CleanAtlantic

Tackling Marine Litter in the Atlantic Area

Evaluation of the potential harm caused to the marine environment by plastic cotton bud sticks

Work Package 5.4

Cedre

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Disclaimer

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Executive summary

Plastic cotton bud sticks (CBS) have been reported on beaches worldwide including in remote areas. In 2016, they were the 6th most frequent litter types found on European beaches during beach litter monitoring, representing 3.8% of beach litter surveyed. This fact poses the question of the impact of this litter type on the marine environment.

In this context, the Interreg Atlantic Area CleanAtlantic project proposed to compile existing knowledge on origin, fate and potential impact of plastic CBS in the marine environment in order to (i) support the design of management plans that aim at reducing the presence and impacts of these items to acceptable levels and (ii) feed the action 48 of OSPAR Regional Action Plan 2014-2020.

The work was divided in two parts. First, an analysis of plastic CBS abundance and distribution on Atlantic Area beaches was conducted over the period 2016-2019, using OSPAR beach litter monitoring data. Secondly, existing knowledge about plastic CBS origin, fate and impact on the marine environment were compiled. The results of this study are presented in this report.

Main lessons learnt are:

- Plastic CBS are found on beaches all over the world, whether in remote or densely populated areas. Analysis of OSPAR beach litter monitoring data indicates that plastic CBS are the 3rd most common items found on Atlantic Area beaches over the period 2016-2019 (7.8% of litter found; plastic fragments 2.5-50 cm and string/cord with a diameter less than 1 cm were the 1st and 2nd most common items). Over the considered period, 32 693 plastic CBS were collected during the 922 surveys conducted on the 62 Atlantic Area survey sites. Plastic CBS were found in 48% of surveys.

- Plastic CBS found in the marine environment are believed to originate primarily from sewage due to improper disposal via toilets and the inability of the wastewater treatment plant to retain them (oversized screening and/or lack of sewage treatment during storms or blockages).

- Plastic CBS are known to float in seawater owing to the low density of its polymer (polypropylene; density: 0.83 – 0.92). Therefore, the fate of plastic CBS in marine environment is mainly governed by winds and surface currents. Nevertheless, during its journey in marine environment, plastic CBS can undergo weathering processes which can lead to a transfer and contamination of the water column and seabed sediment.

- Although no studies regarding the degradation of plastic CBS in environment were found during the analysis, it could be hypothesised that plastic CBS can undergo the same degradation processes than other polypropylene-based products with a high risk of photo-initiated oxidative degradation owing the buoyancy of plastic CBS. This process can lead to erosion with production of micro- and nanoplastics. The high molecular weight and the lack of functional groups of long polyolefin chains like polypropylene cause very limited biodegradation processes (*i.e.* degradation by microorganisms). As other plastic debris, plastic CBS are pervasive and they can persist in the environment over a very long period of time, the exact duration of which is unknown today but could exceeds several decades.

- Potential environmental impacts of plastic CBS are related to the capacity of plastic CBS to release/adsorb hazardous contaminants, physical harm during interactions with animals (*e.g.* ingestion, suffocation) and the capacity of plastic CBS to be colonized by microorganisms potentially vector of diseases or act as substrate for non-indigenous/invasive species. However, these potential environmental impacts are only assumptions based on experimental data as no impact *in natura* has been clearly demonstrated to date.

- Economic impacts associated to plastic CBS are mainly related to (i) the presence of plastic CBS on beaches or bathing waters which is non-aesthetic and decreases tourist attraction of the areas and (ii) the presence of plastic CBS (associated with other litter) in coastal areas requiring cleaning operations which have important costs.

Overall, this study shows that plastic CBS are abundant and problematic marine litter that should be targeted by reduction measures. Due to their small size and their stick form, they can escape into aquatic environments and end in the ocean. In this context, the ban of the plastic part and replacement by a biodegradable material, as implemented in several countries worldwide and at the European Union level (Directive (EU) 2019/904), appears to be an appropriate measure. To replace plastic CBS, the EU recommended to use alternatives such as paper, cardboard and wood sticks. The continuation of beach litter monitoring on the European Union coastline will allow to assess the efficiency of this measure and the effective reduction of plastic CBS in European marine waters.

Introduction

Plastic cotton buds (CBS) are small (less than 8 cm in length), white or colored, opaque or translucent, sticks. They are constituted of double tipped plastic cotton buds, though they are generally found in the environment without cotton wads, these latter being only indicated by the presence of indents on the stick. They are domestic products, generally used for sanitary purposes (*e.g.* cleaning, cosmetics application). Though they are now ban in several countries, plastic CBS have been intensively used, for instance, in 2020, it was estimated that 1.8 billion plastic CBS were used annually in the United Kingdom (**UK Gov, 2020**[1]).

Although they are not always featured in beach litter monitoring protocol (*e.g.* **Lavers and Bond, 2017; Walther *et al.,* 2018**) and potentially mistakenly identified as lolly sticks by untrained volunteers (**Strand *et al.,* 2016**), plastic CBS have been reported on beaches worldwide including in remote areas (*e.g.* **Thushari *et al.,* 2017; Addamo *et al.,* 2017)**. For instance, plastic CBS were found among other stranded marine debris on the remote Alphonse Island (Seychelles) in the Western Indian Ocean (**Duhec *et al.,* 2015**). In Europe, plastic CBS are among the top marine beach litter items. In 2016, they were the 6th most frequent items found on European beaches during beach litter monitoring, representing 3.82% of beach litter surveyed (**Addamo et al., 2017**). They were also the main group of items found on the Grandola coast in Portugal (**Zhukov, 2017**) and on beaches in the Mediterranean (**Basterretxea *et al.,* 2007; UNEP, 2015**) reaching more than 30% of the total amount of collected litter along the Tyrrhenian coast of central Italy (**Poeta *et al.,* 2016**). Still along European coasts, Surfrider Foundation Europe indicated that 44 031 plastic CBS were collected in 2017 through the Ocean Initiatives program (**Surfrider Foundation Europe, 2017**). Plastic CBS constituted 4% (~27730 items) of the items found during beach clean-ups performed by volunteer for the European Environment Agency (EEA)'s Marine LitterWatch (2014 – 2017) on 1 627 beaches across Europe's four regional seas (Baltic Sea, Black Sea, Mediterranean Sea and North-East Atlantic Ocean) (Figure 1; **EEA, 2018**).

To address this environmental issue, national or international authorities have implemented actions to reduce the presence of plastic CBS in the marine environment. At an international level, OSPAR included an action targeting this abundant item in its Marine Litter Regional Action Plan (RAP) 2014-2020[2]. This action (No 48) aims to assess the potential harm caused to the marine environment by cotton buds and to develop proposals on the requirements for the removal, modification or adaptation of this potentially problematic item.

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[1] https://www.gov.uk/government/news/start-of-ban-on-plastic-straws-stirrers-and-cotton-buds
[2] https://www.ospar.org/work-areas/eiha/marine-litter/regional-action-plan

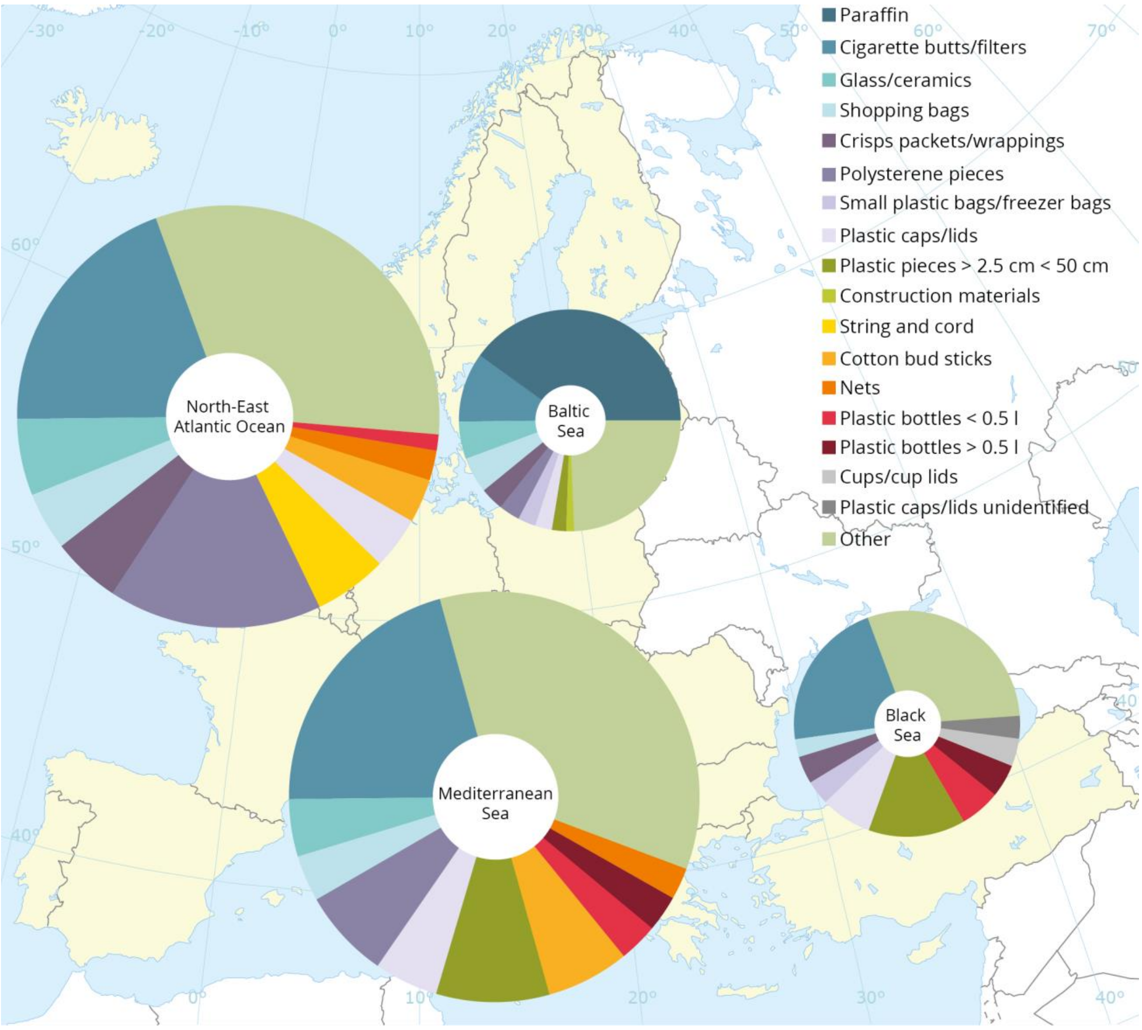

Figure 1. *Results of the MarineLitter Watch program (2014 – 2017) performed on 1 627 beaches across Europe's four regional seas (Baltic Sea, Black Sea, Mediterranean Sea and North-East Atlantic Ocean)* ***(EEA, 2018)***.

In this context, the Interreg Atlantic Area CleanAtlantic project proposed to compile existing knowledge on origin, fate and potential impacts of plastic CBS in the marine environment in order to (i) support the design of management plans that aim at reducing the presence and impacts of these items to acceptable levels and (ii) feed the action 48 of OSPAR RAP. The CleanAtlantic project gathers 18 partners from the five Atlantic Area countries (Ireland, United Kingdom, France, Spain and Portugal). The final goal of the CleanAtlantic project is to protect biodiversity and ecosystem services by improving the regional cooperation and by reinforcing capabilities to prevent, monitor and remove marine litter in the Atlantic Area.

The study was conducted by Cedre (France) as part of action 4 of the work package (WP) 5- Monitoring and data management of the CleanAtlantic project.

The present report is the final deliverables of the study. It compiles (1) an analysis of CBS abundance and distribution on Atlantic Area beaches and (2) existing information about plastic CBS origin, fate and impact in the marine environment.

Part 1: Assessment of plastic cotton bud sticks abundance and distribution on Atlantic Area beaches

Methods

This assessment is based on the work performed in the first action of the WP4 of the CleanAtlantic project "WP4.1: Regional characterisation of marine litter in the Atlantic Area". This assessment is based on OSPAR beach litter monitoring data. Data are collected using a standardized fit-for-purpose monitoring protocol consisting in collecting, identifying and counting all visible litter (> 0.5 cm) on the beach sand surface, four times a year, on fixed survey site of 100 m in length (https://www.ospar.org/work-areas/eiha/marine-litter/assessment-of-marine-litter/beach-litter).

This assessment includes only data obtained on sites located in the Atlantic Area. Data were downloaded from OSPAR beach litter database (https://beachlitter.ospar.org/). It includes data collected on 62 sites over the period 2016-2019 (4 years; Figure 2): 4 in Ireland, 18 in the United Kingdom, 9 in France, 12 in Spain and 19 in Portugal. In total, 922 surveys were considered to obtain the assessment. Based on the work carried out for CleanAtlantic WP4.1, the following indicators have been calculated at country and Atlantic Area scale:

- Total number of plastic CBS collected,
- Percentage of plastic CBS collected in the total number of beach litter,
- Rank in the Top 5 of the most collected beach litter,
- Mean and median of plastic CBS collected over a survey,
- Minimum and maximum of plastic CBS collected over a survey,
- Number and percentage of surveys where plastic CBS were found.

For more details, see the CleanAtlantic report "Regional characterisation of beach litter in the Atlantic Area" (**Cedre, 2020**)[3].

[3] The report can be found on the CleanAtlantic website: http://www.cleanatlantic.eu/wp-content/uploads/2021/04/CleanAtlantic-4-1-Overview-of-marine-litter-status-in-the-Atlantic-area-beach-litter.pdf

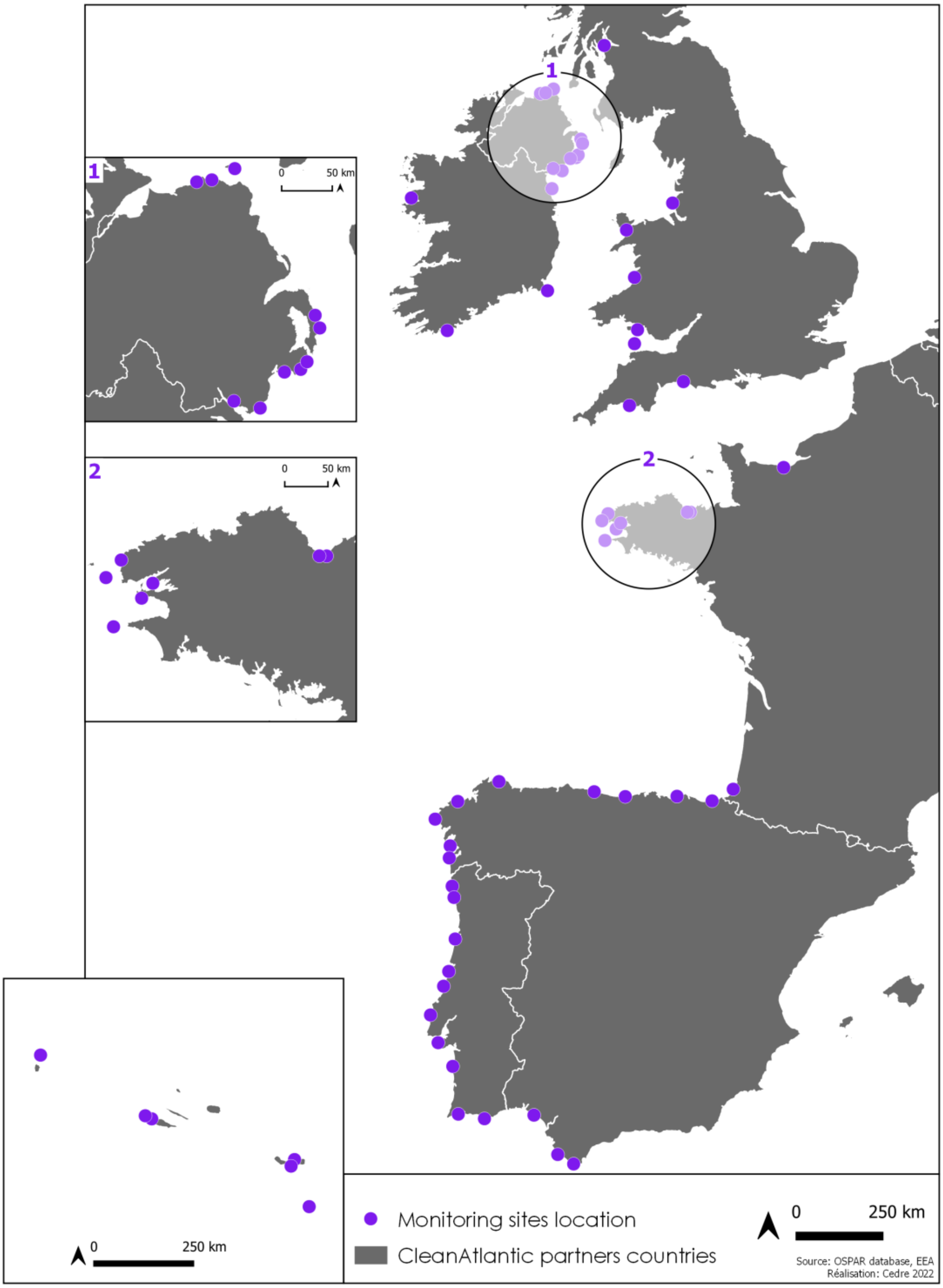

Figure 2. *OSPAR beach litter survey sites considered in the assessment of plastic CBS pollution in the Atlantic Area (source: OSPAR Beach Litter Database).*

Results

Analysis of OSPAR beach litter monitoring data indicates that plastic CBS are the 3rd most common items found on Atlantic Area beaches over the period 2016-2019 (7.8% of the number; plastic fragments 2.5-50 cm and string/cord with a diameter less than 1 cm were the 1st and 2nd most common items; Figure 3).

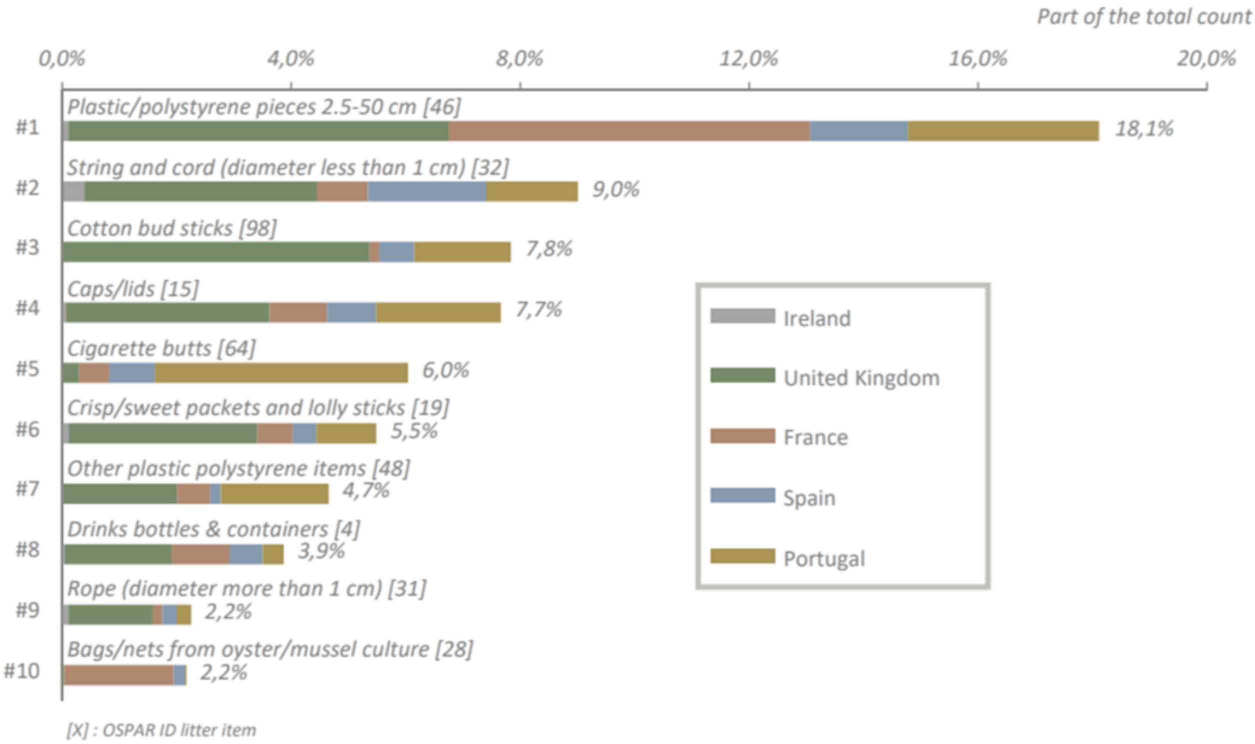

Figure 3. *Top 10 of items collected during the 922 surveys considered by the CleanAtlantic project over the period 2016-2019 (figure from* ***Cedre, 2020****).*

The United Kingdom and Portugal exhibited higher percentages of plastic CBS in their surveys (11.8% and 7.1%, respectively) than the three other countries (5.8% in Spain, 0.9% in France, 0.3% in Ireland). Over the considered period, 32 693 plastic CBS were collected during the 922 OSPAR beach litter surveys conducted on the 62 Atlantic Area survey sites (Table 1). Overall, plastic CBS were found in 48% of surveys (438/922) but there are geographical differences highlighted by an occurrence of plastic CBS in 95% of Irish surveys while they are found only in 31% of the British surveys. These differences could be related to the location of the surveys site and the proximity with wastewater treatment plants identified as the main source of plastic CBS releases in aquatic environments (**Mourgkogiannis *et al.*, 2018**).

Table 1. *Results of data analyses from OSPAR beach litter datasets regarding occurrence and abundance of plastic CBS in the Atlantic Area.*

	Ireland	United Kingdom	France	Spain	Portugal	Atlantic Area
Nb of sites	4	18	9	12	19	62
Nb of surveys	64	264	137	189	268	922
Total nb of CBS collected	11	22 365	719	2 549	7 049	32 693
% of CBS in the total nb of litter collected	0.3%	11.8%	0.9%	5.8%	7.1%	7.8%
CBS rank in the Top 5 of the most frequent litter collected	Not in the Top 5	2	Not in the Top 5	5	5	3
Mean nb of CBS (mean of all surveys; CBS/100m)	0	85	5	14	26	36
Median nb of CBS (median of all surveys; CBS/100m)	0	3	0	1	1	1
Minimum nb of CBS collected over a survey (CBS/100m)	0	0	0	0	0	0
Maximum nb of CBS collected over a survey (CBS/100m)	7	2859	199	218	397	2859
Nb of surveys where CBS were found	61/64	81/264	85/137	93/189	125/268	438/922
% of surveys where CBS were found	95%	31%	62%	49%	47%	48%

A mean abundance of 36 plastic CBS/100 m and a median abundance of 1 plastic CBS/100 m were obtained considering all surveys of the Atlantic Area over the studied period (Table 1). The median abundance, the metric used by the OSPAR Convention and the MSFD (Marine Strategy Framework Directive) Technical Group on Marine Litter (TG-ML) varied from 0 – 3 plastic CBS/100 across the five countries considered. The Figure 4 illustrates the median abundance of plastic CBS per site. Data analyses showed plastic CBS are common during surveys but they do not exceed alone the European threshold value of 20 items/100 m defined by the MSFD TG-ML. However, with all items considered by OSPAR, the threshold value is largely surpassed in the Atlantic Area, requiring implementation of strong and efficient measures to reach the objective (median of 172 items/100 m; **Cedre, 2020**).

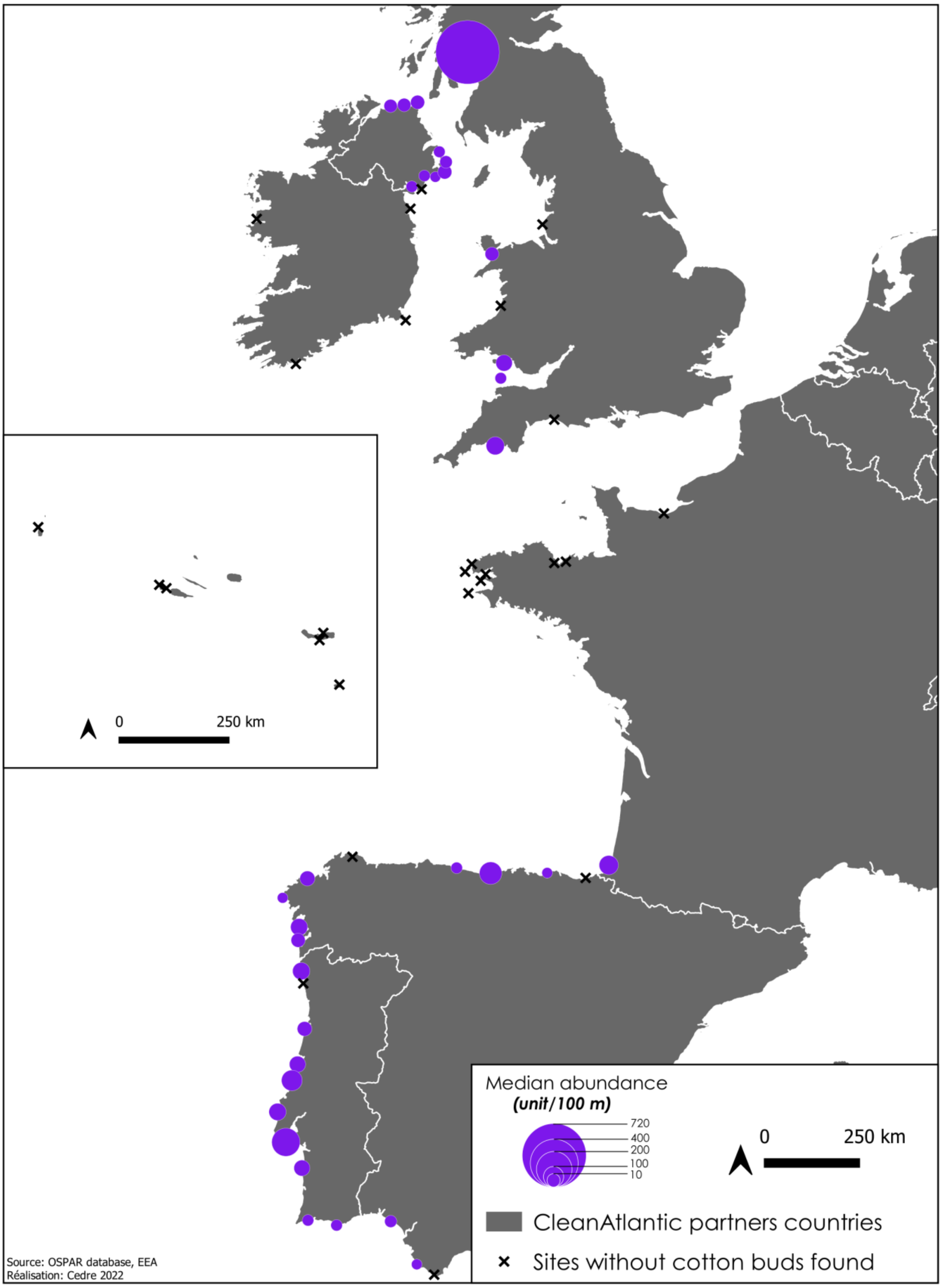

Figure 4. *Plastic CBS median abundances (number of items/100m) found on OSPAR beach litter monitoring sites of the Atlantic Area between 2016 and 2019 (source: OSPAR Beach litter database).*

Part 2: Origin, fate and impacts of plastic cotton bud sticks in the marine environment

Compilation of existing information

A literature review was conducted using search engines such as Web of Science or Google Scholar by searching for the following key words: “cotton buds”, “cotton swabs”, “Q-tips”, “marine environment”, “pollution”, “marine litter”, “beach litter”, “source”, “fate”, “degradation”, “behavior”, “harm”, “impact”, “effect”.

Key information obtained are synthesised in following paragraphs.

Plastic CBS found on beaches: what are they?

The polymer used to produce plastic CBS is polypropylene (PP), the second worldwide most produced polymer (19% of the global production in 2020; **PlasticsEurope, 2021**).

In studies investigating beach litter, the size of cotton bud sticks found on beaches is, in our knowledge, never mentioned. However, most pictures indicate that small colored double-tipped plastic cotton buds for domestic use are mostly observed on beaches though cotton wads, often indicated by indents, have disappeared. In most cases, collected sticks appear to be visually intact though some are found twisted or broken in smaller pieces (Figure 5). To our knowledge, there is no mention of longer sticks (used for other applications) found in the marine environment.

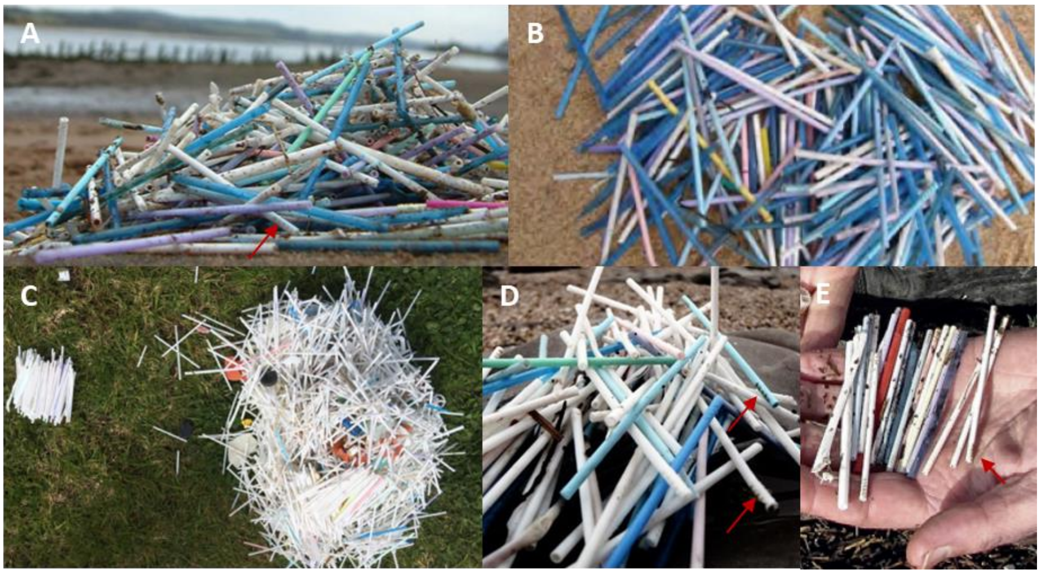

Figure 5. Plastic cotton buds collected on beaches (A, B, C and D) or on river banks (E) during cleans-up or litter monitoring (Sources: (A) Marine Litter Watch item list, (B) OSPAR beach litter monitoring photo guide, (C) the Cotton Bud Project, (D) and (E) Surfrider Foundation Europe). Indents used to fix cotton wads are highlighted with red arrows.

Sources of plastic CBS in aquatic environments

All reviewed studies agree on the fact that plastic CBS found in the marine environment originate mainly from domestic origin and come predominantly from sewage (wastewater treatment plants (WWTP) and/or cruise ship) though some could also originate from other sources (*e.g.* direct disposal on the beaches or inland) (**Poeta *et al.*, 2016; Prevenios *et al.,* 2018, Arcadis, 2012**). When plastic CBS are disposed in toilets or sinks, they enter though the domestic sewage and can reach aquatic environments and end in the marine and coastal environment due to the inefficiency of the sewage treatment plants to retain them during the process (Figure 6). In 2018, a study investigated the potential of WWTP as plastic litter sources in Greece using an extensive questionnaire-based survey sent to managers of 101 wastewater treatment plants located all over the country (**Mourgkogiannis *et al.,* 2018**). The authors identified plastic CBS as the most common plastic found in the different WWTP's compartments and in the surrounding marine and coastal areas of the effluent pipes (Figure 7). Indeed, despite the presence of nets or filters, plastic CBS can pass through wastewater treatment systems due to their small diameter (**Williams *et al.,* 1996**). Some screening gears at outfall headworks or sewage-treatment works sites have widely varying performance with some clearly failing to perform the standards which are required to avoid discharge in the marine environment (**Thomas *et al.,* 1989**). In addition, weather-related events can allow to the entrance of plastic debris including plastic CBS in the environment, notably during storm events through combined sewer overflows (CSO) where wastewater is released without treatment, leading to the integral release of plastics in the environment (**Mourgkogiannis *et al.,* 2018**).

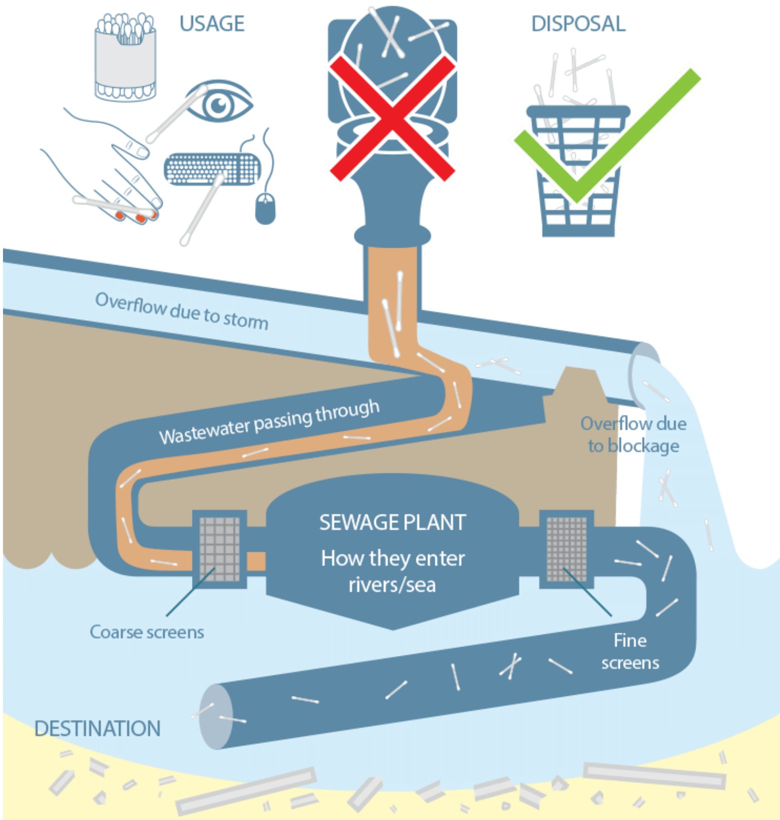

Figure 6. *Plastic cotton buds ways from toilets to the marine environment (source: The Cotton bud project)*

The amount of plastic CBS released in environment depends on the specificities of each region. **Mourgkogiannis *et al.* (2018)** observed that the presence of plastics is increased mostly during summer in wastewater treatment plants that serve coastal and touristic areas in Greece, probably due to the increase of population density with tourism. On the contrary, **Poeta *et al.* (2016)** noted that the highest number of plastic CBS was found during autumn and winter seasons along the Tyrrhenian coast of central Italy due to a higher river discharge and the inefficiency of the sewage treatment plants in the study area. Same observations were made by **Basterretxea *et al.* (2007)** indicating that in wintertime, when there were few beachgoers, debris were mainly composed of pieces of plastic notably CBS, the most abundant item reaching up to 42 items m^{-1}.

It is interesting to note that, already in the late eighties, **Thomas *et al.* (1989)** mentioned and advised manufacturers of sanitary products to pay much more attention to produce biodegradable products and to encourage alternative means of disposal as in practice, fine screening of all flows may not be possible and sewage related debris were expected to be continuously released in the environment. It is also worth remembering that in Italy, the production and sale of plastic CBS sticks has been banned with the article 19 of the National Law 93/01 until 2006, when this article was abrogated by the National Law 152/2006 (**Poeta *et al.*, 2016**).

Figure 7. *Photographs of (A) plastic CBS, (B) in a wastewater treatment plant (WWTP), (C) floating on the sea surface close to the WWTP outlet and (D) on the nearby beach (**Mourgkogiannis et al., 2018**)*

Behavior of plastic CBS in the marine environment

Plastic CBS are known to float in still water or seawater (**Davies *et al.,* 1998; Poeta *et al.,* 2016**). This behavior is related to the polypropylene exhibiting a density of 0.83-0.92 which is lower than the seawater density. Indeed, the density is the first parameter influencing the position of the debris in the water column (**Kooi *et al.*, 2017**). Therefore, due to its buoyancy, the fate of plastic CBS in marine environment is mainly governed by wind and surface current. Nevertheless, during its journey in the marine environment plastic CBS will undergo a weathering that can imply a biofilm formation which can increase the density of the item and lead to a contamination of water column and seabed sediment by plastic buoyant debris (**Rummel *et al.,* 2017**).

Degradation of plastic CBS in the marine environment

To our knowledge, no studies specifically focus on the weathering and degradation of plastic CBS in the marine environment. Only one study was found mentioning physical degradation of cotton buds in a sewer. In this study, physical degradation has been investigated experimentally and results showed that plastic CBS tended to remain intact although it was observed that in some instances, cotton portions became detached from the ends of the stick, which is in line with observations made on beaches (**Davies *et al.,* 1998; Mourgkogiannis *et al.,* 2018**). Nevertheless, several studies have investigated the degradation of polymers in marine conditions, including polypropylene (PP). This polymer, similarly to other polymers (*e.g.* polyethylene, polystyrene, polyvinylchloride), is known to undergo oxidative degradation due to solar radiation (*i.e.* photo-initiated oxidative degradation), which is considered as the most important abiotic degradation pathway in aerobic outdoor environments. Indeed, due to the high molecular weight and the lack of functional groups of long polyolefin chains like polypropylene, biodegradation (*i.e.* degradation by microorganisms) of this polymer is limited (**Gewert *et al.,* 2015**). Considering the buoyancy of plastic CBS, this item will undergo the maximum of photo-initiated oxidative degradation in marine environment as the intensity of solar radiation decreases with the depth of the water column. Below the photic zone, the photo-initiated oxidative degradation does not affect plastic items.

Photo-initiated oxidative degradation consisted in a three-steps reaction initiated by light (primarily sunlight ultraviolet B (UV-B) radiation), producing free radicals that react with oxygen to form peroxy radicals concomitantly with further complex radical reactions leading to oxidation. The reaction ends in chain scission or crosslinking with a predominance of reactions leading to a diminution of the molecular weight of the polymer that becomes brittle and more susceptible to fragmentation (**Andrady, 2011; Gewert *et al.,* 2015**). The degradation mechanisms in a first time will affect the morphology and the appearance of plastic items. In line with this, **Brandon *et al.* (2016)** observed that PP pellets increase in opacity, yellowness and brittleness as time increased when weathered for 3 years in three experimental treatments (dry/sunlight, seawater/sunlight and seawater/darkness) especially in the dry/sunlight treatment. Similarly, **Gewert *et al.* (2018)** have developed a laboratory protocol that simulates the exposure of plastic floating in the marine environment to UV light and showed that PP visibly yellowed after weathering indicating degradation. However PP specific-degradation products were not identified. Regarding PP stranded on beaches, artificial weathering simulating beach conditions showed that PP was minimally fragmented by mechanical abrasion in absence of UV photo oxidation (**Song *et al.*, 2017**). Degradation was also described in natural conditions. Strips of PP deployed for 32 weeks in a salt marsh habitat exhibited surface erosion characterized by extensive cracking as well as microplastic fragments and fibers production after 8 weeks despite the development of a biofilm after 4 weeks decreasing the UV transmittance by approximately 99% (**Weinstein *et al.*, 2016**).

It has to be mentioned that degradation rates appears to be different in dry and seawater conditions. Unlike plastics exposed to air, plastics in seawater exhibited a slowdown of degradation which is primarily due to the relatively lower temperatures and the lower oxygen concentration in water environments. **Resmerita *et al.* (2018**) compared the degradation of PP injected pieces in air and in a seawater wave tank fitted in an artificial UV light weathering chamber to mimic ocean-like conditions. In air, they observe a degradation of PP in the bulk with a decrease of mechanical properties, a little change of crystal properties and nearly no change of surface chemistry whereas weathering in the seawater wave tank shows only surface changes, with no effect on crystals or mechanical properties but with loss of small pieces of matter in the sub-micron range and a change of surface chemistry, suggesting an erosion dispersion mechanism. The difference of degradation between air (*e.g.* beach condition) and seawater is exacerbated by fouling effects rapidly covering the debris (**Andrady, 2011**). Indeed, upstream of the degradation process which can induce release of micro- and nanoparticles until a complete mineralization ultimately, plastic items are rapidly (timeframe: days - weeks) colonized by molecules (*e.g.* organic matter, pollutants, metals) forming an ecorona, and microorganisms (biofouling) modifying the plastic's surface properties (**Paul-Pont *et al.*, 2018**; Figure 8).

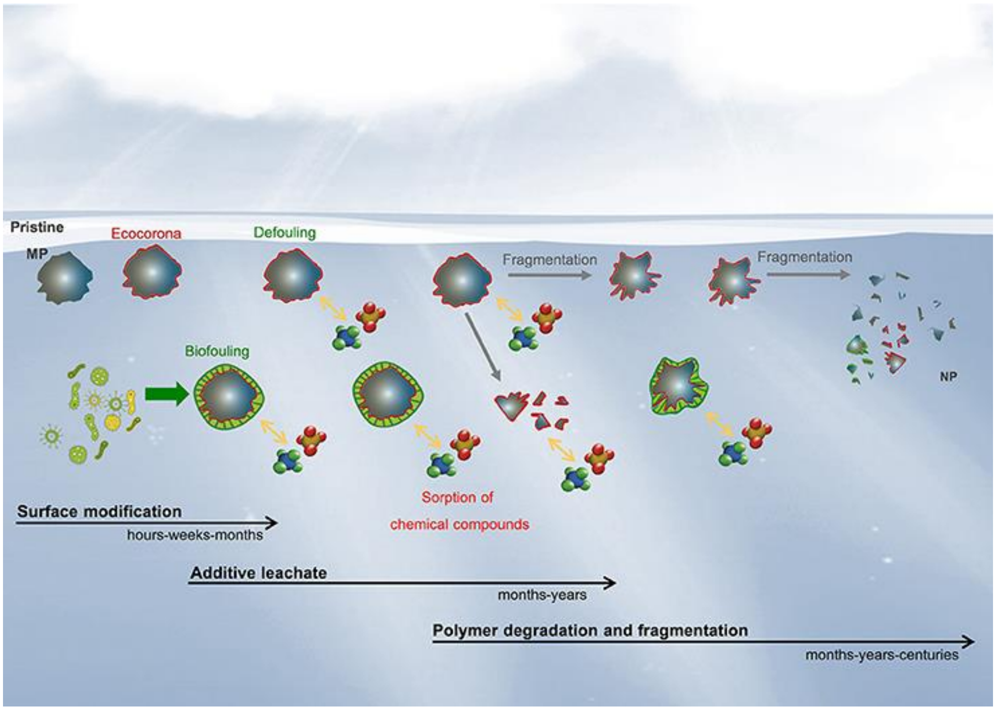

Figure 8. *Processes implied during the weathering of plastic debris in marine environment (**Paul-Pont et al., 2018**).*

Degradation in natural environments has consequences on the recycling processes and circular economy. A study showed that a 6.5 months experimental exposure to UV radiation in a marine environment affected both thermal and mechanical properties of PP (like nylon, PE and polyethylene terephthalate (PET)), causing a weakening of the material which became less elastic and more rigid. Imaging analyses showed cracks, flakes and granular oxidation as well as a loss of homogeneity on the surface of the samples. All these changes make mechanical recycling unfeasible, since the quality of the recycled material is insufficient to ensure a high virgin material substitution rate (**Iniguez *et al.,* 2018**).

It is also worth mentioning that plastic items during the weathering and degradation processes are able to release numerous compounds as additives potentially hazardous or greenhouse gases. For instance, polypropylene items can produce methane and ethylene when incubated in seawater and exposed to ambient solar radiation at concentrations of 170 ± 10 pmol g^{-1} d^{-1} and 50 ± 1 pmol g^{-1} d^{-1}, respectively (**Royer *et al.,* 2018**).

Finally, it has to be noted that polymer degradation rates are strongly influenced by the use of additives (**Gewert *et al.,* 2015**) and observation described above may not apply to CBS PP depending on additives they contain. To our knowledge, there is no information in the literature regarding additives added to plastic CBS.

Potential environmental impacts of plastic CBS

1. Contaminants transportation and release

4.1. Chemicals

To our knowledge, there are no mention of plastic CBS acting as a vector of contaminants in the literature. However, as primarily originating from sewage, they could interact with wastewater-associated contaminants, especially hydrophobic ones (**Loos *et al.,* 2013, Wu *et al.,* 2016**) and represent a potential source of hazardous chemicals in the marine environment.

Moreover, as they are made of PP, knowledge about chemical transportation and release for this polymer potentially apply to plastic CBS. As other polymers, PP can sorb and concentrate environmental contaminants. For instance, in experimental conditions, PP has been shown to sorb polychlorinated biphenyls (PCB) dissolved in simulated seawater with a sorption capacity that increases with decreasing particle size and temperature (**Zhan *et al.,* 2016**).

In situ, PP pellets sampled on beaches were found to be contaminated with persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAH), PCB, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE) and nonylphenols (**Mato *et al.*, 2001; Frias *et al.,* 2010**). In particular, **Mato *et al.* (2001)** observed that marine PP pieces had 100.000–1 million times higher concentrations of PCB and DDE than surrounding seawater.

Regarding PP constituents, hazards coming from monomers are expected to be low as PP monomers are known to be among the least hazardous. Based on this, environmental and health hazard ranking proposed by **Lithner *et al.* (2011)** attributes a low hazard score to PP. For additives, as said above there is, to our knowledge, no information in the literature regarding the additives added to plastic CBS (except for colorants that are clearly visible in some plastic CBS). However, additives added to plastic CBS could be released in the marine environment and therefore represent a potential source of contamination (**Hahladakis *et al.,* 2018**). In addition, toxic non-intentionally added substances (NIAS; byproducts, degradation products, contaminants) can be found in plastic materials (**Wiesinger *et al.,* 2021**).

In terms of leaching, hazardous metallic elements (*e.g.* cadmium) were detected in leachates of PP objects found on UK beaches obtained using an avian physiologically-based extraction test simulating chemical conditions in the gizzard-proventriculus of the northern fulmar, suggesting ingested PP could contribute to seabird exposure to contaminants (**Turner, 2019**).

Regarding leachates toxicity, **Lithner *et al*. (2012***)* did not observed any toxicity of PP leachates obtained from different objects (bucket, food container, plastic bag clip, plate cover or toolbox) using the freshwater flea (*Daphnia magna)* acute toxicity test. In line with this, leachates of DVD case made of PP did not exhibit toxicity toward saltwater copepod *(Nitoca spinipes*) (**Bejgarn *et al.,* 2015**). However, toxicity of plastic leachate is highly dependent of the considered species/biological model and of the product itself. Indeed, other studies showed that leachates from PP products exhibited a toxicity higher than other polymers (*e.g.* polystyrene, polyethylene) on survival of the copepod *Nitocra spinipes* (**Gewert *et al.,* 2021**) and on growth and physiology (DNA damages, antioxidant defenses) of the marine microalgae *Dunaliella tertiolecta* (**Schiavo *et al.,* 2020**). In addition, the leachate toxicity of PP products is influenced by the weathering in environment. **Bejgarn *et al.* (2015)** observed an increase of leachates toxicity with artificial weathering as authors observed that weathered PP produces toxic leachates after 192h of UV exposure, suggesting hazardous chemicals could be released from weathered PP. Similar results were observed on *Nitocra spinipes* after exposures to leachates from PP products exposed to UV light compared to leachates from PP products kept in dark condition (**Gewert *et al.,* 2020**). The weathering can affect the chemical structures of additives and creates degradation products exhibiting toxicity to living organisms (*e.g.* **Tian *et al.,* 2021**).

4.2. Microplastics and nanoplastics

When they degrade, plastic CBS can release microplastics and nanoplastics in the marine environment. In an experimental study, **Lambert and Wagner (2016)** showed that PP accelerated-degradation in aquatic medium resulted in formation of micro- and nanoparticles. Similar results were observed using accelerated weathering experiment simulating beach environment, where 12-month UV exposure followed by 2-month of mechanical abrasion resulted in production of 6084 ± 1061 particles/pellet by PP pellets (**Song *et al.,* 2017**). These observations were confirmed in the field where strips of PP exposed to salt marsh conditions for eight months produced microplastics fragments (**Weinstein *et al.,* 2016**). This release of micro- and nanoplastics is problematic as it increases the bioavailability for living organisms (more organisms are able to ingest a part of plastic CBS due to the size of the particles) and potentially the toxic impacts as previous studies showed an increased toxicity of plastic debris when the size decreases (*e.g.* **Tallec et *al.,* 2018; Jeong *et al.,* 2018**).

2. Interaction with biota

4.3. Micro-organisms transport

Plastic CBS may act as a micro-organisms vector, as polymers including PP, are known to be colonized by micro-organisms which may facilitate their persistence and long-term dispersal in the marine environment. Nevertheless, the potential role of plastic debris on pathogen transport and disease emergence is not well understood (**Paul-Pont *et al.,* 2018**).

In addition, as they are likely to originate mainly from sewage, plastic CBS may interact with wastewater-associated bacteria and pathogens and transport them to the marine environment which may represent an environmental risk but also a human health issue especially in highly touristic beaches that could last as long as the plastic persists. However, to our knowledge, no study has, to date, investigated bacteriological and pathogenic hazards associated with the presence of debris of sewage origin, including plastic CBS, in the marine environment.

4.4. Non-indigenous species (NIS) transport

As other floating marine debris, plastic CBS may be involved in the transport of non-indigenous species (NIS). It is known that some marine sessile organisms can fix themselves to plastic CBS. For example, a Lepas barnacle has been found attached to a plastic CBS on Tristan de Cunha, a small island located between South Africa and Argentina (**Pr. P. Ryan, pers. comm**; Figure 9).

Figure 9. *A Lepas barnacle attached to a plastic CB (Source: Pr. P. Ryan).*

4.5. Ingestion

As other marine debris, plastic CBS can be ingested by marine organisms. Pieces of plastic CBS were observed in fulmar stomachs during the OSPAR/MFSD monitoring of plastic ingestion by the northern fulmar *Fulmarus glacialis*. At least two pieces were identified with certainty by the presence of indents, however, it is very hard to quantify exactly the frequency of ingestion because without indents, broken pieces are hardly recognizable as plastic CBS (**Dr. Van Franeker,**

pers. comm.). Whole sticks have also been found in loggerhead turtles, and reported as the cause of death for one individual following piercing of the intestine (**Cavers *et al.,* 2017**). In addition, as previously described, animals can ingest micro- and nanoplastics from plastic CBS but it is impossible to identify them as plastic CBS during analyses due to their morphology similar to other plastic products at this size range (*i.e.* fragments).

Conclusion

Overall, this study shows that plastic CBS are abundant and problematic marine litter that should be targeted by reduction measure. Due to their small size and their stick form can escape in aquatic environments and end in the ocean. In this context, the ban of the plastic part and replacement by a biodegradable material, as implemented in several countries (France since January 2020, United Kingdom since October 2020, New Zealand since October 2022, in specific regions of Australia (e.g in New South Wales since November 2022)) and at the European Union level (Directive (EU) 2019/904, implemented since July 2021), appears to be an appropriate measure. To replace plastic CBS, the EU recommended to use alternatives such as paper, cardboard and wood sticks. The continuation of beach litter monitoring on the European Union coastline will allow to assess the efficiency of this measure and the effective reduction of plastic CBS in European marine waters.

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