material types collected by A) the Seabin device during a total of 750 hours of operation and B) from five manual trawls each lasting approximately 5 minutes.

The pilot deployment in 2019 found a similar retention rate of 40.2 items d^{-1} (3501 items over 87 days in operation) to the 2021 deployment. Likewise, the most commonly retained items by the catch bag in 2019 were biobeads, fragments, and polystyrene balls, contributing more than 86 % of the total items recovered.

Manual cleaning of the marina with the use of a plankton net collected a total of 619 items (116.1 g d.w.) across 5 manual cleans, on average capturing 123.8 items ± 80.4 ($\bar{x}$ ±σ) or 19.3 g ± 16.6 g ($\bar{x}$ ±σ) per clean. The most abundant items were; plastic fragments 0 - 2.5 cm (n=297), plastic pellets (n=225), followed by plastic pieces 2.5 - 50 cm (n=27), and food packets (i.e. crisps/sweet/sandwich) (n=10). The average item collected by the Seabin measured 1.7 cm at its longest length, the smallest 0.1 cm, and the largest measuring 90 cm. The most common sized item was 0.43 cm. Whereas the average item collected from manual cleans measured 1.8 cm, the smallest 0.2 and the largest 160.5 cm. Likewise, the most common size item was 0.43 cm.

3.2 Retention of marine life

In total 505 marine organisms were retained by the Seabin over 750 hours of operation; 283, 187, 24 and 11 individuals collected during replicate 72, 48, 24 and 6 hour operation durations respectively. Marine organisms were captured at a rate of 13 organisms/24 hrs ± 16.7 ($\bar{x}$±σ), or 1 individual for every 3.6 items of litter. Of the 505 organisms captured the majority (68 %) were *Ammodytes tobianus* (Lesser sandeel), 10.5 % were *Crangon crangon* (Brown shrimp), 5.94 % unidentified species from the order Isopoda and 4.75 % *Carcinas maenas* (Common shore crab). The largest individual organism retained was *Spinachia spinachia* (Fifteen-spined stickleback) which was recorded on two occasions. Other organisms infrequently recorded within the Seabin were identified within the Orders Amphipoda; Families, Glyceridae (Bloodworms) and Species, *Ascidiella aspersam* (Fluted Sea Squirt) and *Chrysaora hysoscella* (Compass Jellyfish). Additionally, unidentified juvenile fishes accounted for 3.16 % of captured organisms. The pilot study again reported similar findings in terms of retention of marine life; *A. tobianus* being the most commonly captured individuals followed by Isopoda and Crustacea. The rate of capture was however lower at 5.9 ± 2.9 ($\bar{x}$±σ), equating to 1 individual for every 6.8 items of litter.

Of the organisms retained by the Seabin, 37 % were alive upon retrieval of the catch bag, 63 % were deceased. A one-way ANOVA showed a significant difference in the total number of organisms collected with varying operation durations ($F_{(3,26)}$=3.324, p=0.0352). The ratio of dead to alive individuals typically increased with operation period (Fig. 5), on average 11 % were deceased after 6 hours of operation, whereas 62 % were dead after 72 hours of deployment (Fig. 5). However, the difference in the number of dead and number of alive organisms collected by the Seabin across the four operational periods tested was not significant (A Wilcox Rank Sum).

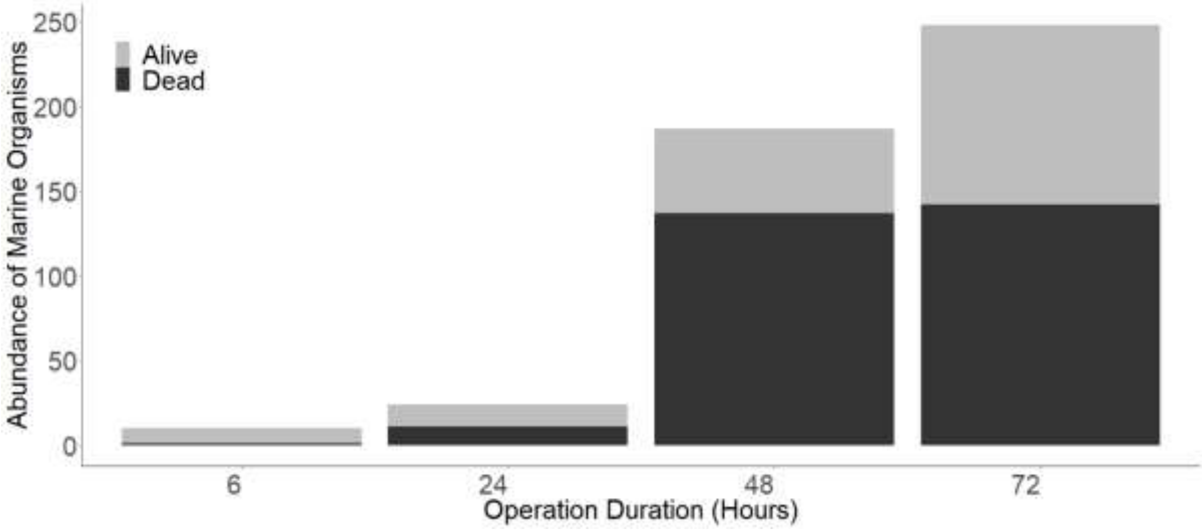

Figure 5: Abundance of marine macrobiota captured by the Seabin, shading indicating if organisms were dead or alive upon retrieval from the Seabin.

3.3 Litter retention with time

Both the average mass and average abundance of litter collected by the Seabin increased with operation time. On average 11 items or 0.71 g was collected over a 6-hour period, while 151 items or 19.37 grams were collected on average over 72 hours (Fig. 6A & B) but neither the mass or abundance of litter retained was found to be significant with changes in cleaning duration (One-way ANOVA, $F_{(3,16)}$=1.715, p=0.204, Fig. 4A and $F_{(3,16)}$=2.907, p=0.0668, Fig. 4B respectively).

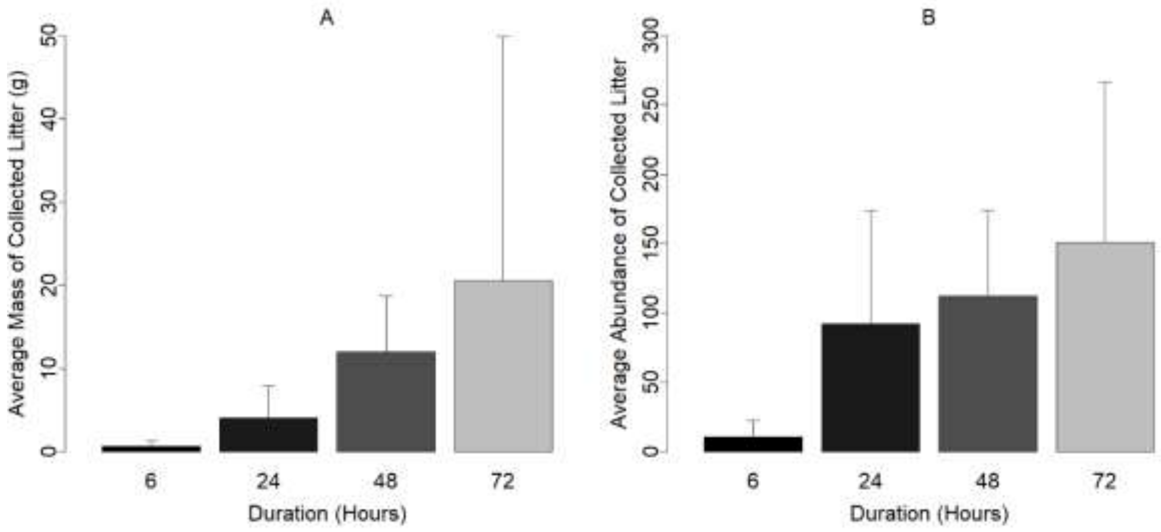

Figure 6: The average mass (B) and abundance (A) of litter collected by the Seabin with operation time.

Over the 8-week deployment a negative correlation was observed between the length of time the Seabin had been installed in the marina and the abundance of collected litter, when normalised to 24 hours operation period litter collection per unit of time decreased significantly from week 1 to week 8 ($F(1,19)=16.84$, p=<0.01).

Additionally, the amount of organic matter inside the catch bag overwhelmed the amount of litter captured, as observed in Figure 7A, typically accounting for the vast majority of the collected mass (between 0.5 and 6.65 kg w.w.). Among the commonly retained species were *Fucus vesiculosus* (Bladder wrack), *Fucus spiralis* (Spiral wrack), *Himanthalia elongate* (Thong Weed), *Fucus serratus*, (Serrated Wrack), and *Ulva lactua* (Sea lettuce). The collection of organic matter was also observed during manual trawls.

3.4 Seabin function in variable weather conditions

During operation periods, gust wind speeds ranged between 13 and 43 mph. Litter retention by the Seabin, both abundance and mass, increased with increasing wind speeds, but was not significant (p=>0.05, F - 1.29 and p=1.54, F = 2.21 respectively). Ambient air temperature ranged between 10 and 26 ºC during operational periods. There was a significant negative correlation between temperature and the abundance of floating marine litter captured (p=<0.01, F = 7.49). A similar trend between temperature and the mass of litter retained by the Seabin was observed (p=>0.05, F = 2.94) but was not significant.

Daily rainfall varied between 0 and 20.8 mm d^{-1} and tide height between 4.09 and 5.7 m during operational periods. No correlation was observed between rainfall and the abundance or mass of marine litter captured (p=>0.05, F - 0.01 and p=>0.05, F = 0.36 respectively). A negative correlation was observed between tide height and litter abundance (p=>0.05, F = 2.84) while no correlation was observed between tide height and mass of litter collected (p=>0.05, F = 0.00).

3.5. The influence of Seabin devices on floating marine litter vs. other cleaning approaches

Litter density in Queen Anne's Battery marina was estimated between 1.4 – 6.6 items m^2 (and assumed to be uniform) based upon the extent of litter collected during manual trawls which were conducted over a set distance. Litter extent was then scaled to the approximate area of Queen

Anne's Battery marina (25,000 m^2). This was coupled with the daily average number of items removed from the marina by the Seabin, (58 items) to give an approximate number of Seabins required to keep Queen Anne's Battery marina 'free' from floating litter, estimated in excess of 500 devices.

3.5.1. End users of Seabins.

Surveys of other users revealed that in two of the four marinas, no cleaning occurred prior to Seabin instillation. All other users, including the inland river system user, employed manual cleaning. In each instance the Seabin was placed in areas of floating litter accumulation, but placement was also dictated by minimising interference with boating activities. Reasons for purchase included a desire to protect the environment, being gifted a device, and to alleviate time required to conduct manual cleaning. The frequency at which users emptied the Seabin was comparable to our experimental study, every 1 - 2 days. A hose was the most common cleaning method, typically undertaken every few weeks.

The mass of litter retained was not formally recorded by any user, but estimations in the marinas were consistently in the order of grams of litter per day, with the operator in the river system reporting ~1 kg per day. No formal record of the composition of litter was kept by any users, but the most commonly retained items were reported to be plastic pellets, polystyrene, cigarette butts, plastic fragments, food wrappers, drinks bottles and bottle tops. Users reported that collected litter typically reflected what was present in the surrounding marina, one noting however that the Seabin would not capture large items. No users reported any change in performance during variable weather conditions.

Issues flagged by users included; personnel time required to maintain the device (empty and clean), outgoings of electricity and staff costs outweighing the benefits in terms of litter removal, and challenges in manually lifting the device in and out of the water. None of the users flagged capture of aquatic organisms as an issue. Of the users we spoke to half still had their Seabin in operation, the three devices removed from the water attributable to the issues raised above.

3.5.2. Manual cleaning efforts in Plymouth marinas

Of the four local marinas and ports consulted, 3 conducted cleans all year round, the remaining reliant on the flush of the tide to remove floating litter from the area. The frequency of cleans was variable (daily to monthly) or conducted on a 'as and when' basis. All marinas employ manual cleaning, operating from the docks or pontoons, and some frequently increase their reach with the use of a small vessel. The estimated mass of litter removed per clean was in the range of ~10 - 100 kg (estimated w.w.). The composition of litter collected typically included; organic matter (notably seaweed and wood), food and drink packaging (shop bought and takeaway), and fragmented plastic.

The approximate cost of operations varied amongst manual cleaning efforts and were comparable with the operation costs of the Seabin. However, due to the Seabins lower rate of litter retention (g/d compared to kg/d) it comes out consistently, by 2 to 3 orders of magnitude, more expensive (in £/kg removed) than manual operations.

4.0 Discussion

Our study showed the Seabin not to be selective in the litter it retains, capturing the most common items present in the surrounding area. Similarly, the size of items collected was largely comparable between the mechanical and manual approaches. They differed slightly where the manual clean recovered an item almost twice the size of the largest item found within the Seabin, the dimensions of the catch bag (~28 cm) likely limiting the upper size limit of items it can retain.

Conversely, the five manual trawls conducted at Queen Anne's Battery marina during the 8-week Seabin deployment collected an average of 123.8 items or 19.3 g per clean (5 minutes) whereas the Seabin on average captured the equivalent of 58 items, or 0.0059 g when scaled to a 24-hour operating period. Consequently, it can be concluded that despite the Seabin showing little material or item selectivity, it had a poor capture rate compared with the time required to collect comparable quantities via manual efforts. This is also in contrast with the Seabin website which estimates each device can capture an estimated '*1.4 tonnes of litter a year*' (Seabinproject, 2022). In the environment examined, our data showed the retention of a large number of marine organisms in addition to floating litter. It could be hypothesized that some species were attracted to the device to forage or to seek refuge. Previous studies have observed juvenile fish utilising structures in estuaries and ports as a nursery habitat (Duffy-Anderson *et al.*, 2003). Additionally, algal growth was observed around the rim of the device which increased the habitat complexity, consequently increasing food availability and shelter for refuge (McCoy and Bell, 1991; Di Franco *et al.*, 2021). Therefore, when the Seabin is switched on, organisms in close proximity risk being sucked into the device.

The majority of marine life (>60 %) retained were found to be dead upon retrieval of the Seabin catch bag. It can be speculated that some organisms were dead prior to their capture. However, our findings suggest some individuals entered the Seabin alive and died as a result of their capture. This was evident by the ratio of deceased to alive individuals typically increasing with operation time (Fig. 5). This could be attributable to being crushed by the surrounding material weight in the catch bag or a lack of oxygen. With a mortality of 88 % and 74 % respectively *A.tobianus* and *C. maenas* appear to have the lowest likelihood of survival. More resilient organisms captured appeared to be *C. crangon,* isopods and some juvenile fish species (excluding *A. tobianus*) with mortality rates of 19 % 24 % and 24 % respectively. Additionally, unless users of the device separate organic matter and organisms from the litter, those that do survive capture will likely die following disposal of the catch bag contents. Such separation was found to be time consuming as organisms are difficult to see Fig. 7A.

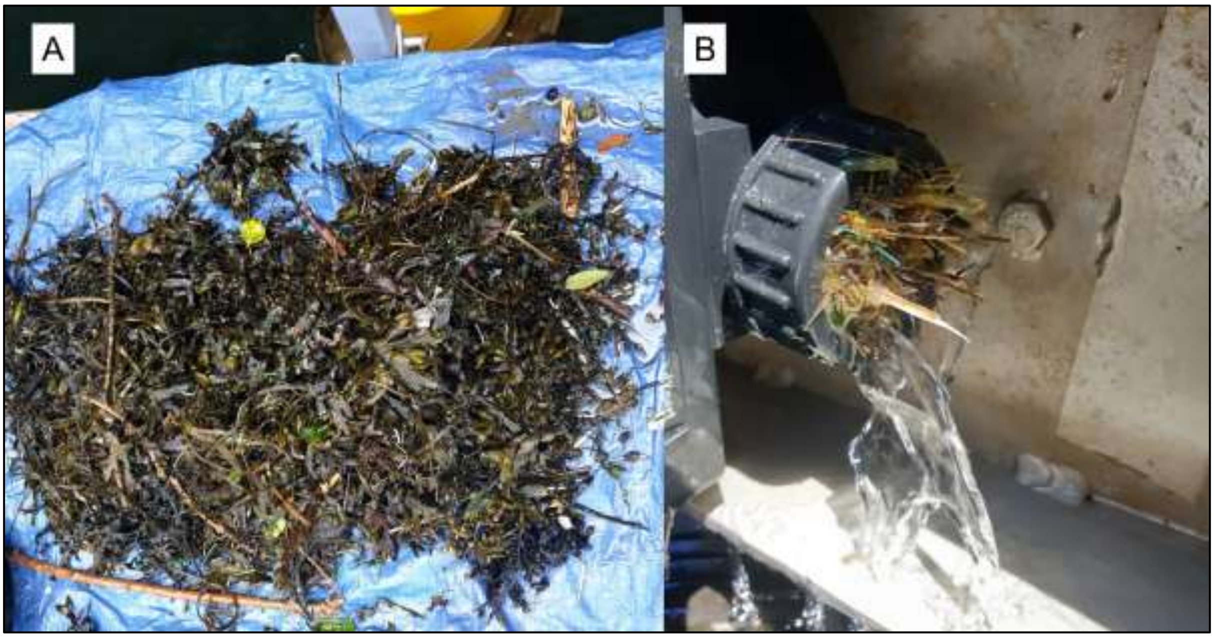

Figure 7: [A] showing the contents of the Seabin catch bag following a 72-hour deployment containing >100 *A. tobianus* tangled in organic matter and litter and [B] the build-up of such organic and inorganic material that resulted in a blockage in the pump system.

Of the different taxonomic groups recorded, the Seabin retained mostly pelagic, but also benthic individuals such as *C. maenas* and other organisms from the order Isopoda*.* While pelagic individuals reached the Seabin either by swimming or at the mercy of currents and tides, we can speculate that benthic species could have entered the Seabin via the pontoon and other marina infrastructure, or they were pumped into the Seabin once deceased. Appendages of species such as the *C. maenas* were occasionally found within the catch bag but only whole organisms were counted as bycatch. Sessile organisms, such as *A.aspersa*, may have entered the Seabin while attached to, or tangled in floating debris, after detaching from structures such as pontoons. It is worth noting that other non-selective technology-based approaches to marine litter will likely also suffer with problems relating to bycatch. Likewise, if waste collected during manual cleaning efforts is not separated, any live individuals will likely die upon disposal.

Without modifications to the device to allow for the escape of live organisms, cleaning the external structure of the Seabin in order to deter species seeking refuge or food and increasing the frequency at which the catch bag is emptied to improve the chances of survival of captured organisms would help mitigate the effects of bycatch. Thorough sorting of contents of the catch bag upon retrieval and return of live organisms to the water would also help reduce mortality rates.

In seasonal climates, temporal variations in species richness and abundance are observed in coastal waters (Gibson *et al*., 1993) attributable to breeding and growing seasons over the spring and summer period, leading to an abundance of juvenile fish. In most temperate regions, the growing season is followed by offshore migration in the late summer and autumn, resulting in a reduced density and species diversity (Gibson and Yoshiyama, 1999; Gibson *et al*., 1993). The deployment of the Seabin in this study therefore potentially coincided with a period of greater abundance and diversity of marine life. It could be hypothesised that during the autumn and winter seasons, the retention of marine life by the Seabin may be less extensive.

4.2 Litter retention with deployment duration

On one occasion the Seabin was removed from the water due poor filtration speeds attributed to a blockage in the pump system. In order to reach the clogged part of the pump, which is situated ~1.5m underwater and therefore inaccessible from the surface, the device was removed from the water requiring three people to manually haul the device onto the pontoon. The pump was clogged by an abundance of organic and inorganic material (See Figure 7B) that passed through the mesh of the catch bag and were resultantly sucked into the pump system.

In the absence of regular and thorough cleaning of the Seabin i.e. removal of the device from the water, our results showed there to be a significant decrease in the retention of litter over time. Removal and thorough cleaning is advised to take place on a biweekly basis, placing quite demanding requirements in terms of staff time to maintain the device. In addition, sorting litter from organic litter and marine life was found to be a time intensive process. This aligns with other Seabin users who raised the issues of costs in personnel time and challenges in cleaning the device. If these processes were overlooked, the function of the Seabin declines, and upon discarding the contents of the catch bag any surviving marine life would die upon disposal.

4.3. Seabin function in variable weather conditions

Although the relationship between litter retention and wind speed was not significant, a positive correlation suggested a greater litter retention with higher wind speeds. The relationship between litter retention and decreasing temperatures was found to be significant, possibly attributable to lower temperatures typically coinciding with more turbulent weather events (high winds and rainfall). We suggest that climatic conditions did not affect the performance of the Seabin itself, but likely increase the delivery of litter to the device and consequently the encounter rate. It could also be hypothesised that as a result of the seaward facing wall at our selected study site, the influence of wind and rainfall may somewhat mitigate litter movement from the south and west. That said, by design these devices are intended to be located in sheltered waters so some hindrance of litter delivery by pontoons and similar structures would be observed in many locations.

4.4. Seabin influence on floating marine litter in the surrounding environment

The device location and maintenance regimes of the other users consulted were comparable with findings from Queen Anne's Battery, likewise were the rates of litter retention and commonly flagged issues with the device, most notably the trade-off between time and resources required to operate and maintain the device versus litter removal. When coupled with the cost per kg of litter removed it indicates manual efforts to be favourable. These findings give greater confidence and generality to the results recorded in this study.

Furthermore, with such a high number of devices estimated to be required to keep Queen Anne's Battery marina free from floating litter, capture of marine organisms, maintenance costs, and energy use would also scale considerably.

4.5 Techno-optimism - can clean-up devices impact human perceptions and littering behaviour?

Technological innovations, such as the Seabin have a part to play in reducing litter, complementing existing clean-up efforts particularly in coastal environments. Furthermore, visible and innovative means of addressing the marine litter problem can raise awareness and create momentum locally or on a wider scale (Peytavin, 2021). Although physical interventions such as the Seabin are unlikely to replace community-led clean-up initiatives, at least in their current state of development, they can shape people's risk perceptions around the issue of marine litter. However, excessive reliance on technological innovation and advancements in solving environmental problems, or 'techno-optimism' (Barry, 2012), can also undermine motivation for mitigating actions (Gardezi and Arbuckle, 2018). At an extreme, techno-optimism may alleviate one's personal sense of responsibility for waste and litter, by aiding the illusion that technology is 'taking care of the problem' where littering could be seen as more acceptable in the presence of clean-up devices. Evidence on the psychological impacts of clean-up devices is lacking at present, but such unintended consequences are possible.

Nevertheless, given that technological clean-up solutions to marine litter are yet to reach widespread implementation, techno-optimism is unlikely to have resulted in a widespread shift in behaviour, but may gain prevalence if the use of clean-up technology increases. Furthermore, manual community-led clean-ups do not only recover visible litter, but they also render various wellbeing benefits (both physical and psychological) to participating individuals (Wyles *et al.*, 2017).

5.0. Conclusion

This study provides the first formal independent evaluation of the performance of the Seabin device. While the Seabin was largely effective in capturing the diversity of floating litter

present in the surrounding marina, in the environment examined, the
rate of litter capture was substantially inferior to manual cleaning. When considered in conjunction with the unintentional retention
of marine organisms and associated maintenance requirements it indicates
manual cleaning efforts to be a more advantageous approach than the Seabin in its current state of development. A pilot deployment and consultations with other users of the devices help and give generality to our findings. Further evaluations of mechanical devices designed to intercept plastic litter flow in coastal environments are necessary to help indicate the efficacy of mechanical cleaning solutions for the removal of litter from the marine environment and inform key policy interventions such as the UNEA 5.2 Plastics Treaty.

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References

Barnes, D. (2009) ‘Accumulation and fragmentation of plastic debris in global environments’, *Philosophical Transactions of the Royal Society B: Biological Sciences*. The Royal Society, 364(1526), p. 1985. doi: 10.1098/RSTB.2008.0205.

Beaumont, N., Aanesen, M., Austen, M., Börger, T., Clark, J., Cole, M., Hooper, T., Lindeque, P., Pascoe, C. and Wyles, K. (2019) ‘Global ecological, social and economic impacts of marine plastic’, *Marine Pollution Bulletin*. Pergamon, 142, pp. 189–195. doi: 10.1016/J.MARPOLBUL.2019.03.022.

Campani, T., Baini, M., Giannetti, M., Cancelli, F., Mancusi, C., Serena, F., Marsili, L., Casini, S. Fossi, M. (2013) ‘Presence of plastic debris in loggerhead turtle stranded along the Tuscany coasts of the Pelagos Sanctuary for Mediterranean Marine Mammals (Italy)’. doi: 10.1016/j.marpolbul.2013.06.053.

Carson, H., Lamson, M., Nakashima, D., Toloumu, D., Hafner, J., Maximenko, N., McDermid, K. (2013) ‘Tracking the sources and sinks of local marine debris in Hawaii’, *Marine Environmental Research*. Elsevier, 84, pp. 76–83. doi: 10.1016/J.MARENVRES.2012.12.002.

Caruso, G. (2019) ‘Microplastics as vectors of contaminants’, *Marine Pollution Bulletin*. Pergamon, 146, pp. 921–924. doi: 10.1016/J.MARPOLBUL.2019.07.052.

Cheung, W., Jones, M., Reygondeau, G., Stock, C., Lam, V. Frölicher, T. (2016) ‘Structural uncertainty in projecting global fisheries catches under climate change’, *Ecological Modelling*. Elsevier B.V., 325, pp. 57–66. doi: 10.1016/j.ecolmodel.2015.12.018.

Coe, J., Rogers, D. (2012) ‘Marine Debris: Sources, Impacts, and Solutions’. Springer New York, p. 432. Available at: https://books.google.com/books/about/Marine_Debris.html?id=RRIGCAAAQBAJ (Accessed: 31 October 2021).

Courtene-Jones, W., Quinn, B., Gary, S., Mogg, A., Narayanaswamy, B. (2017) ‘Microplastic pollution identified in deep-sea water and ingested by benthic invertebrates in the Rockall Trough, North Atlantic Ocean.’, *Environmental Pollution (Barking, Essex: 1987)*. Elsevier Ltd, 231(Pt 1), pp. 271–280. doi: 10.1016/J.ENVPOL.2017.08.026.

de Souza Machado, A., Kloas, W., Zarfl, C., Hempel, S., Rillig, M. (2018) 'Microplastics as an emerging threat to terrestrial ecosystems', *Global Change Biology*. Glob Chang Biol, pp. 1405–1416. doi: 10.1111/gcb.14020.

Denuncio, P., Bastida, R., Dassis, M., Giardino, G., Gerpe, M., Rodríguez, D. (2011) 'Plastic ingestion in Franciscana dolphins, Pontoporia blainvillei (Gervais and d'Orbigny, 1844), from Argentina', *Marine Pollution Bulletin*, 62(8), pp. 1836–1841. doi: 10.1016/J.MARPOLBUL.2011.05.003.

Derraik, J. (2002) 'The pollution of the marine environment by plastic debris: A review', *Marine Pollution Bulletin*. Pergamon, pp. 842–852. doi: 10.1016/S0025-326X(02)00220-5.

Di Franco, E., Di Franco, A., Calò, A., Di Lorenzo, M., Mangialajo, L., Bussotti, S., Bianchi, C., Guidetti, P. (2021) 'Inconsistent relationships among protection, benthic assemblage, habitat complexity and fish biomass in Mediterranean temperate rocky reefs', *Ecological Indicators*. Elsevier, 128, p. 107850. doi: 10.1016/J.ECOLIND.2021.107850.

Duffy-Anderson, U., Manderson, J., Able, K. (2003) 'A CHARACTERIZATION OF JUVENILE FISH ASSEMBLAGES AROUND MAN-MADE STRUCTURES IN THE NEW YORK-NEW JERSEY HARBOR ESTUARY', *BULLETIN OF MARINE SCIENCE*, 72(3), pp. 877–889.

Duncan, E., Botterell, Z., Broderick, A., Galloway, T., Lindeque, P., Nuno, A., Godley, B. (2017) 'A global review of marine turtle entanglement in anthropogenic debris: A baseline for further action', *Endangered Species Research*, 34, pp. 431–448. doi: 10.3354/esr00865.

Eriksen, M., Lebreton, L., Carson, H., Thiel, M., Moore, C., Borerro, J., Galgani, F., Ryan, P., Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS one*, *9*(12), p.e111913.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A. Rifman, S. (2013) 'Plastic pollution in the South Pacific subtropical gyre', *Marine Pollution Bulletin*. Pergamon, 68(1–2), pp. 71–76. doi: 10.1016/J.MARPOLBUL.2012.12.021.

European Commission. Horizon: the EU Research & Innovation magazine. (2019). *Garbage-collecting aqua drones and jellyfish filters for cleaner oceans*. Available at: https://horizon-magazine.eu/article/garbage-collecting-aqua-drones-and-jellyfish-filters-cleaner-oceans.html [Accessed 19 Sep. 2019].

Gardezi, M., Arbuckle, J. (2018) 'Techno-Optimism and Farmers' Attitudes Toward Climate Change Adaptation:', *https://doi.org/10.1177/0013916518793482*. SAGE PublicationsSage CA: Los Angeles, CA, 52(1), pp. 82–105. doi: 10.1177/0013916518793482.

Geyer, R., Jambeck, J., Law, K. (2017) 'Production, use, and fate of all plastics ever made', *Science Advances*. American Association for the Advancement of Science, 3(7). doi: 10.1126/SCIADV.1700782.

Gibson, R., Ansell, A., Robb, L. (1993) 'Seasonal and annual variations in abundance and species composition of fish and macrocrustacean communities on a Scottish sandy beach', 98, pp. 89–105.
Gibson, R., Yoshiyama, R. (1999) 'Intertidal Fish Communities', in *Intertidal Fishes*, pp. 264–296. doi: 10.1016/b978-012356040-7/50014-7.
Gong, L., Trajano, J. (2019) 'Tackling East Asia's New Environmental Challenge Marine Plastic Pollution'.

Kasparavičiūtė, G., Nielsen, S., Boruah, D., Nordin, P., Dancu, A. (2018) 'Plastic Grabber: Underwater Autonomous Vehicle Simulation for Plastic Objects Retrieval Using Genetic Programming', *Lecture Notes in Business Information Processing*. Springer, Cham, 339, pp. 527–533. doi: 10.1007/978-3-030-04849-5_46.

Krelling, A., Williams, A., Turra, A. (2017) 'Differences in perception and reaction of tourist groups to beach marine debris that can influence a loss of tourism revenue in coastal areas', *Marine Policy*. ELSEVIER SCI LTD, 85, pp. 87–99. doi: 10.1016/J.MARPOL.2017.08.021.

Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D., Law, K. (2012) 'The effect of wind mixing on the vertical distribution of buoyant plastic debris', *Geophysical Research Letters*. John Wiley & Sons, Ltd, 39(7). doi: 10.1029/2012GL051116.

Laist, D. (1997) *Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records*. doi: 10.1007/978-1-4613-8486-1_10.

Langston, W., Chesman, B., Burt, G., Hawkins, S., Readman, J., Worsfold, P. (2003) 'Characterisation of the South West European Marine Sites: Plymouth Sound and Estuaries cSAC, SPA. Occasional Publication of the Marine Biological Association 9'.

Leeuwen, C., Koop, S. (2017) 'The challenges of water, waste and climate change in cities', *Environment, Development and Sustainability*. Springer Netherlands, 2017(2), pp. 385–418. doi: 10.1007/S10668-016-9760-4.

Lima, A., Costa, M., Barletta, M. (2014) 'Distribution patterns of microplastics within the plankton of a tropical estuary', *Environmental Research*. Academic Press, 132, pp. 146–155. doi: 10.1016/J.ENVRES.2014.03.031.

McCoy, E., Bell, S. (1991) 'Habitat structure: The evolution and diversification of a complex topic', *Habitat structure*. Springer, Dordrecht, pp. 3–27. doi: 10.1007/978-94-011-3076-9_1.

Moore, C. (2008) 'Synthetic polymers in the marine environment: A rapidly increasing, long-term threat', *Environmental Research*. Academic Press, 108(2), pp. 131–139. doi: 10.1016/J.ENVRES.2008.07.025.

Moore, C., Moore, S., Weisberg, S., Lattin, G., Zellers, A., (2002). A comparison of neustonic plastic and zooplankton abundance in southern California's coastal waters. Marine pollution bulletin, 44(10), pp.1035-1038.doi: 10.1016/S0025-326X(02)00150-9.

National Geographic. (2017). *Googly-Eyed Trash Eaters May Clean a Harbor Near You.* Available: https://www.nationalgeographic.com/science/article/mr-trash-wheels-professor-trash-wheels-baltimore-harbor-ocean-trash-pickup. Last accessed 2nd Feb 2022.

Nicolau, L., Marçalo, A., Ferreira, M., Sá, S., Vingada, J., Eira, C. (2016). Ingestion of marine litter by loggerhead sea turtles, Caretta caretta, in Portuguese continental waters. *Marine pollution bulletin*, *103*(1-2), pp.179-185. doi: 10.1016/J.MARPOLBUL.2015.12.021.
NOAA (2017). *Implementing Trash Traps to Remove Litter in the Anacostia River Watershed in Maryland.* Available: https://marinedebris.noaa.gov/removal/implementing-trash-traps-remove-litter-anacostia-river-watershed-maryland. Last accessed 2nd Feb 2022.

O'Brine, T., Thompson, R. (2010) 'Degradation of plastic carrier bags in the marine environment', *Marine Pollution Bulletin*, 60(12), pp. 2279–2283. doi: 10.1016/J.MARPOLBUL.2010.08.005.

Ocean Cleanup. (2019). *The Ocean Cleanup Unveils First Prototype | Press Releases*. [online] Available at: https://theoceancleanup.com/press/pressreleases/the-ocean-cleanup-unveils-first-prototype/ [Accessed 19 Sep. 2019].

OSPAR (2020) *Beach Litter Monitoring*, *Marine Litter Assessment*. Available at: https://oap.ospar.org/en/ospar-assessments/committee-assessments/eiha-thematic-assessments/marine-litter/beach-litter-monitoring/ (Accessed: 1 September 2021).

Plastics Europe. (2020). Plastics – the Facts 2020. Plastics Europe, Brussels Belgium.
Provencher, J., Bond, A., Hedd, A., Montevecchi, W., Muzaffar, S., Courchesne, S., Gilchrist, H., Jamieson, S., Merkel, F., Falk, K., Durinck, J. (2014) 'Prevalence of marine debris in marine birds from the North Atlantic'. doi: 10.1016/j.marpolbul.2014.04.044.

Rech, S., Pichs, Y., García-Vazquez, E. (2018) 'Anthropogenic marine litter composition in coastal areas may be a predictor of potentially invasive rafting fauna', *PLOS ONE*. Public Library of Science, 13(1), p. e0191859. doi: 10.1371/JOURNAL.PONE.0191859.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B., Proietti, M., Thums, M., Pattiaratchi, C. (2013) 'Marine Plastic Pollution in Waters around Australia: Characteristics, Concentrations, and Pathways', *PLOS ONE*. Public Library of Science, 8(11), p. e80466. doi: 10.1371/JOURNAL.PONE.0080466.

Rillig, M. (2012). Microplastic in terrestrial ecosystems and the soil?. *Environ Sci Technol*, 46(12), pp. 6453–6454. doi: 10.1021/ES302011R.

Ryan, P. (2016) 'Ingestion of Plastics by Marine Organisms', *Handbook of Environmental Chemistry*. Springer, Cham, 78, pp. 235–266. doi: 10.1007/698_2016_21.

Seabin Project. (2022). https://seabinproject.com/the-seabin-v5/. Available: https://seabinproject.com/. Last accessed 16 January 2022.

Sheavly, S., Register, K. (2007) 'Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions', *Journal of Polymers and the Environment 2007 15:4*. Springer, 15(4), pp. 301–305. doi: 10.1007/S10924-007-0074-3.

Shimizu, T., Nakai, J., Nakajima, K., Kozai, N., Takahashi, G., Matsumoto, M., Kikui, J. (2008) 'Seasonal variations in coastal debris on Awaji Island, Japan', *Marine Pollution Bulletin*. Pergamon, 57(1–5), pp. 182–186. doi: 10.1016/J.MARPOLBUL.2007.10.005.

Thompson, R., Moore, C., Vom Saal, F., Swan, S. (2009) 'Plastics, the environment and human health: current consensus and future trends.', *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*. The Royal Society, 364(1526), pp. 2153–66. doi: 10.1098/rstb.2009.0053.

Todd, V., Lazar, L., Williamson, L, Peters, I., Hoover, A., Cox, S., Todd, I., Macreadie, P., McLean, D. (2020). 'Underwater Visual Records of Marine Megafauna Around Offshore Anthropogenic Structures'. doi: 10.3389/fmars.2020.00230.
Vegter, A., Barletta, M., Beck, C., Borrero, J., Burton, H., Campbell, M., Costa, M., Eriksen, M., Eriksson, C., Estrades, A. Gilardi, K. (2014) 'Global research priorities to mitigate plastic pollution impacts on

marine wildlife', *Endangered Species Research*. Inter-Research, 25(3), pp. 225–247. doi: 10.3354/esr00623.

Villarrubia-Gómez, P., Cornell, S., Fabres, J. (2018) 'Marine plastic pollution as a planetary boundary threat – The drifting piece in the sustainability puzzle', *Marine Policy*. Elsevier Ltd, 96, pp. 213–220. doi: 10.1016/J.MARPOL.2017.11.035.

Wilcox, C., Sebille, E. Van, Hardesty, B. (2015) 'Threat of plastic pollution to seabirds is global, pervasive, and increasing', *Proceedings of the National Academy of Sciences*. National Academy of Sciences, 112(38), pp. 11899–11904. doi: 10.1073/PNAS.1502108112.

Woodall, L., Sanchez-Vidal, A., Canals, M., Paterson, G., Coppock, R., Sleight, V., Calafat, A., Rogers, A., Narayanaswamy, B.Thompson, R.C. (2014). The deep sea is a major sink for microplastic debris. *Royal Society open science*, *1*(4), p.140317

Wright, S., Kelly, F. (2017) 'Plastic and Human Health: A Micro Issue?', *Environmental Science and Technology*. American Chemical Society, 51(12), pp. 6634–6647. doi: 10.1021/acs.est.7b00423.

Wyles, K., Pahl, S., Holland, M., Thompson, R. (2017) 'Can Beach Cleans Do More Than Clean-Up Litter? Comparing Beach Cleans to Other Coastal Activities', *Environment and Behavior*. SAGE Publications Ltd, 49(5), pp. 509–535. doi: 10.1177/0013916516649412.

Zbyszewski, M., Corcoran, P., Hockin, A. (2014) 'Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America', *Journal of Great Lakes Research*. Elsevier, 40(2), pp. 288–299. doi: 10.1016/J.JGLR.2014.02.012.

Zettler, E., Mincer, T., Amaral-Zettler, L. (2013). Life in the "plastisphere": microbial communities on plastic marine debris. Environmental science & technology, 47(13), pp.7137-7146.