Universidad de La Laguna

Facultad de Ciencias
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Caracterización e implicaciones de conservación de los eventos de enmallamiento de tortuga boba (*Caretta caretta*) en las Islas Baleares, Mediterráneo occidental.

Characterization and conservation implications of loggerhead turtle (*Caretta caretta*) entanglement events in the Balearic Islands, western Mediterranean.

Rita Font de Benito

Máster Universitario en Biología Marina: Biodiversidad y Conservación

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AUTORIZACIÓN DEL TUTOR/ES

Universitat de les Illes Balears

Fundación Palma Aquarium
Para la Protección del Medioambiente

La **Dra. Covadonga Rodríguez González**, Profesora Titular de la Universidad de La Laguna y el **Dr. Samuel Pinya Fernández** Profesor Titular de la Universitat de les Illes Balears, como Tutora Académico y Tutor Externo, respectivamente,

DECLARAN:

Que la memoria presentada por **Rita Font de Benito** titulada "Caracterización e implicaciones de conservación de los eventos de enmallamiento de tortuga boba (*Caretta caretta*) en las Islas Baleares, Mediterráneo occidental", ha sido realizada bajo su dirección y consideran que reúne todas las condiciones de calidad y rigor científico requeridas para optar a su presentación como Trabajo de Fin de Máster, en el Máster Oficial de Postgrado de Biología Marina: Biodiversidad y Conservación de la Universidad de La Laguna, curso académico 2022-2023.

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Resumen

El presente trabajo pretende estudiar los eventos de enmallamiento de tortuga boba (*Caretta caretta*) en las Islas Baleares con el objetivo de aumentar el conocimiento sobre esta amenaza. Para ello, a partir de la información disponible sobre los varamientos asociados a este acontecimiento entre enero del 2018 y septiembre del 2022, se recopilaron y analizaron, de lo general a lo más específico, datos sobre los eventos de enredo, el material involucrado, las consecuencias sobre los ejemplares de *C. caretta* y los aspectos sociales implicados. Los resultados obtenidos han demostrado que el enmallamiento por desechos plásticos es la principal amenaza que afecta a las tortugas bobas en las Islas Baleares desde los últimos años. Mientras su distribución espacial y temporal corresponde a lo esperado, la distribución por grupos de edades señala una mayor afectación y vulnerabilidad de los especímenes jóvenes tempranos. Los materiales mostraron una semejanza con los desechos marinos globales y regionales en términos de tipo de polímero y color, pero no tan evidente en relación con la procedencia. Como consecuencia de los enredos, se halló una mortalidad moderada pero una alta gravedad en las lesiones, principalmente afectando a las aletas delanteras. A pesar de la utilidad de los registros de varamientos como herramienta para estudiar los eventos de enmallamiento, una falta de conocimiento y subestimación generalizada enfatiza la necesidad de más estudios y una mayor colaboración desde diversos ámbitos para comprender mejor y afrontar esta amenaza.

Palabras clave: desechos plásticos, enmallamiento, tortuga boba, registros de varamientos, Islas Baleares

Abstract

This work aims to study entanglement events of loggerhead turtle (*Caretta caretta*) in the Balearic Islands in order to increase knowledge about this threat. To do so, from available information on strandings associated with this event between January 2018 and September 2022, from general to more specific, data on the entanglement events, the involved material, consequences for *C. caretta* specimens and concerned social aspects was collected and analyzed. The obtained results have shown that entanglement by plastic debris is the main threat affecting loggerhead turtle in the Balearic Islands since recent years. While its spatial and temporal distribution corresponds to what is expected, the distribution by age groups indicates a greater affectation and vulnerability of early juvenile specimens. The materials showed a similarity with global and regional marine debris in terms of polymer type and color, but not as evident in relation to source. As a result of entanglements, a moderate mortality but a high severity in the lesions, mainly affecting the front flippers, were found. Despite the usefulness of stranding records as a tool for studying entanglement events, a widespread lack of knowledge and underestimation emphasizes the need for more studies and greater collaboration from various areas to better understand and address this threat.

Keywords: plastic debris, entanglement, loggerhead turtle, stranding records, Balearic Islands

1. Background

Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 2009). It consists of items that have been made or used by people and deliberately discarded or unintentionally lost into the sea and on beaches, including materials transported into the marine environment by rivers, drainage or sewage systems or winds (Commission Decision 2010/477/EU) (UNEP, 2009; European Commission & Directorate-General for Environment, 2020). Since huge amounts of items are continuously reaching the seas and oceans (Jambeck et al., 2015; European Commission & Directorate-General for Environment, 2020), marine litter has become ubiquitous in marine environments (Derraik, 2002; Eriksen et al., 2014; Suaria & Aliani, 2014). Consequently, the presence of anthropogenic debris in the marine environment is now recognized as one of the most pervasive pollution problems affecting the oceans (Suaria & Aliani, 2014). It is regarded as one of the most significant problems for the marine environment and a major threat to biodiversity (Harding, 2016) alongside other key environmental issues such as climate change and ocean acidification (Anastasopoulou & Fortibuoni, 2019; Suaria & Aliani, 2014; Harding, 2016).

Originating from sources both on land and in sea, marine litter is made up of a wide range of materials (plastic, rubber, metal, glass, paper, wood) (UNEP, 2009; Joint Research Centre & Institute for Environment and Sustainability, 2011). However, although the type of litter found in the world's oceans is highly diverse, there is clear evidence that plastic litter, which include all petroleum-based synthetic materials, is by far the most abundant type of debris found in all marine environments (Darmon, et al., 2017; Derraik, 2002; Galgani et al., 2015; Gall & Thompson, 2015; Nelms et al., 2016; Pedrotti et al., 2022; Pham et al., 2014; Schuyler et al., 2013). Being a versatile, light weight, strong, cheap, and potentially transparent material (Derraik, 2002; Andrady, 2011), plastics are highly appreciated and valued for their physical and mechanical properties, which confer them high durability and resistance (Ehlers & Elrich, 2020; Solomando et al., 2022). Consequently, plastics have rapidly moved into all aspects of everyday life (Derraik, 2002; Andrady, 2011; Ehlers & Elrich, 2020). Nevertheless, the intense consumption and rapid disposal of plastic products favoured poorly managed debris to accumulate progressively in marine ecosystems, reaching even the most remote areas of the planet, including the surface waters of the open ocean, deep sea canyons and polar regions (Cózar et al., 2014; Ehlers & Elrich, 2020; Nelms et al., 2016; Solomando et al., 2022). Global plastic production has increased from 5 million tons in 1960 to 360 million tons in 2018 and is expected to increase to 1.1 billion tons in 2050 (EPRO 2020; Zhang et al. 2022). For that reason, plastic waste is placed among the prevalent pollutants in seas and oceans, with a proportion representing up to 80% of the total marine litter (Derraik, 2002; Barnes et al., 2014; Andrady, 2011) according to the European Parliament (Solomando et al., 2022).

While marine habitats are spoiled with man-made debris from the poles to the equator (Gall & Thompson, 2015), the situation in the Mediterranean Sea is not an exception. In its case, several factors must be considered: the Mediterranean Sea is a semi-enclosed sea (Bigagli et al., 2019; Cózar et al., 2015; Grelaud & Ziveri, 2020; Mansui et al., 2014) with limited exchanges with other oceans; it is densely populated, with a strong demographic pressure of the 466 million inhabitants around the coastal areas (Pedrotti et al., 2022; UNEP, 2015); is one of the busiest maritime routes in the world, with 30% of the world's maritime traffic passing through the basin (UNEP, 2015; Pedrotti et al., 2022); it supports highly developed and massive tourism (Anastasopoulou & Fortibuoni, 2019; UNEP, 2015) that attracts about one third of the world's tourism (Grelaud & Ziveri, 2020); and, finally, the fishing industry is of significance (UNEP, 2013), as well as the shipping industry, especially off the African coast (UNEP, 2015). Taken together, the mentioned anthropogenic pressures with both physical and demographic conditions exacerbate the global situation and places the Mediterranean Sea as a trap for marine litter (UNEP, 2015). Hence, the Mediterranean Sea has been described and recognized as one of the most affected areas in the world by marine litter (Bigagli et al., 2019; Fossi et al., 2017; Grelaud & Ziveri, 2020), confirming marine litter in the Mediterranean as a critical issue (UNEP, 2015).

Following the global trend, marine litter in the Mediterranean is largely composed of plastics (70-90% of the total) (UNEP, 2015; Bigagli et al., 2019). According to UNEP (2015), assessments of the composition of beach litter in different regions of the Mediterranean Sea reveal synthetic materials (bottles, bags, caps/lids, fishing nets, and small pieces of unidentifiable plastic and polystyrene) as major constituents of overall litter pollution. In any case, considering the Mediterranean Sea in the context of the global-scale distribution of plastic pollution clearly identifies it as a region of particularly high plastic concentration (Cózar et al., 2015) (Figure 1).

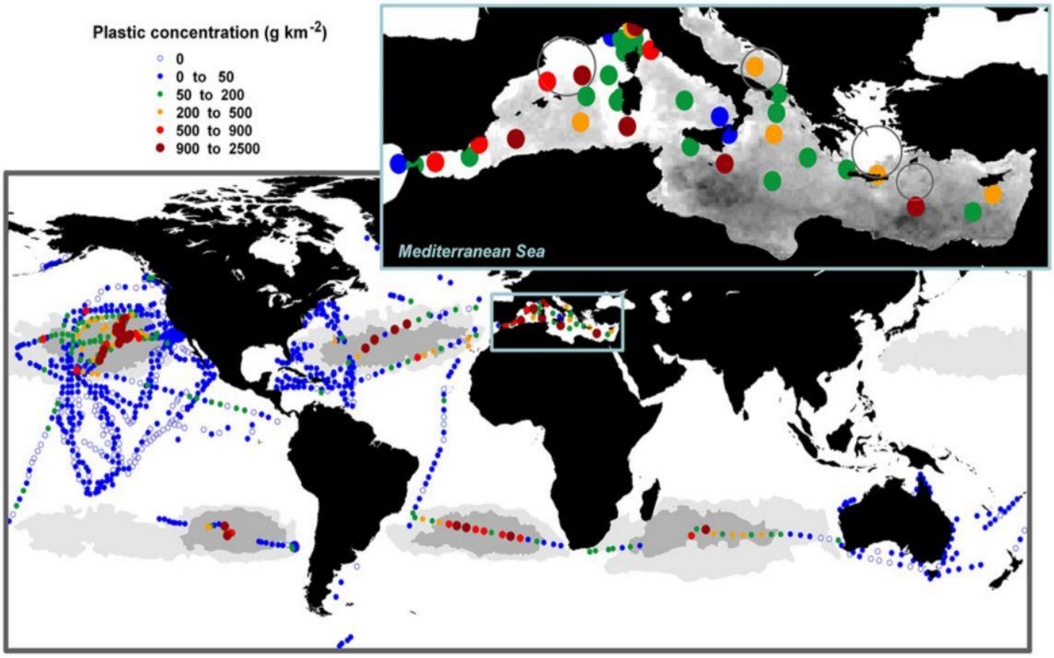


Figure 1. Concentrations of plastic debris in surface waters of the Mediterranean Sea at basin scale (zoomed in the top right corner inset) and compared to the plastic concentrations reported for the global ocean. Grey-scale base map in the Mediterranean basin shows the relative surface plastic concentrations predicted by numerical modelling. Darker areas are predicted to have higher concentrations. Source: Cózar et al., 2015.

Depending on where the litter enters the water, sources of marine litter are traditionally classified as either land or sea based (Galgani et al., 2015; UNEP, 2015). In addition, factors such as ocean current patterns, climate and tides, proximity to urban, industrial, and recreational areas, sea routes and fishing grounds also influence the types and quantity of litter found in the open ocean or along beaches (Galgani et al., 2015). In the Mediterranean, items found show an origin that comes mainly from land sources (Bigagli et al., 2019; Joint Research Centre & Institute for Environment and Sustainability, 2011; UNEP, 2015), specifically, between 69 and 80% of the litter (Galgani et al., 2015 Joint Research Centre & Institute for Environment and Sustainability, 2011). This land-based litter predominance stems mostly from shoreline and recreational activities (UNEP, 2015). Poor waste management practices, discharges of untreated municipal waste, and industrial outfalls also participate as sources of land-based litter (Bigagli et al., 2019). Furthermore, it should be considered that, in some cases, specific activities account for local litter densities well above the global average (Galgani et al., 2015). This effect is particularly important in the Mediterranean, where marine litter from 'shoreline and recreational activities' is highly connected to tourism (UNEP, 2009). As a result, notably during summer, marine litter densities on beaches can be increased by up to 40% because of high tourist numbers (Galgani et al., 2015). This is particularly true for sea-locked areas such as the islands of the region, which due to their attractiveness will host a far greater population during the summer (Grelaud & Ziveri, 2020). A clear example of this is the case of the Balearic Islands, where research carried out by the Balearic Government in 2005 figured out that debris found in summer was twice as much as in winter (UNEP, 2015).

For its part, sea-based sources represent between 20 and 26% of the waste (Galgani et al., 2015; Joint Research Centre & Institute for Environment and Sustainability, 2011) and are based on activities such as maritime transport, both commercial and recreational fisheries, offshore oil and gas platforms and aquaculture (Joint Research Centre & Institute for Environment and Sustainability, 2011). Those occupations can also contribute to the inputs of sea-based litter in specific contexts, especially through direct discharge of waste and through Abandoned, Lost, or otherwise Discarded Fishing Gears (ALDFG) (Bigagli et al., 2019), commonly referred as "ghost fishing" (Macfadyen et al., 2009; Kühn et al., 2015) since they passively drift over large distances, sometimes indiscriminately 'fishing' marine organisms (Duncan et al., 2017), and inducing mortality without human control (Anastasopoulou & Fortibuoni, 2019). All those ALDFG end up in the marine environment for some reasons including bad weather, gear conflicts, too much gear for the vessel or the crew, snagging on living and inert structures, operator error, abandonment, or as Illegal, Unreported and Unregulated fishing (IUU) (Toole, 2017). Moreover, ghost fishing is often closely related to IUU, linked to the use of cheap plastic fishing materials of low quality. In the Mediterranean, in fact, these materials, together with a lack of proper control, pose a major problem in fisheries using gillnets, traps, long-lines and Fish Aggregation Devices (FADs) (Save the Med Foundation, 2020). FADs are permanent, semi-permanent, or temporary structures made from any material and used to attract fish and to improve pelagic fish catches (Blasi et al., 2016). These structures attract small fishes that congregate under the floating structure, which turns out to be an effective system since fish approach floating objects in search of shelter from predators (shade effect) (Blasi et al., 2016). In the Mediterranean, those FADs have been used since ancient times, especially in Mallorca, to increase the availability and exploitation of migratory oceanic fish species like *Coryphaena hippurus*, commonly known as "llampuga" (Morales-Nin, 2000). There, FADs are made of different cheap floating materials, and are moored in fixed places, ranging from shore waters to areas 60 miles off the coast; then, special gears are used to capture fish under these typical FADs (Morales-Nin, 2000). However, it seems that these types of artefacts are currently used inappropriately around the Mediterranean, as they are illegally anchored or left adrift floating in the open sea waiting for the concentration of small fish under these FADs to attract larger predators that, in turn, can be caught more easily (Save the Med Foundation, 2020). In that sense, oceanic and coastal FADs provide a possibility to decrease both the search time and operating costs for fishing vessels (Blasi et al., 2016).

As the indiscriminate disposal of plastic waste from different sources makes marine plastic pollution a chronic and long-recognized global problem (Gregory, 2009), the interaction between marine litter and wildlife has led to several adverse effects and consequences for many groups of marine fauna: benthic biota, seabirds, pelagic fish, marine mammals, and sea turtles (Guzzetti et al., 2018; Solomando et al., 2022). Sea turtle (Reptilia, Cheloniidae) populations are, among a significant number of species affected (over 250) (Laist, 1997), the most impacted wildlife groups by plastic debris worldwide (Solomando et al., 2022). This group consist of only seven species that are distributed circumglobally (Wallace et al., 2011), inhabiting almost all the world's temperate and warm-water oceans and seas, where they occupy unique ecological niches as a fundamental part of marine ecosystems (Febrer-Serra et al., 2018; Camiñas et al., 2021). On a global scale, six of those seven marine turtle species are considered 'Vulnerable', 'Endangered' or 'Critically Endangered' according to the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN, 2022). An 86% (6 of 7) of all sea turtle species are threatened by plastic litter (Laist, 1997).

The behaviour of sea turtles makes them particularly vulnerable to marine pollution since they interact with debris because of their normal behaviour patterns (Anastasopoulou & Fortibuoni, 2019). First, they tend to be in alignment with ocean fronts, convergences and drift-lines for their food supply and shelter but where marine debris frequently occurs. Also, since marine litter is commonly made of non-biodegradable synthetic material, mainly plastic, drifting debris persist in the marine environment and so potentially becoming biofouled by marine organisms, acting as a FAD and attracting, by its associated prey species, both grazers and predators such as marine turtles. And finally, juveniles tend to be under floating objects in search of shelter to avoid predation (Anastasopoulou & Fortibuoni, 2019; Duncan et al., 2017; NOAA Marine Debris Program, 2014).

In the Mediterranean Sea, the loggerhead sea turtle, *Caretta caretta* (Linnaeus, 1758*)*, is the most common and abundant marine turtle species that frequent the basin (Camiñas et al., 2021; Carreras et al., 2004; Casale, 2011; DiMatteo et al., 2022; Febrer-Serra et al., 2018; Margaritoulis et al., 2003; Revelles et al., 2007). In the Spanish Mediterranean, the main area of concentration of the loggerhead turtle is the Levantine-Balearic demarcation (Camiñas et al., 2021) (Figure 2).

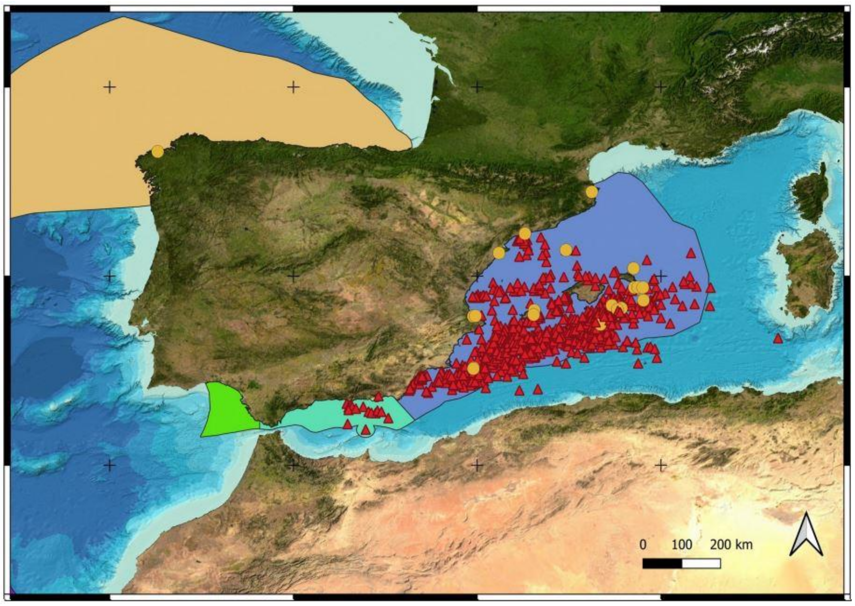


Figure 2. Record map of loggerhead turtles obtained by Camiñas et al. (2021) in the Levantine-Balearic zone (blue area) from by-catches of the Spanish fleet in surface drift long-line in the western Mediterranean and sightings during the study period (2013-2018). Yellow circles represent sightings provided by the Asociación Herpetológica Española (AHE) and red triangles represent bycatch data provided by the Instituto Español de Oceanografía (IEO). Source: Camiñas et al., 2021.

In these waters, specimens from both rookeries located in the eastern Mediterranean and the north-western Atlantic share foraging areas (Báez et al., 2019; Carreras et al., 2004; Revelles et al., 2007). Indeed, although large numbers of loggerhead turtles can be observed in the Balearic Islands all year round (Carreras et al., 2004), spatial analysis indicated the existence of a seasonal trend (Camiñas et al., 2021). Specifically, a seasonal concentration of loggerhead turtles occurs around the Balearic Islands between the warm season (May-June), pointing out this area as an important spring-summer feeding area for juveniles and subadults (Baéz et al., 2013; Camiñas et al., 2021). This is also confirmed by fishermen, whose sighting reports of loggerhead turtles peaked from late spring to late summer in the Balearic Islands (Carreras et al., 2004) (Figure 3). For Atlantic specimens, data analysis in the Gibraltar area shows an entry during the spring and an exit at the end of the summer, while few turtles remain around the Balearic Islands during winter (Margaritoulis et al., 2003). Hundreds of juvenile and subadult loggerhead turtles are annually concentrated around the feeding grounds in the western Mediterranean, as mentioned, mainly in waters around the Balearic Islands (Báez et al. 2019).

In its turn, for sub-adults and adults, the south of the islands is the most relevant area throughout the year (Camiñas et al., 2021). In fact, the south of the Balearic Islands has been identified as one of the high abundance areas predicted according to spatial density models (DiMatteo et al., 2022).

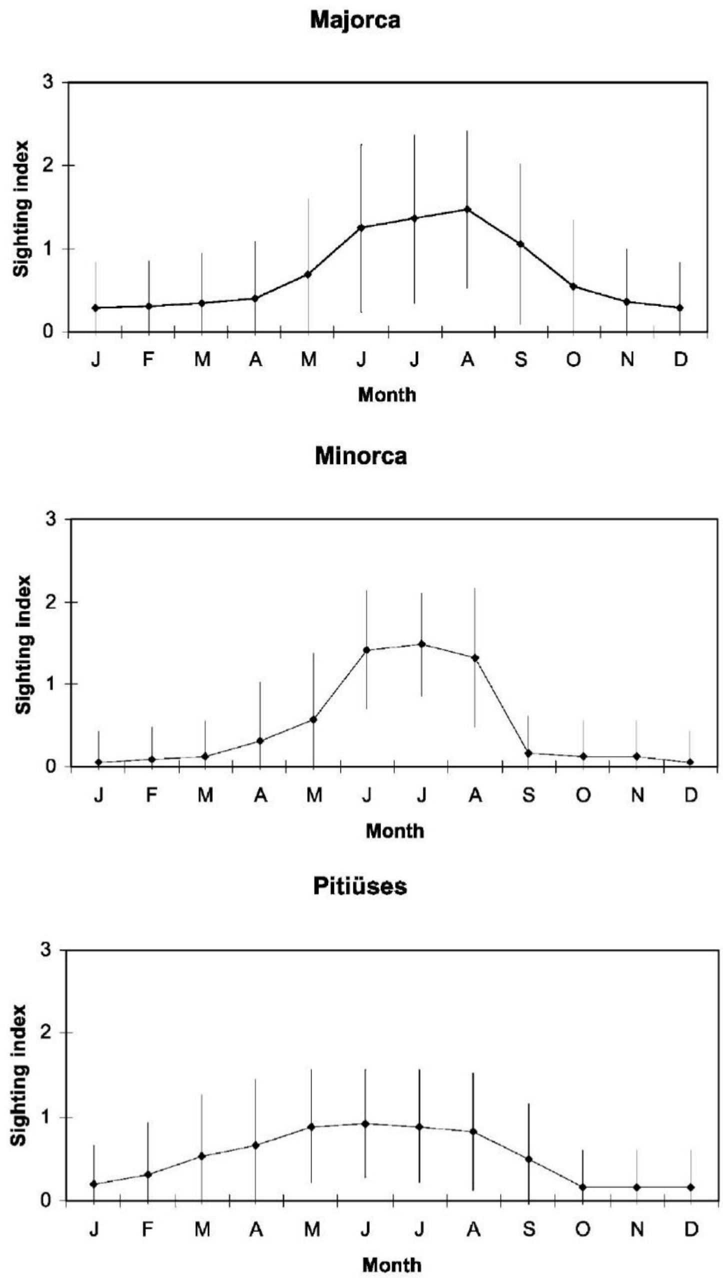


Figure 3. Temporal distribution of loggerhead turtle sightings of the Balearic Islands, ranging from 0 (no turtles) to 3 (many turtles) Source: edited from Carreras et al., 2004.

Loggerhead sea turtle, as long-lived, slow growing and late sexual maturity species which has a complex and migratory life cycle and requires different habitats, is a particularly vulnerable species by a wide range of factors at all stages of their life cycle (FAO Fisheries Department, 2009; Revelles et al., 2007). Unfortunately, threats to loggerhead turtle in the Mediterranean are numerous: anthropogenic degradation of the habitats due to an extensive coastline urbanisation and the high touristic pressure (Casale & Margaritoulis, 2010), boat strike (Margaritoulis et al., 2003), impact of fishing by incidental catch and mortality (Casale, 2011), and marine pollution (Carreras et al., 2004; Nelms et al., 2016; Febrer-Serra et al., 2018; Solomando et al., 2022). Hence, *C. caretta* is globally catalogued as "Vulnerable" species in the IUCN Red List of Threatened Species (IUCN, 2022) and recognised as a priority species in accordance with the Habitats Directive of the European Union 92/43/CEE (Camedda et al., 2014; Solomando et at., 2022). Furthermore, it is also protected by Spanish legislation, since it is included in the *Listado de Especies Silvestres en Régimen de protección especial (Real Decreto 139/2011, de 4 de febrero)* and in the *Catálogo Español de Especies Amenazadas* (Camiñas et al., 2021).

In the Balearic Islands, since 1993, the *Servei de Protecció d'Espècies del Govern de les Illes Balears* and the *Consorci de Recuperació de la Fauna de les Illes Balears* (COFIB), in collaboration with the Fundación Palma Aquarium since 2014 (Fernández et al., 2015) as the reference rescue centre, is responsible for assistance to sea turtle stranding, mainly *C. caretta*. Thus, the work of the Fundación Palma Aquarium, as a reference recovery centre in the islands, allows the rehabilitation and subsequent release of species back to their habitat, reinforcing the survival rate of vulnerable species such as loggerhead turtle. It also contributes to provide useful information for the study of this endangered marine species, to better understand and determine recovery and conservation measures. Accordingly, several studies have been able to analyse the main causes of stranding for multiple years. Between 1993 and 2017 by-catch of *C. caretta* mainly by surface drifting longline fishing gear was described as the main problem affecting loggerhead turtle populations, with 31.5% of the specimens that arrived having obvious signs of interaction with this fishing activity (Fernández et al., 2015; Febrer-Serra et al., 2018). The remaining arrival of loggerhead turtles at the recovery centre in that period was due to entanglement with anthropogenic waste such as plastics, remnants of fishing nets or other floating targets (13.7%) and trauma with boats (5.48%) (Febrer-Serra et al., 2018).

As in studies of stranded specimens of *C. caretta*, many other studies reveal longline fishing as the main threat of this species in the western Mediterranean, especially around the Balearic Islands (Carreras et al., 2004; Margaritoulis et al., 2003; Revelles et al., 2007), since it is an important fishing ground for the Spanish long-line fishery, mainly targeting swordfish (*Xiphias* *gladius*), bluefin tuna, (*Thunnus thynnus*), and albacore (*Thunnus alalunga*) (Báez et al., 2013). Due to a spatial (Báez et al., 2013) and temporal overlap between the concentration of the loggerhead turtle in the Levantine-Balearic demarcation and the fishing activity of long-lines in the waters of the Balearic Sea (Figure 4), both around the warm season, long-line fishing has been considered a critical threat (Baéz et al., 2013). Between 1,950 and more than 35,000 *C. caretta* juveniles are estimated to be caught annually around the Balearic Islands, where the most severe catch occurs (Margaritoulis et al., 2003).

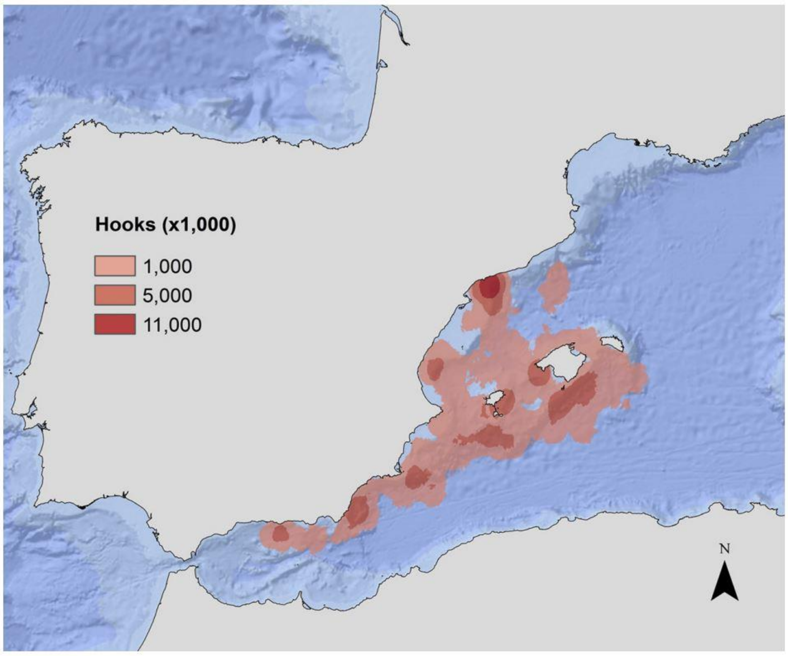


Figure 4. Distribution of the Spanish long-line fishing effort observed over between 2000–2016. Source: Báez et al., 2019.

However, bycatch rates vary depending on a range of technical differences in fisheries operations, gear configurations (e.g., hook and bait type) and strategic approaches (Baéz et al., 2013, 2019). From 2009, substantial reduction of stranding cases by longline hooks has been observed (Febrer-Serra et al., 2018), which is related to the introduction of different modifications in the operation of the longlines that, from 2008, began to work at greater depth, between 200 and 900 metres, where the loggerhead turtle does not usually descend (Fernández et al., 2015) (Figure 5).

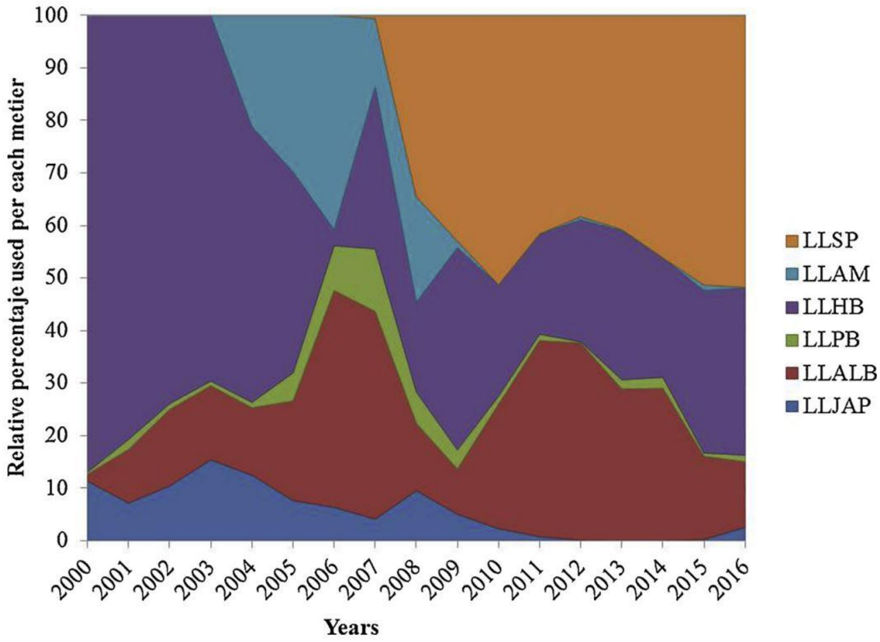


Figure 5. Trends in Spanish long-line fishing effort per metier between 2000–2016. LLSP: Semi-Pelagic drifting long-line targeting swordfish, LLAM: American surface drifting long-line targeting swordfish, LLHB: Home-Base surface drifting long-line; LLPB: Bottom long-line targeting swordfish; LLALB: Surface drifting long-line targeting albacore or little tunny; LLJAP: Surface drifting long-line targeting bluefin tuna. Source: Baéz et al., 2019.

Hence, with the increased use of the semi-pelagic long-line around 2008, which has a much lower incidence on turtles, to the detriment of the surface long-line, long-line by-catch have decreased significantly (Camiñas et al., 2021). In fact, results from the western Mediterranean showed that modifying the depth of fishing leaving the long-line at a depth inaccessible to sea turtles can reduce loggerhead by-catch by up to 99.5% in comparison to other metiers (Baéz et al., 2019).

Therefore, based on a significant reduction in longline interaction, the main known threat for *C. caretta* in the Balearic Islands, studies assessing the next known major threat to this species are needed to direct and improve conservation efforts of this vulnerable and protected species: marine debris pollution.

As mentioned, sea turtles like *C. caretta* are especially susceptible to marine plastic litter. Turtles can be principally affected in a mechanical way through entanglement and or ingestion (Isangedighi et al., 2018; Laist, 1997; (NOAA Marine Debris Program, 2014; Solomando et al., 2022). Entanglement, defined as ‘the process under which, in this case, a marine turtle becomes entwined or trapped within anthropogenic materials’ (Duncan et al., 2017) is the most visible effect of plastic pollution on marine environment as it can be directly observed, while it is very difficult to predict the consequences for turtles that ingest this debris (Anastasopoulou & Fortibuoni, 2019; Isangedighi et al., 2018; Kühn et al., 2015) (Figure 6).

Figure 6. Sea turtle of the species *Caretta caretta*, loggerhead turtle, found on 03.09.2020 in the surroundings of the island of Cabrera (Balearic Islands, Spain) entangled in marine litter. Source: Fundación Palma Aquarium Rescue Centre.

Negative consequences from entanglement can be severe since entangled turtles are hindered in their ability to move, feed, and breathe (Kühn et al., 2015), what has the potential to cause a range of fatal impacts (Duncan et al., 2017) including death by drowning, suffocation, strangulation, or starvation (Anastasopoulou & Fortibuoni, 2019; Isangedighi et al., 2018). In addition, even if not directly causing death, entanglement can potentially cause a variety of non-fatal impacts such as lacerations, skin infections from the abrasive or cutting action of attached debris, serious wounds leading to maiming, amputation, choking, increased drag and restricted movement (Figure 7). Consequently, they may exhibit altered behaviour patterns, potentially hampering their survival like reduced abilities to avoid predators, for foraging or to surfacing to breathe, seriously affecting the entangled turtle (Anastasopoulou & Fortibuoni, 2019; Duncan et al., 2017; Isangedighi et al., 2018; Kühn et al., 2015; NOAA Marine Debris Program, 2014). Hence, marine turtles' susceptibility to entanglement in all forms of marine debris (NOAA Marine Debris Program, 2014) evidences the fact that *C. caretta* survival is being hampered by plastic waste, posing entanglement as a major risk and serious threat for them (Duncan et al., 2017; Isangedighi et al., 2018).

Figure 7. Sea turtle of the species *C. caretta,* found on 18.07.2021 at Caló d'es Mort in Formentera (Balearic Islands, Spain) with the right front flipper entangled in marine litter consisting of plastic and raffia bags that were extracted by the private person who found the turtle. The affected fin was practically necrosed. Source: Fundación Palma Aquarium Rescue Centre.

In the Mediterranean Sea, the highest number of species affected by entanglement was reported by Anastasopoulou & Fortibuoni (2019), being the loggerhead sea turtle *C. caretta* the species with the highest number of entanglement records. However, although loggerhead turtle interaction with marine litter is well studied in regions of the western Mediterranean, such as Sardinia, Malta, or the Adriatic Sea (Deudero & Alomar, 2015), little is known in the Balearic Islands (Figure 8), where few studies have been carried out and have mainly focused on the threat from plastic ingestion (Anastasopoulou & Fortibuoni, 2019; Solomando et al., 2022).

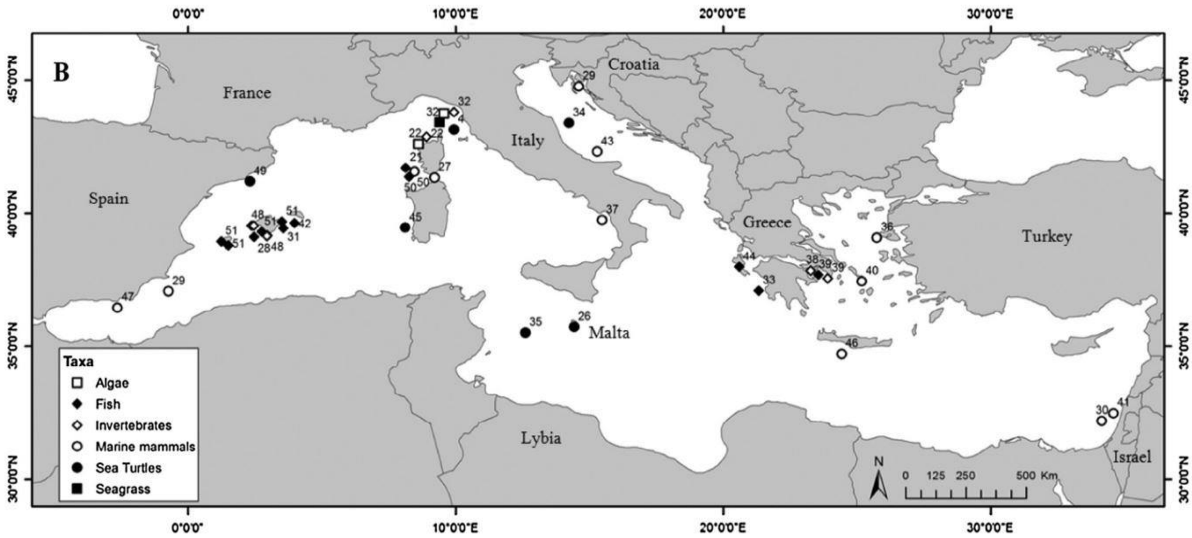


Figure 8. Location of geographic regions in the Mediterranean and Black Sea where research has been conducted on interaction between marine litter and different groups of biota (Algae, Fish, Invertebrates, Marine mammals, Sea turtles, Seagrass). Source: Deudero & Alomar, 2015.

Indeed, considering the wide distribution of *C. caretta* throughout all subtropical and temperate regions, along with their mentioned long lifespan, habitat use, migratory behaviour, and its propensity to interact with marine litter, makes it a good sentinel species for environmental assessment of plastic pollution. In fact, loggerhead turtle is a species selected as an indicator for the European Union's Marine Strategy Framework Directive (MSFD) and recommended by the expert group of the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) as a target species for monitoring marine litter (Anastasopoulou & Fortibuoni, 2019; Save the Med Foundation, 2020). In the Mediterranean, loggerhead sea turtle is considered as an indicator species for three main reasons: as mentioned, it is the most abundant sea turtle species, many accidental catches of this species occur in this basin and there is data available on many turtles from recovery centres and stranding networks (Domènech et al., 2018) like Fundación Palma Aquarium.

Considering all of the above, altogether, we have that: the loggerhead turtle is the most abundant species in the Mediterranean, one of the seas with the greatest accumulation of plastic marine litter; which congregates in the Levantine Balearic area during the most critical months taking into account the high tourist pressure concentrated in the warm season; and, finally, it is an emblematic species and protected at different levels due to its threats among which we find entanglement as a potential threat product of its interaction with marine litter, a significant problem for the marine environment at a global scale.

In this sense, an urgent monitoring research is essential to understand the entanglement impact of pollution in the loggerhead turtle populations in the Balearic Islands and assess the real scale of this problem, which will help to determine the reference situation in relation to global scenario. All this information is required to define sea turtle conservation and management efforts as well as future public policies focused on reducing arrival of plastic in the marine environment (Duncan et al., 2017; Solomando et al., 2022). Thus, it is also important to understand the variation in entanglement rates among life stages to better evaluate vulnerability and the frequency of interactions with different marine debris types (Nelms et al., 2016), a task in which plastic type identification of marine debris can be a powerful tool to determine plastic sources and therefore help focus efforts to reduce specific types of plastics entering the oceans (Solomando et al., 2022).

1.1. Objectives

The aim of this work was to analyse the available information on stranding associated with loggerhead turtle entanglements in the Balearic Islands in order to increase knowledge about and better understand this problem as a threat to *C. caretta* in the islands.
To address this general objective, a series of specific objectives have been proposed:

- First, to quantify the frequency of occurrence of entanglement events within the global context of threats to this species in the Balearic Islands region.
- Second, to characterize the entanglement events.
- Third, to describe both the entanglements and the involved materials.
- Fourth, to outline the consequences on the affected turtles and its impacts.
- And finally, to analyse the social involvement towards the problem of turtle entanglement.

2. Materials & methods

To better understand entanglements as a threat to *C. caretta* in the Balearic Islands, a reverse pyramid approach was adopted as a methodology. From general to more specific, information on entanglement events, the material involved, and their consequences was collected and studied.

2.1. Area of study

The Balearic Islands, located in the western Mediterranean Sea, are formed by four inhabited islands (Mallorca, Menorca, Eivissa and Formentera) (Figure 9) which, along with minor islands and islets, have more than 1700 km of coastline (Solomando et al., 2022). In this Spanish archipelago, around 1.173.008 inhabitants live conforming the resident population (IBESTAT, 2022). Nevertheless, these islands are an important tourist destination, especially during the summer months, so there is an important seasonal peak of the population due to the entry of more than 8.650.000 tourists, for example, in the last year (IBESTAT, 2022). This implies a high tourist pressure and, due to shoreline and recreational activities, mainly during summer, an important increase in marine litter. Indeed, a higher litter density, with 4.0 ± 1.8 kg of litter ha^{-1} (mean ±SE), was found in Palma de Mallorca, compared to densities ranging between 0.7 and 1.8 g of litter ha^{-1} in other sampled sites around the Mediterranean (Pham et al., 2014).

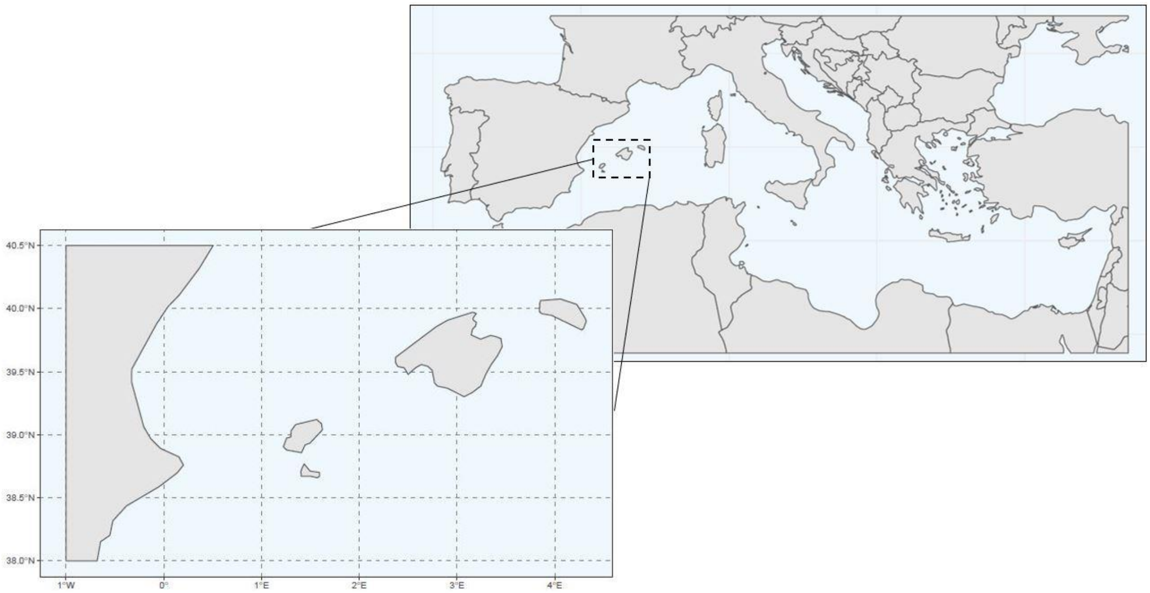


Figure 9. Location of the study area, the Balearic Islands, in the context of the Mediterranean Sea. Highlighted with a dashed black line, in the western Mediterranean Sea.

2.2. Sample and data collection

2.2.1. *Harmed loggerhead turtle records in the Balearic Islands*

A total number of 314 cases of harmed loggerhead turtles registered by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre, as the reference centre authorised by the Government of the Balearic Islands, were studied. Those cases were found floating adrift or stranded around the Balearic Islands and its coasts between January 2018 and September 2022 by citizens, tourists, or public authorities, who notified it to the stranding network calling 112 emergencies number. Specimens found alive were rapidly moved to the hospitalization area in the rescue centre facilities inside a special plastic box with protective pads and subjected to veterinary examination (Solomando et al., 2022). On the contrary, bodies of dead animals were taken to the necropsy chamber for future analysis. Cases not directly notified to Fundación Palma Aquarium Rescue Centre were also taken into consideration within the register of the stranding network of the Balearic Islands. This includes events where private individuals found a specimen and released it by themselves prior to notify the event (e.g., after a liberation of a turtle from an entanglement); or cases that, directly, were not notified but came to light through news, social media publications or by transmitting information.

According to the standards followed by the Fundación Palma Aquarium Rescue Centre, from each registered case, whenever possible, different information is compiled: turtle code number, species, date, location, municipality, island, cause of stranding, status (alive, dead, or unknown), turtle weight and biometrics (CCL, standard Curved carapace length, and SCL; Straight carapace length) upon arrival and finally, the release date of *C. caretta* specimens who entered the rescue centre.

2.2.2. *Events of loggerhead turtle entanglements in the Balearic Islands*

For the 120 cases of entanglement found included in the sea turtle stranding network of the Balearic Islands between January 2018 and September 2022, further information was collected. The data compilation of entanglements was carried out following INDICIT II "Standard protocol to monitor entanglement of sea turtles and biota in marine debris" (INDICIT Consortium, 2021). INDICIT (Implementation Of Indicators Of Marine Litter On Sea Turtles And Biota In Regional Sea Conventions And Marine Strategy Framework Directive Areas), with Indicator Impact Taxa as the short name, is a two-year project funded by the European Union committed to support the implementation of the MSFD (Marine Strategy Framework Directive) by developing a set of standardized tools for monitoring the impacts of litter on marine fauna, including "Marine wildlife entanglement in floating debris (turtles, mammals, birds)" (INDICIT Consortium, 2022; Solomando et al, 2022). In brief, in addition to the information previously collected by the Fundación Palma Aquarium Rescue Centre, for every entanglement case, data on litter size (finger size < 10 cm, hand size 10 – 20 cm, elbow size 20 – 40 cm, arm size 40 – 60 cm, half-body size 60 – 100 cm, 1 person 100 – 200 cm, 2 people 200 – 400 cm, 3-6 people 400 – 1000 cm, >6 people > 10 m, or unknown), size ratio between debris and the entangled turtle specimen (<1 when litter was smaller than the entangled turtle, 1 when size was similar, >1 when litter was larger, or unknown), severity of injuries ("Minor" for quickly healing injuries like mild skin abrasions or epidermal slightly cuts; "Medium" for deeper injuries that will take longer to heal; "Severe" for serious injuries that alter the natural condition of the animal like amputations, bone fractures or deformations; "Extreme" for injuries that kill the animal, both natural or euthanised; and "Unknown") and, finally, the affected part of the body (Head/Beck, Neck, Front flippers, Rear flippers, Carapace, Whole body, Other or

Unknown) (INDICIT Consortium, 2021), was gathered. Data collection on these variables was made possible by images (Figure 10), videos, and documentation (monitoring sheets, veterinary reports, etc.) on entanglement events. All this was provided as part of the database of the registry of the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre. For this reason, for the entanglement events scarcely documented by the registry, many of the variables were classified as "Unknown".

Figure 10. Example of two images of the entanglement event of a *C. caretta* specimen called Jarana, a loggerhead turtle found at sea on 24.08.2022 at Cala Mesquida in Mallorca (Balearic Islands, Spain). (A) Jarana with the left front flipper highly swollen by strangulation of the entanglement, partially removed by the private person who found the turtle. Source: Fundación Palma Aquarium Rescue Centre. (B) Jarana after arriving at the rescue centre inside the plastic transport box along with raffia-based entanglement material and plastic bottles, which were not thrown away but delivered to the rescue centre. Source: Fundación Palma Aquarium Rescue Centre.

In addition, other information on the notification of the event was sought: whether it was correctly reported by calling 112 emergencies number as stipulated in the protocol (Annex 1) or not.

2.2.3. *Entanglement characterization and involved material*

As specified in the protocol established by the Fundación Palma Aquarium Rescue Centre, in case of finding an entangled sea turtle, no rope, wires, plastics or nets that tighten any member of the turtle should be removed, as it can be harmful instead of beneficial (Fundación Palma Aquarium Rescue Centre, 2022) (Annex 1). Then, if the entanglement events are properly notified and the recommendations indicated in the protocol are followed, the turtles arrive at the rescue centre still with the entanglement attached. In any case, whenever the possibility exists, it is intended that the entanglement material reaches the hands of the rescue centre; for example, if it has already been removed from the turtle, it is explicitly requested not to be thrown away (Figure 10). For this reason, the Fundación Palma Aquarium Rescue Centre has a collection of the entanglement material assembled over the years, including those from January 2018 to September 2022. From a total number of 37 items stored as part of the collection of the entanglement material between the mentioned dates, 5 could not be related to its loggerhead turtle affected by that entanglement. Thus, a total of 32 of these items were considered in this study. For each of them, taking advantage that they were physically held, the following data was taken. Firstly, the weight of all the entanglement material hooked and dragged by the turtle, both dry and wet, after immersing it in water to hydrate it, was measured using ADAM Latitude (LBX) series industrial compact bench scale with a capacity of 12 kg and 2 g of resolution. The value of the wet weight was obtained considering that bottles or bags remained empty for those cases of entanglement material which presented those items. Secondly, the presence or absence of plastic bottles (Yes, No, or Unknown) was recorded (Figure 10, B). Finally, all the different plastic items found between the entanglement material (Figure 11) were collected and counted. Organic content including wood pieces, small mollusks and algae fragments were obtained too but were excluded from the count, since organic elements are probably not anthropogenic in origin (Solomando et al., 2022).

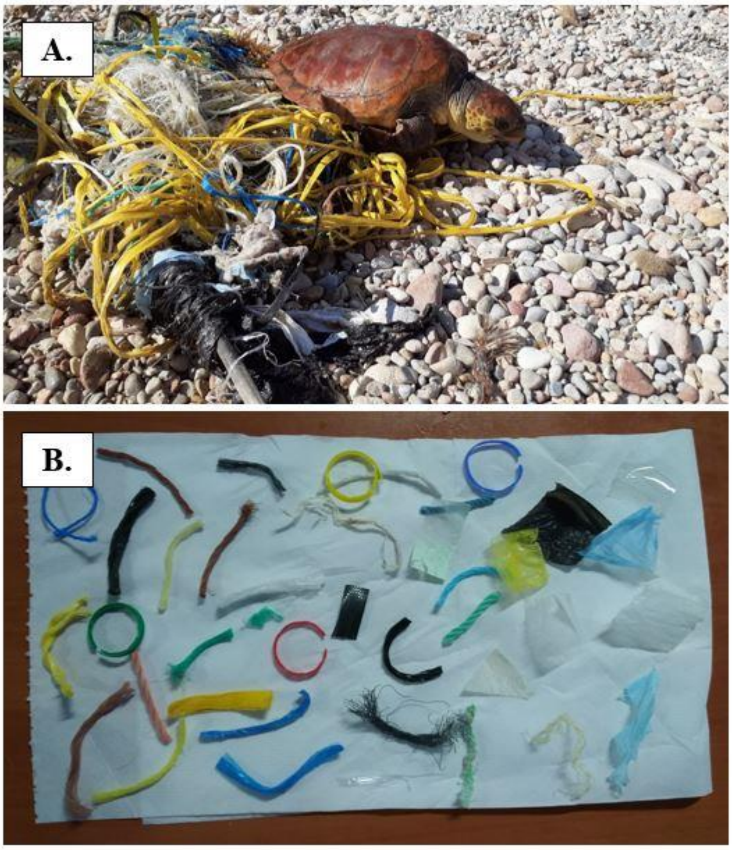


Figure 11. (A) Sea turtle of the species *C. caretta* called Hidra, found stranded with an entanglement on 19.07.2020 at Cala Morell in Menorca (Balearic Islands, Spain). Source: Fundación Palma Aquarium Rescue Centre. (B) Image of the numerous different plastic samples found between the entanglement material of the mentioned specimen. The author's own source.

Finally, for every plastic sample extracted from the 32 analysed entanglement items, other data was collected. In the first place, again following INDICIT II "Standard protocol to monitor entanglement of sea turtles and biota in marine debris" (INDICIT Consortium, 2021), data on litter classification was gathered. That is, if every plastic corresponds to fishing, aquaculture, and maritime uses (fishing nets, lines, ropes, strings, cords, buoys, traps...), if it is packaging-related (plastic bags, heavy-duty sacks, trapping bands...), if it belongs to other land-based sources (textile, medical and hygienic care, recreational related...) or if it is unknown. In the second place, all the different items found among the tangling material, 312 samples in total, were characterized by FT-IR (Fourier-transform infrared spectroscopy) (Bruker OPTICS, Germany) to identify common polymers. This analysis was carried out with the support of the Scientific and Technical Services (STC) at the University of the Balearic Islands (UIB). Following the methodology of Solomando et al. (2022), prior to FT-IR analysis, plastic items were carefully rinsed with deionised water and dried, with the purpose to achieve precise spectra. FT-IR measurements were conducted in attenuated total reflectance (ATR) mode using a wave number range between 400 and 4000 cm^{-1},16 co-added scans and a spectral resolution of 4 cm^{-1} (Solomando et al., 2022). The spectra generated were subjected to baseline correction in order to lessen noise and improve the spectrum quality. All spectra were then compared with commercial and custom-made spectral databases (Annex 2); similarities greater than 70% of Hit Quality Index (HQI) were considered acceptable (Solomando et al., 2022). Only one sample was discarded because of a HQI minor than 70% since the plastic sample, coming from a buoy, was too thick. Organic content including wood pieces, small mollusks and algae fragments, a total number of 5 items, were characterized by FT-IR too but were excluded from the analysis, since organic elements, as mentioned before, are probably not anthropogenic in origin. Thus, out of a total of 312 samples characterized according to FT-IR, 306 were confirmed as plastics and could be classified into different common polymers. Finally, plastic items were classified into different colour categories. Items with more than one colour were classified according to the dominant one.

2.3. Data analysis

2.3.1. *Harmed loggerhead turtle records in the Balearic Islands*

In this study, the mentioned 314 cases of harmed *C. caretta* registered by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre were reclassified according to the cause of stranding following six different categories or modalities: buoyancy problems, entanglement, interaction with fishing (including any fishing gear except longline fishing), longline fishing interaction, other causes (disease, trauma or boat collision) and finally unknown, for events where the reason for the damage was not known.

Following INDICIT II "Standard protocol to monitor entanglement of sea turtles and biota in marine debris", entanglement and other different causes of stranding were quantified as the frequency of occurrence (percentage of loggerhead turtle specimens registered in the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre per every stranding cause), both between the 2018 – 2022 previously mentioned period and individually for every year. In addition, data on frequency of occurrence of the different cause of stranding obtained by Febrer-Serra et al. (2018) were used to make comparisons.

2.3.2. *Events of loggerhead turtle entanglements in the Balearic Islands*

For each category within the variables of location (island), state, circumstance and in relation to timing (month), both absolute and relative frequencies were obtained to study the distribution of cases.

Entangled loggerhead turtle specimens were classified into three life stage groups following Solomando et al., (2022), who defined three size classes in accordance with their CCL size: early juveniles (CCL smaller than 40 cm), late juveniles (CCL 40–70 cm) and adult specimens (CCL larger than 70 cm). They did so by considering that Mediterranean loggerhead turtles switch their habitat from oceanic to neritic when they reach about 40 cm CCL and maturation is achieved near 70 cm CCL (Solomando et al., 2022). Then, frequencies per each one of the three defined life stage groups categories were calculated.

2.3.3. *Entanglement characterization and involved material*

On one hand, for the qualitative variables studied, the characterization of the entangling material and the involved plastic items were assessed by quantifying, as absolute and relative frequencies, the different classes, or categories included for each variable: litter size, size ratio debris/individual, presence of plastic bottles, litter classification according to its origin, polymer type and colour. On the other hand, the average number and standard deviation were calculated for quantitative variables: weight (both dry and wet) and number of plastic items per tangle material.

2.3.4. *Consequences on the entangled turtles*

As regards the impacted loggerhead turtles by entanglement, rate of mortality was calculated as percentage of specimens arrived dead, died during the time of stay at the Rescue Centre of the Fundación Palma Aquarium or had to be euthanized, with respect to the total number of entangled individuals recorded during the study period.

Moreover, relative frequencies on every Impact Severity class and Affected body part were calculated to assess the distribution of impacts caused by entanglement.

2.3.5. *Social aspects*

Finally, in order to assess the level of social awareness and involvement in the cases of entanglement of loggerhead turtles in the Balearic Islands, the number of cases of entanglement notified to the stranding network and those in which the entanglement material was delivered to the Fundación Palma Aquarium Rescue Centre were evaluated. The relative frequency of entanglement cases not properly reported by citizens, tourists, or public authorities to the sea turtle stranding network of the Balearic Islands by calling 112 emergencies number was calculated; as well as the frequency of the number of collected entanglement materials in relation to the total number of cases registered.

2.4. Statistical analysis

The obtained data are shown as average ± standard deviation (SD). For the studied quantitative variables, normality of the data was verified through Kolmogorov-Smirnov Test. Differences between groups were assessed using the non-parametric Kruskal-Wallis test, as well as paired Mann-Whitney's U test. For qualitative variables, differences between groups were tested through Chi square homogeneity Test. Furthermore, association between categories of those qualitative variables was studied via Chi square independence Test in which Yate's correction was applied in case of finding expected values below five. The relationship between the number of plastic items found in every entanglement material and its weight, both dry and wet, was evaluated using the Coefficient of determination (R^2). In any case, a significance level of 5% ($\alpha = 0.05$) was used to determine significant differences. Analyses and tests were performed with the SPSS Statistics Version 25.0 for Windows® and Excel (Microsoft).

2.5. Ethical statement

The *Fundación Palma Aquarium Rescue Centre*, together with the *Servei de Protecció d'Espècies del Govern de les Illes Balears* and the *Consorci de Recuperació de la Fauna de les Illes Balears* (COFIB), is the local authorized Rescue Centre by the Government of Balearic Islands, so it has the competence to attend any stranding of any sea turtle as well as to host and provide veterinary attention to the specimen in order to recover it before releasing them back to the sea. For the development of this study, it was previously necessary to request a special permit from the *Servei de Protecció d'Espècies* of the *Conselleria de Medi Ambient i Territori* of the Balearic Islands. The granting of this permit (Annex 3) authorised, on an individual basis, the capture of this protected species, *C. caretta*, to study the entanglement events and its characteristics. In addition, the study was carried out according to the guidelines of the Local Ethics Committee of the University of The Balearic Islands (UIB).

3. Results

3.1. Entanglement's frequency of occurrence

From January 2018 to September 2022, a total number of 314 loggerhead turtles arrived around the Balearic Islands and its coasts: 40 in 2018, 61 in 2019, 83 in 2020, 74 in 2021 and 56 between January and September 2022; 62.8 ± 16.60 (average ± SD) per year. Without considering the cases registered by unknown cause, entanglement was the main cause of stranding. With 24.0 ± 13.7 (average ± SD) cases of entanglement per year, the frequency of occurrence (%) of entanglements was of 25.0 %, 26.2 %, 55.4 %, 35.1 % and 39.3 % for each year studied (Figure 12, A). Altogether, between 2018 and September 2022, 38.0 % of the *C. caretta* specimens registered by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre showed obvious signs of interaction with marine litter by entanglement (Figure 12, B). Statistically significant differences were identified in the frequency of occurrence (%) of entanglements as a cause of stranding of loggerhead turtles in the Balearic Islands between the study period of 1993 to 2017 (13.7 %), obtained by Febrer-Serra et al. (2018), and the present study, from 2018 to 2022 (Chi square homogeneity test; $p = 0.0001$).

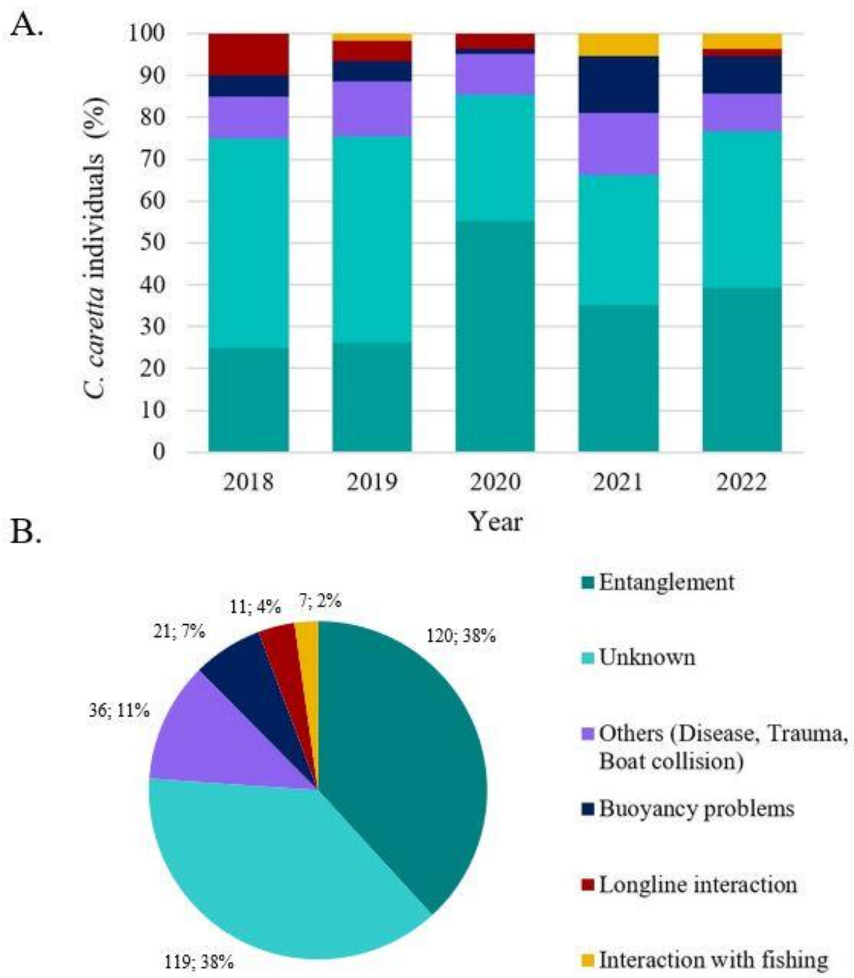


Figure 12. (A) Frequency of occurrence (%) of different stranding causes per year in relation to the total number of cases (N = 314). (B) Number and frequency of occurrence (%) of different stranding causes between the study period (2018 – 2022) in relation to the total number of cases (N = 314).

The frequency of occurrence (%) of the different causes of stranding for the different years considered in this study (2018-2022) are shown in Figure 12, A. Significant differences were found when comparing the frequency of occurrence (%) of the different stranding causes between the studied years (Chi square homogeneity test; $p = 0.002$). Entanglement was the most frequent cause of stranding except in 2018 and 2019, were the lack of knowledge on the cause of stranding meant a higher percentage of individuals registered, 50.0 % and 49.2 % respectively, compared to the turtles that arrived by entanglement (Figure 12, A). Moreover, while significant differences were obtained from the comparison of the number of cases registered for every cause of stranding (Kruskal-Wallis H test; $p = 0.0002$) along the period of study (Figure 13); Mann-Whitney U paired tests showed significant differences between entanglement and every stranding cause except with unknown cases (Figure 13 and Table 1).

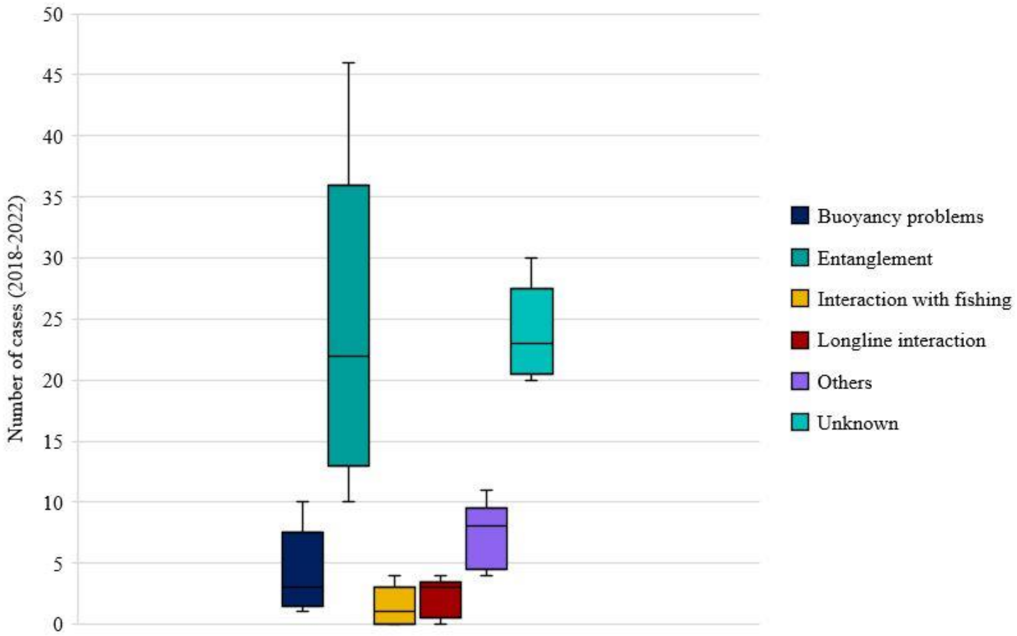


Figure 13. Boxplot of the number of *C. caretta* cases recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre for each stranding cause over the years of the study (January 2018 – September 2022; N = 5 for each cause of stranding, N total = 30).

Table 1. Mean number of *C. caretta* cases (mean ± SD) recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre for each stranding cause per year of the study (2018 – 2022; N = 5 for each cause of stranding) and results of the U Mann-Withney test and significance from the comparison of the number of cases between every cause of stranding and entanglement. * Significant differences (p-value < 0.05).

Cause of stranding	**Number of cases Mean ± SD**	**Entanglement's comparison U Mann-Whitney**	**Significance**
Buoyancy problems	4.2 ± 3.6	0.5	0.0119*
Entanglement	24 ± 13.7	-	-
Interaction with fishing	1.4 ± 1.7	0.0	0.0088*
Longline interaction	2.2 ± 1.7	0.0	0.0088*
Others (Disease, Trauma, Boat collision)	7.2 ± 2.8	1.0	0.0160*
Unknown	23.8 ± 4.0	11.0	0.7540

The rest of the stranding causes (interaction with fishing, longline interaction, buoyancy problems and other causes) maintained a lower frequency of occurrence both throughout the studied period and for each year considered individually (Figure 12), as well as smaller mean number of cases (Table 1). In fact, for interaction with fishing and longline interaction causes, zero cases have been found for some years: 2018 and 2020 for interaction with fishing and 2021 for longline interaction (Figure 12, A).

Finally, considering cases of *C. caretta* stranding for longline interaction, statistically significant differences were found in its frequency of occurrence (%) between the study period of 1993 to 2017 (31.5 %), obtained by Febrer-Serra et al. (2018), and the present study (4.0 %) (Figure 12, B), from 2018 to 2022 (Chi square homogeneity test; p = 2.5571E-7). Even considering the frequency of occurrence (%) of interaction with fishing together with those of longline interaction, since the cases classified as interaction with fishing could be non-detected as cases of longline interaction, significant differences are found in comparison with frequencies found by Febrer-Serra et al. (2018) (Chi square homogeneity test; p = 0.000003).

3.2. Characterization of the entanglement events

Location, Status and Circumstance

From January 2018 to September 2022, a total number of 120 entangled loggerhead turtles arrived around the Balearic Islands and its coasts: 62 reached the coasts of Mallorca and its surroundings, 22 of Menorca, 17 of Eivissa, 16 Formentera (Figure 14) and at an unknown location for the 3 remaining turtles. Most of the specimens were found at sea (87.5 %), while the rest of a *C. caretta* specimens were found stranded (5.8 %) or no information was available (6.7 %) (Figure 14). Moreover, 95.0 % of the turtles were found alive while the remaining 5.0 % were found dead (Figure 14).

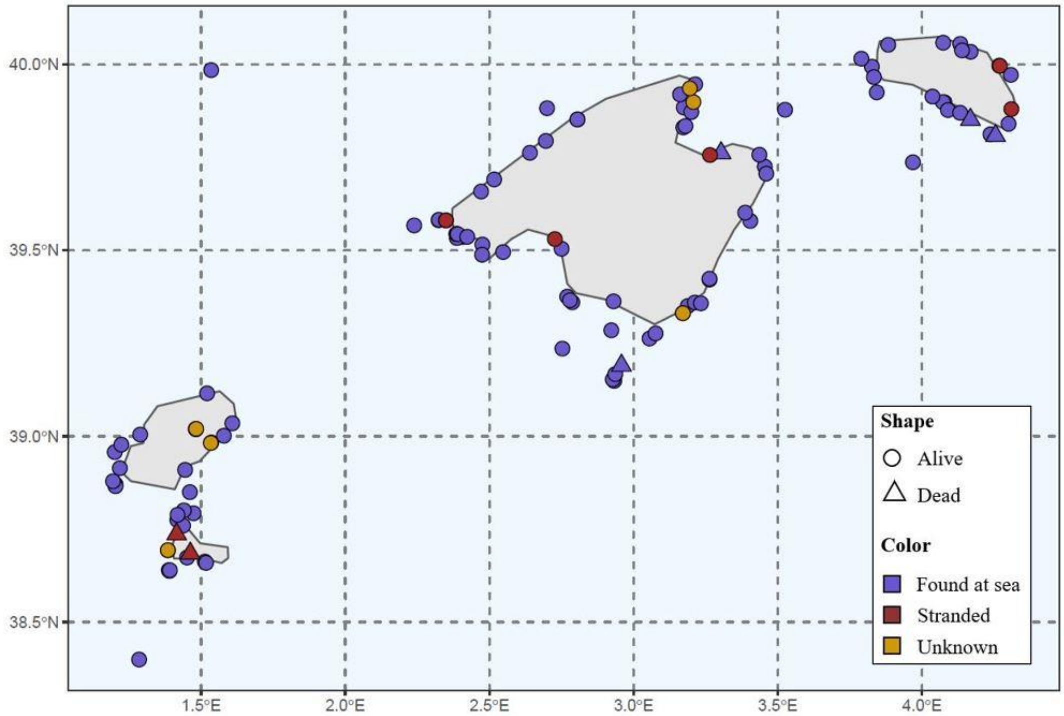


Figure 14. Map of the spatial distribution of events of C. *caretta* entanglements recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre between January 2018 and September 2022 (N = 120). For shapes, the circle represents the alive turtles and triangle the dead specimens. For colours, slate blue is for specimens found at sea, dark red for the stranded ones and gold for the unknown cases.

Timing

Of the 120 entangled *C. caretta* specimens that reached the Balearic coast and its surroundings on a date between January 2018 and September 2022, 118 arrived in a known date. From those, most arrived during the month of August, followed by July (Figure 15). Thus, 72.0 % of the turtles arrived between the summer months of July, August, and September. The two remaining cases arrived at an unknown date.

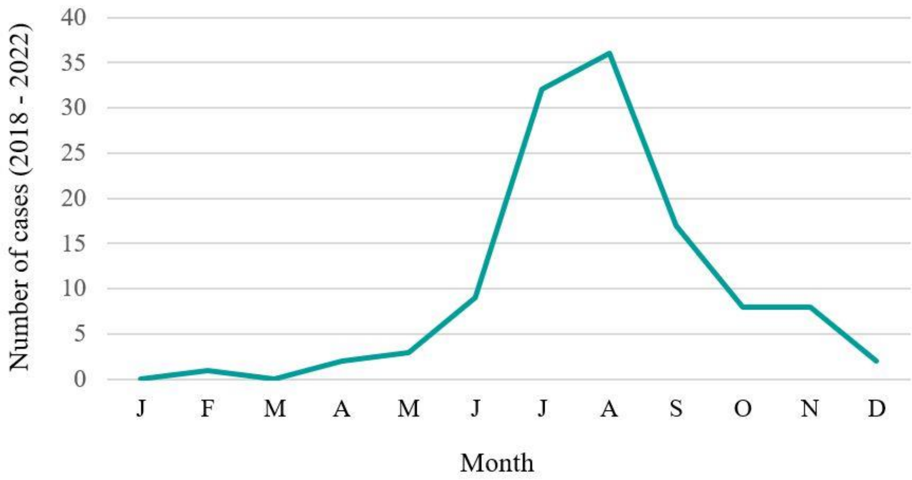


Figure 15. Seasonal distribution of events of C. *caretta* entanglements recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre between January 2018 and September 2022 (N = 118, 2 unknown).

Biometrics of turtles

From the 120 entangled specimens of *C. caretta* analysed, 38 were classified into early juveniles, 47 late juveniles, 6 adults and 29 could not be classified due to lack of information (Figure 16). CCL values ranged from 20.4 to 78.6 cm, with an average of 45.40 ± 15.46 cm (average ± SD). The average size was 30.23 ± 5.49 cm for early juveniles, 53.93 ± 8.11 cm for late juveniles and 74.75 ± 2.78 cm for adults. Weight values ranged from 1.2 to 35.6 kg, with an average of 13.44 ± 10.27 kg. The average weight for the three age stages was 3.50 ± 1.83 kg, 20.58 ± 8.40 kg, and 46.1 ± 7.94 kg, respectively.

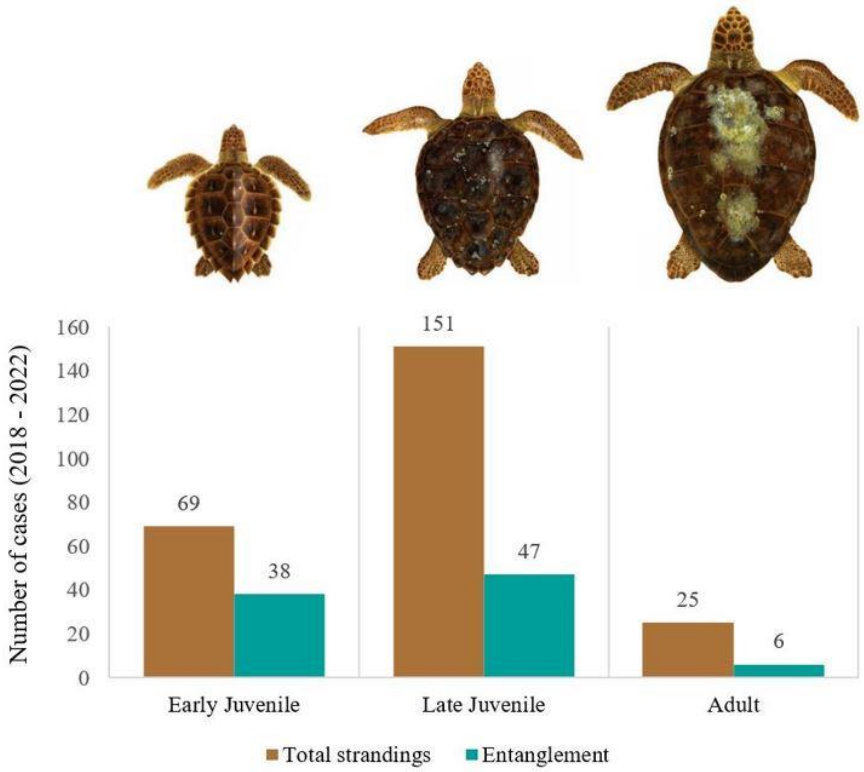


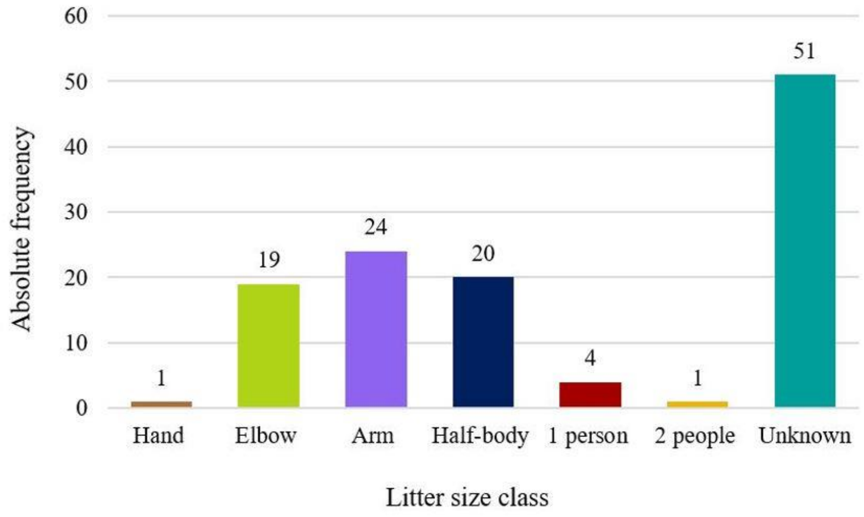
Figure 16. Distribution of life stage groups of C. *caretta* entanglements recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre between January 2018 and September 2022 (N = 91, 29 unknown) in comparison with the total strandings (N = 245, 69 unknown). Loggerhead turtle images adapted from Witherington, 2015.

3.3. Entanglement's material characterization

Measurements: size and weight

Litter size present in 42.5 % of the cases of the 120 entangled specimens of *C. caretta* was mainly unknown (Figure 17, A). Considering the known cases, the obtained main size classes were, in order, arm size (40 – 60 cm), half-body size (60 – 100 cm) and elbow size (20 – 40 cm) (Figure 17, A), which together represent 52.50 % of the cases. No case of entanglement’s material corresponding to finger size, 3-6 people, and >6 people litter size classes were found. Similarly, size ratios between the litter, that is, the entanglement material, and the corresponding loggerhead turtle specimen, were predominantly unknown (Figure 17, B). For the known ones, the size ratio debris/individual of 1 was found for the most part: *C. caretta* specimens were mainly around a similar size in comparison to the litter in which they have been entangled; followed by <1, when litter was smaller than the entangled turtle, and finally >1, cases were litter was larger (Figure 17, B).

A.



B.

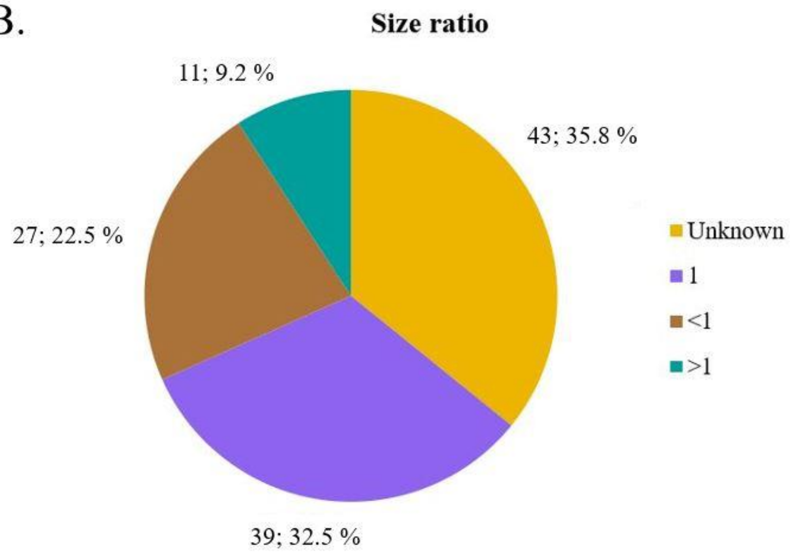


Figure 17. (A) Absolute frequency of entanglement cases per litter size class according to INDICIT II (finger size, hand size, elbow size, arm size, half-body size, 1 person, 2 people, 3-6 people, >6 people or unknown) (B) Number and relative frequency of number of cases per classes of size ratio debris/individual according to INDICIT II (<1 when litter was smaller than the entangled turtle, 1 when size was similar, >1 when litter was larger, or unknown). Both represent the entanglements of C. *caretta* recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre between January 2018 and September 2022 (N = 120).

Frequencies of entangled loggerhead turtles classified for every size ratio debris/individual according to the three identified life stage groups are shown in Figure 18. Significant differences were found when comparing the different size ratio frequencies between life stages (Chi square homogeneity test; p = 0.0036). For those considered variables, association was found between the life stage group category of early juveniles and the ratio of >1 (bigger debris size than the corresponding entangled turtle specimen) in comparison to <1 which was in contrast found between both adults (Chi square independence test, $p = 0.0074$) and late juveniles (Chi square independence test, $p = 0.0015$).

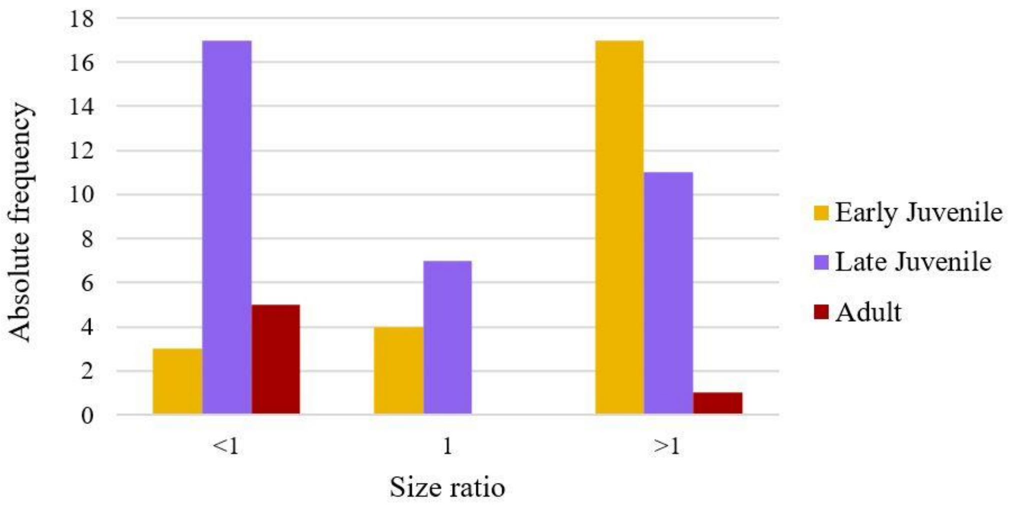


Figure 18. Absolute frequency of the distinct size ratio classes defined by INDICIT II (<1 when litter was smaller than the entangled turtle, 1 when size was similar, >1 when litter was larger), excluding the unknown cases, between the different life stage groups (N = 65). Entanglements of C. *caretta* recorded by the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre between January 2018 and September 2022 are represented.

Of the 32 available entanglement items analysed at the rescue centre, the weight of entangling material, both dry and wet, showed high variability. While dry weight ranged between 2 g and 2 kg, with a 482 ± 600 g (average ± SD), wet weight ranged between 8 g and 3.94 kg, with 1010 ± 1140 g (average ± SD). From the comparison of average dry and wet weights it was obtained that the hydration of the material of entanglement involves approximately the dragging of a weight twice greater by the specimens of *C. caretta*. This was true for 71.9 % of the cases; but 15.6 % showed higher relations, even with one case of a wet weight ten times higher; and 12.5 % showing smaller relations. For both dry and wet weight, no case was found where the weight of the entanglement material was greater than the weight of the loggerhead turtle specimen affected by it: division of the weight of the entanglement material by loggerhead turtle specimen weight was < 1 for all the cases.

Plastic items characteristics

While plastic bottles were not present in a 50.0 % of the different entanglement's material considered, 46.9 % had plastic bottles (Figure 19) forming part of the distinct plastic items in the entanglement material. For the resulting 3.1 %, presence of plastic bottles could not be assessed.

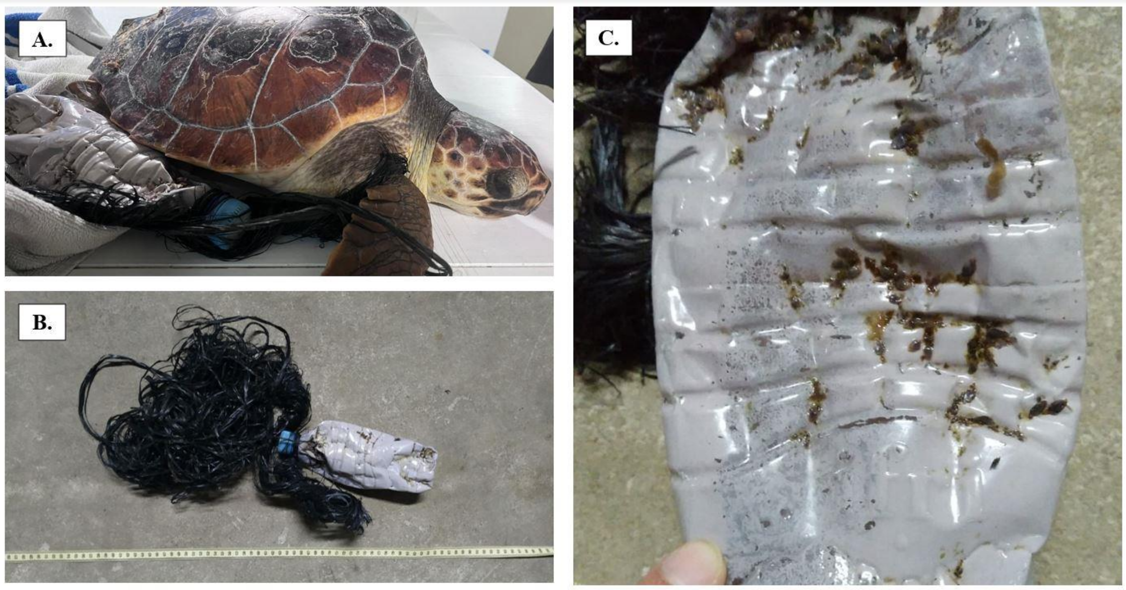


Figure 19. (A) Sea turtle of the species *C. caretta* called Riusec, an early juvenile found stranded with an entanglement on 05.08.2022 in Cabrera (Balearic Islands, Spain). Source: Fundación Palma Aquarium Rescue Centre. (B) Image of the entanglement material which affected the mentioned specimen. The author's own source. (C) Image of the plastic bottle of the brand "Ifri", from Algeria (country of origin and sale), found as an item between the entanglement material of Riusec. The author's own source.

Among the 32 available entanglement items or material analysed, a total number of 306 plastics have been counted. Ranging from 1 unique to 57 distinct plastics, an average of 9.59 ± 11.13 (average ± SD) number of plastics have been found between each one of the studied entanglement materials. No relation has been found between the number of plastic items found in any material analysed and the weight of the corresponding entanglement material, both dry (R^2 = 0.3455) or wet (R^2 = 0.5041).

Results from the litter classification of the 306 plastics found among the 32 available entanglement material according to its origin or source following INDICIT II (fishing, aquaculture and maritime uses, packaging-related items, other land-based sources or unknown) are shown in Figure 20. The most abundant litter class was fishing, aquaculture, and maritime uses, closely followed by packaging-related items, which together accounted for almost all the cases, specifically 91. 2 %. Other land-based sources exhibit a lower frequency. Only 7 of the 306 plastics could not be classified and consequently remain as unknown litter classification.

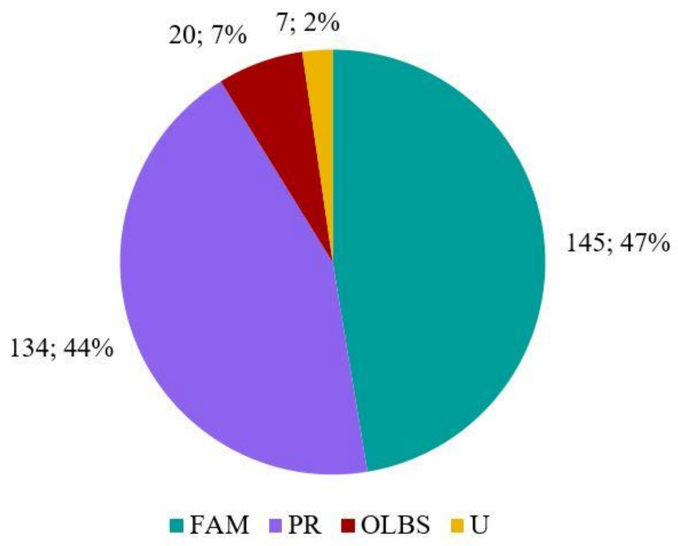


Figure 20. Number and relative frequency of plastic items found for every INDICIT II litter class: fishing, aquaculture and maritime uses (FAM), packaging-related items (PR), other land-based sources (OLBS) or unknown (U).

The 306 plastics found among the 32 available entanglement material analysed could be classified into 10 different types of polymers identified: copolyamide, copolyester, high density polyethylene (HDPE), low density polyethylene (LDPE), polyester, polyethylene terephthalate (PET), polypropylene (PP), polystyrol, polyurethane, polyvinylchloride. PP was the most abundant polymer type identified among the studied plastics, followed by HDPE (Figure 21), which together represent 79.4 % of the plastics found. The rest of the plastics were determined, from highest to lowest frequencies, into PET, polyester, LDPE, and, finally, other polymers which absolute frequency was below five cases, including polyurethan, copolyamid, polyvinylchloride, copolyester and polystyrol. The Hit Quality Index (HQI) obtained for the characterization of the polymers in the analysed plastics ranged between 703 and 980, with 903.2 ± 63.8 (average ± SD).

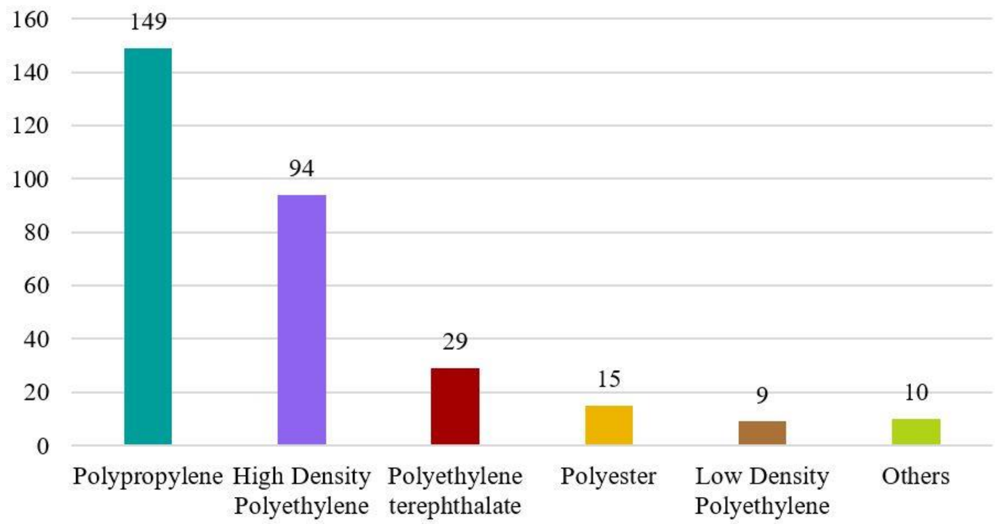


Figure 21. Absolute frequency of plastic items classified into every polymer type identified: Polypropylene, High Density Polyethylene, Polyethylene terephthalate, Polyester, Low Density Polyethylene, and Others (Polyurethan, Copolyamid, Polyvinylchloride, Copolyester and Polystyrol).

Regarding colour, a total number of 11 categories were observed among the plastics found in the 32 available entanglement material analysed: black, blue, brown, green, orange, purple, red, transparent, turquoise, white and yellow. A dominance of blue pieces was detected among the plastics found among *C. caretta* entanglement material (Figure 22), which represented 19.9 % of the cases. Then, from higher to lower frequency, the following colours found were transparent (16.3 %), white (13.4 %), yellow (12.1 %), black (10.5 %), turquoise (8.5 %), orange (5.9 %), green (5.6 %), red (4.9 %), brown (2.6 %) and finally purple (0.3 %). Blue, transparent, white, and yellow elements constituted 61.8 % of the debris entangling loggerhead turtle specimens.

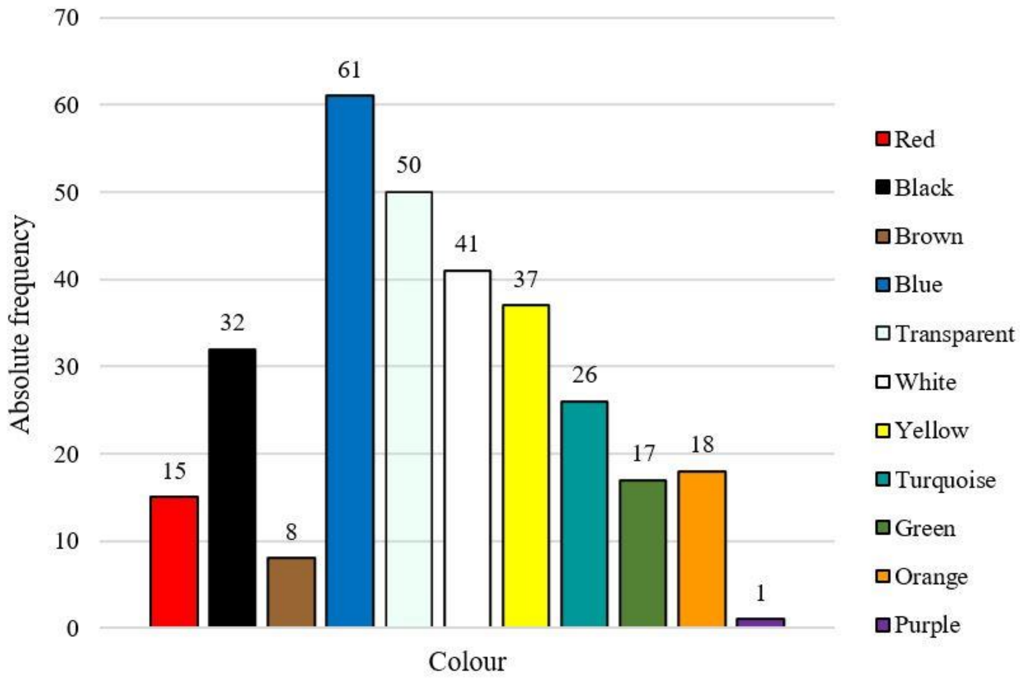


Figure 22. Absolute frequency of plastics according to the 11 colour categories identified: black, blue, brown, green, orange, purple, red, transparent, turquoise, white and yellow.

Significant differences were found from the comparison of both the different polymer type (Chi square homogeneity test; $p = 7.909E-25$) and colour (Chi square homogeneity test; $p = 1.1816E-7$) frequencies between the distinct litter classification groups. Considering only the three most abundant categories both for polymer type (PP, HDPE, and PET) and colour (blue, transparent, and white), significant differences were found between frequencies in the most abundant litter classes (fishing, aquaculture and maritime uses and packaging-related items) (Chi square homogeneity test; $p = 2.2093E-7$ and $6.5013E-8$, respectively). For those considered variables, three cases of association between some of its categories were found. Regarding polymer classification among distinct litter groups of origin, association was found between the polymer PET and the litter class packaging-related, both comparing it with PP (Chi square independence test, $p = 2.39E-07$) or HDPE (Chi square independence test, $p = 1.04E-07$). Regarding colour classification, two associations were found. First, association was found between transparent and packaging-related plastic items, both comparing it with blue items (Chi square independence test, $p = 3.04E-09$) or white ones (Chi square independence test, $p = 0.001021$). And second, association was found between colour blue and plastics coming from fishing, aquaculture, and maritime uses both comparing it with transparent items (Chi square independence test, $p = 3.04E-09$) or white ones (Chi square independence test, $p = 0.016553$).

3.4. Consequences on the entangled turtles

From a total number of 120 entangled loggerhead turtles found between 2018 and September 2022, 16 died, representing a 13.3 %. While 6 of them were found directly dead, the rest, a total of 10 specimens, died after entering the Rescue Centre of the Fundación Palma Aquarium, where they could not be saved or had to be sacrificed.

The classification on the severity of the injuries suffered by the entangled *C. caretta* specimens according to INDICIT II showed a higher number for cases with a severe impacts or affectations, which represented a 34.2 % and included serious injuries that alter the natural condition of the animal (amputations, bone fracture of flippers or carapace, eye loss and body deformations). Following severe affectations, the unknown ones were the most abundant, with 22.5 % of the cases and closely followed by medium effects, with 20.4 %, which comprised deep injuries that take long to heal like deep cuts crossing epidermis and dermis, suffocation and dermatitis affecting a large area of the animal body. As mentioned before, 13.3 % of the cases were extreme since this category encompasses injuries that killed the animal (natural or euthanised in the rescue centre). Finally, the lesser part of the cases was represented by injuries of a minor severity, specifically a 9.2 %, which implied minor injuries that could heal quickly on their own like mild skin abrasions or slightly cuts affecting only the epidermis.

From the known cases (N = 68), the mentioned impacts implied 68.5 ± 53.1 (average ± SD) number of days in the rescue centre, ranging from 9 to 300 days. For the rest of the cases, no information is available, except for two cases of loggerhead turtle specimens that remain under care at the rescue centre.

Regarding the affected body part, 75.8 % of *C. caretta* specimens were entangled in its front flippers. The remaining specimens were affected in the following parts of the body: neck (6.7 %), whole body (5.0 %) and rear flipper (3.33%); to which must be added the 9% of the specimens of which there is no information in this regard. Of turtles entangled by the front flipper, 39.2 % were entangled by the right front flipper, 27.5 % by the left front flipper and 9.2 % with both. For the rear flippers, 3 loggerhead turtles were trapped by its left rear flipper (2.5 %) while only one (0.8 %) by its right rear flipper.

3.5. Social aspects

Of the total of 120 cases of entanglement found between January 2018 and September 2022, 89 (74.2 %) were correctly notified to the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre as stipulated in the protocol (Annex 1). The remaining cases, 31 in total (25.8 %), were not properly notified and therefore limited information is available. In addition, of these 120 cases, only for 32 (26.7 %) the entanglement's material is available and could be examined; so, for the remaining cases (73.3 %) no information about the involved material and its characteristics was accessible.

4. Discussion

According to the available data on loggerhead turtle stranding from recovery centres and stranding networks such the Fundación Palma Aquarium, the reference centre by the Government in the Balearic Islands, entanglement has been shown to be the main cause of stranding of *C. caretta* individuals of the Balearic Islands for the last few years. This trend is evident when comparing the presented data with previous publications such as those of Fernández et al. (2015) and Febrer-Serra et al. (2018), where the frequency of occurrence of entanglements was 12% (1993 - 2014) and 13.70% (1993 - 2017), respectively. In fact, statistically significant differences have been found between the frequency of occurrence of entanglements obtained by Febrer-Serra et al. (2018), between the period 1993 – 2017 (13.7 %, as mentioned) and the present study (38.0 %), between 2018 – 2022. Therefore, this data indicates that there has been a significant increase in cases of entanglement of loggerhead turtle in Balearic Islands in recent years. In accordance, when analysing the changes in the frequency of occurrence of stranding cases by interaction with the longline fishing gear, a clear trend of reduction has been also observed between the suty period of Febrer-Serra et al. (2018) (31.5 %) and the current study period (4.0 %). These results confirm the already known progressive reduction in cases of longline interaction due to the increased use of the semi-pelagic long-line since around 2008 (Camiñas et al., 2021), as well as a decrease in the stranding cases by longline hooks, noticed by Febrer-Serra et al. (2018) from 2009. Thus, after several publications pointing out longline interaction as the main threat to the loggerhead turtle in the Levantine-Balearic demarcation for several years (Carreras et al., 2004; Margaritoulis et al., 2003; Revelles et al., 2007), the interaction with longline is no longer the greatest threat to this species in the Balearic Islands, but the entanglement in marine litter. Actually, since significant differences have been found between the number of cases of entanglement and the other known stranding causes, entaglement is noticed as the main threat to loggerhead turtles at present. Nonetheless, the lack of significant differences between the number of cases of entanglement and stranding by unknown cause, highlights the magnitude of the importance of cases where there is a lack of knowledge and information regarding threats to the loggerhead turtle. In fact, for the last few years, stranding due to unknown cause have turned out to be as important as reported entanglements.

With reference to characterization of these entanglement events, the present study has shown important results. The rates of entanglement in debris may be greatly underestimated since reports of incidences like entanglement are scarce between scientific literature and, it is likely that many individual cases of entanglement are never published (Nelms et al., 2016). Therefore, while it is clear that entanglement with anthropogenic plastic materials such as discarded fishing gears and land-based sources is an under-reported and under-researched threat to marine turtles (Duncan et al., 2017), the use of stranding data from expert records like the sea turtle stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre has given the opportunity to gain an initial baseline information around this events happening to loggerhead turtles in the western Mediterranean. General trends in both spatial and temporal distribution of this events have been obtained in this study, showing a concentration in the largest island, Mallorca (Figure 14), and between the summer months of July, August, and September (Figure 15). In terms of spatial distribution, entanglement's allocation corresponds to studies like Fernández et al. (2015) and Solomando et al. (2022), which identified Mallorca as the island with greatest numbers of loggerhead sea turtle specimens found stranded. Likewise, results found on temporal distribution of entanglements are in line with known seasonal trends from both the study of strandings and the sightings of loggerhead turtles in the archipelago. Carreras et al. (2004) found that sighting reports of loggerhead turtles from fishermen peaked from late spring to late summer, while Fernández et al. (2015) and Cardona (2015) indicated a higher presence of turtles during the summer months according to strandings. A clear season pattern with a significant increase in the summer months was found, which can be attributed to different aspects. First, the presence of more *C. caretta* specimens in the surroundings of the Balearic Islands (Fernández et al., 2015): the Balearic Islands have been demonstrated to be an important spring-summer feeding area, leading to a seasonal concentration of loggerhead turtles between the warm season (Camiñas et al., 2021), while few turtles remain around the islands during winter (Margaritoulis et al., 2003). Secondly, the increase in tourist pressure associated to that time of the year. Particularly during the summer, the beaches of the Mediterranean Sea are a hotspot for leisure, especially for those who are looking for the three S's—sea, sand, and sun (Grelaud & Ziveri, 2020). Due to the region's natural and cultural resources and desirable climate, the Mediterranean Sea is one of the biggest tourist regions in the world (UNEP, 2015). The good climate enhances the use of the coast for recreational activities, what favours the increase of detections and a consequent raise on stranding warnings. And, finally, an increase in waste production, since marine litter from shoreline and recreational activities is highly connected to the mentioned tourism activities (UNEP, 2015). Actually, Compa et al. (2020) found out almost two-fold as much plastic in coastal water in August in comparison with the other months.

While the present results indicated that all life stages of *C. caretta* had been affected by entanglement, differing entanglement rates among life stages groups showed a higher incidence of entanglements in juvenile loggerhead turtles. Generally, there are few investigations of the susceptibility to debris entanglements of the various sea turtle life stages (Blasi et al., 2016). Furthermore, despite Duncan et al. (2017) considered that entanglement could have an effect at the population level, larger rates of entanglement in juveniles were also found by Blasi et al. (2016). The latter, specifically, found that turtles that were entangled in debris were smaller (mean CCL = 38.2 ± 9.5 cm), which is equivalent to an early juvenile according to the classification followed in the present study. In fact, although the results showed a higher number of late juveniles affected by entanglement compared to early juveniles, the proportion of entanglements in relation to the total number of strandings is much higher for early juveniles (Figure 16). More than half of all the early juveniles registered by the stranding network of the Balearic Islands of the Fundación Palma Aquarium Rescue Centre arrived because of entanglement. Even though most recorded strandings are of late juveniles, a smaller proportion of these are due to entanglement. This interaction is probably due to the characteristic pelagic phase of juvenile loggerhead turtles, which are dependent on drift-lines for their food supply and shelter (Anastasopoulou & Fortibuoni, 2019). The currents that form drift-lines and transport *C. caretta* specimens to oceanic convergence zones also concentrate floating anthropogenic debris, resulting in a trap for these young turtles, that, with greater susceptibility, may become entangled (Anastasopoulou & Fortibuoni, 2019; Galgani et al., 2015). Indeed, adult loggerhead sea turtles are capable to better discriminate colours to find food and reduce the probability of biting non-preferred preys (Camedda et al., 2014; Solomando et al., 2022; UNEP, 2015), which means an advantage over juveniles in the possibility of avoiding a potential entanglement. Several studies indicate that demography in loggerhead turtle populations is particularly sensitive to changes in the growth and mortality of older juveniles and adults, pointing out that the loss of late juveniles and adults has a more dramatic impact on populations than the loss of younger individuals (eggs, hatchlings, and younger juveniles) (Báez et al., 2013; Carreras et al., 2004). Therefore, although rookery protection is a priority for marine turtle conservation, the protection of large juveniles and adults is also necessary for the successful of an effective measure accoding to those studies, which recommend greater efforts to reduce mortality in large juveniles and adults as they have an increased potential reproductive value. However, as the development and survival of young turtles is critical for the persistence of the species, it should be emphasized to generate greater understanding of the impacts of plastic entanglement for this life stage and, therefore, the future population viability (Nelms et al., 2016). In this sense, it is worth highlighting how information on strandings aid with the assessment of harder-to-access life stages, yielding key information on the risk to specific populations and contributing to building a global perspective for conservation issues (Duncan et al., 2017).

Respect to the distribution of entanglements between the different loggerhead turtle life stage groups and, consequently, its size, the size of the entanglement material has been studied. Since most of the registered entangled turtles have been classified as late juveniles and most of the material studied corresponds to intermediate size measurements (elbow size, arm size and half-body size) (Figure 17), it is not surprising that the most frequently encountered size ratio debris/individual is 1 (similar sizes between debris and specimens). In any case, it should be noted that there is a great abundance of cases of entanglement in which the information in this sense remains unknown; in fact, it supposes most of the cases for both variables (litter size and size ratio debris/individual). Considering that these are two variables to determinate according to the INDICIT II "Standard protocol to monitor entanglement of sea turtles and biota in marine debris", this huge lack of knowledge acquires more transcendence. As mentioned before, the aim of INDICIT II is to monitor entanglement in European waters through the collection of standardized data and, it is therefore clear that there is an urgent need to gather more information on these standardized tools in the Balearic Islands to address this problem. To conclude with the comparison of individual and litter sizes, it should be noted that association between the smallest turtles, the early juveniles, and the ratio of <1 has been found from the analysis of the abundance of ratios for each life stage group. This is probably due to the previously referred tendency of young turtles to align along drift-lines, where plastic accumulates (Galgani et al.,

2015) along with the fact that juveniles tend to be under floating objects in search of shelter to avoid predation (Anastasopoulou & Fortibuoni, 2019; Duncan et al., 2017; NOAA Marine Debris Program, 2014).

As part of the studied entanglement materials, from 1 to 57 (9.59 ± 11.13) number of distinct plastics items have been found. In addition, since no relationship has been found between the number of plastics and the weight of the entanglement material, it is seen that monotypic entanglements, based on a single material, are not necessarily lighter and, consequently, smaller. This may indicate that any type of entanglement material, of any size, weight or with greater or lesser number of plastics, is likewise a threat to loggerhead turtle. Another issue to highlight is the important presence of plastic bottles (46.88%) that has been found. In fact, it was possible to identify a plastic bottle coming from Algeria (Figure 19), which fits with the type of waste collected last year by the Alnitak Research Institute, a Spanish non-profit organisation that sail the Mediterranean Sea with a strong will to preserve the oceans. This last year, they have found more than 40 m^3 of marine litter mostly based on rudimentary artefacts linked to North African refugee camps, as well as ghost FADs, illegal surface longlines and illegal drift nets (Alnitak Research Institute, 2022). In this sense, the obtained results from litter classification of the present study reveal a fairly equitable presence of both marine litter stemming from fishing, aquaculture, and maritime uses (47%) and by packaging-related sources (44%) (Figure 20). This is in accordance with Blasi et al. (2016), who found that *C. caretta* resulted impacted both by land-based sources and by sea-based sources; but not with other studies that determined between 69 and 80% of the litter coming from land sources and between 20 and 26% from sea-based sources in the Mediterranean (Galgani et al., 2015; Joint Research Centre & Institute for Environment and Sustainability, 2011). Or even in comparison with the Food and Agriculture Organization (FAO), whose estimates determine that 70% of the macroplastics found in the sea are ALDFG and consequently, coming from sea-based sources and closely linked to IUU activities (Alnitak Research Institute, 2022; Toole, 2017).

Regarding characteristics of plastic items, the obtained outcomes are in line with the general Mediterranean trends (Deudero & Alomar, 2015): plastic is the main component found among entanglements affecting loggerhead turtles in the Balearic Islands. Both land and sea-based sources of marine litter found between the entanglement material are based on synthetic materials that can remain in the marine environment for decades (Duncan et al., 2017) and, consequently, constitute a major part of marine debris. Polypropylene (PP) and high-density polyethylene (HDPE) have been the most common synthetic polymers found among the entanglement materials of the affected loggerhead turtles, followed by polyethylene terephthalate (PET), polyester and low-density polyethylene (LDPE). The other synthetic polymers were found less frequently. This proportion corresponds to results found by Suaria et al. (2016), who tested that plastic distribution and composition in the relative occurrence of different polymer are not homogeneous between Mediterranean sub-basins and that western Mediterranean is dominated by low-density polymers such as polyethylene (HDPE and LDPE) and PP. In addition, this proportion also closely resembles that of the global production stocks of plastic materials, with polyolefin (PE and PP) leading the global plastic demand (EPRO, 2020; Suaria et al., 2016) and accounting for approximately an 80% of the sampled plastics among the entanglement material. As the fate of the different polymers depends on their physico-chemical properties and the environmental conditions (Moore et al., 2008), it is not surprising that the mentioned polymers, widely used in the disposable packaging industry and having lower densities than seawater, constitute the majority of the plastic polymers floating in surface waters (Suaria et al., 2016) and, consequently, becoming an important part of the entangling materials that affect the loggerhead turtle in the Balearic Islands. To finish talking about the polymers found, it is worth mentioning that the association found between PET and the litter class packaging-related it is not surprising since PET is a resin commonly used in the production of beverage and textile packaging such as bottles for drinking water, soft drinks, juices, cleaners, etc. (EPRO, 2020). Concerning plastic colours, the most common found between entanglement materials were blue, transparent, white, yellow, and black (Figure 22); the same colour prevalence found by Martí et al. (2020) from the colour characterization of thousands of items collected with surface trawling plankton nets at the global scale. Considering the inherent interaction of sea turtles with debris due to its behaviour (Anastasopoulou & Fortibuoni, 2019) and the slow and long-term nature of the entanglements, affected turtles can increase the ingestion of plastic from marine debris more easily (Blasi et al, 2016). For that reason, to compare colour preferences between studies of interaction of loggerhead turtle with marine litter, both entanglement and ingestion, could be of interest. Solomando et al. (2022), from the study of loggerhead turtle plastic ingestion in the Balearic Islands, found an analogous predominance of white and transparent, but also a very small proportion of blue. Although the issue of colour preference is controversial in studies of marine turtles (Galgani et al., 2015), similar tendencies were obtained by Casale et al. (2016) from the central Mediterranean, what contrasts with the predominance of blue found between the entanglement material. Association has been found between plastics coming from fishing, aquaculture, and maritime uses and colour blue; as well as between packaging-related plastic items and transparent. Thus, it could be that the huge proportion of blue among the entanglement material is due to a large interaction of turtles with plastics coming from sea-based sources like ALDFG or FADs. Anyway, further research would be necessary to understand possible interactions and differences between ingestion and entanglement with respect to colour preference and turtle's perception.

With respect to the physical consequences suffered by entangled turtles, it should be noted that many species vulnerable to entanglement are scattered across wide ocean areas and individuals that become entangled and die may quickly sink or be consumed by predators at sea without being detected (Anastasopoulou & Fortibuoni, 2019). This is probably why only 5% of the entangled turtles were found dead, while the rest were found alive (Figure 14). Thus, while entanglement of sea turtles and other species in marine debris is the most visible effect of plastic pollution on marine organisms (Anastasopoulou & Fortibuoni, 2019), the estimated mortality rates and the effects of entanglement on the population dynamics are probably underestimated. (Anastasopoulou & Fortibuoni, 2019). The lack of published literature means that the scale of entanglement-induced mortality in loggerhead turtle is unknown, as are the population level impacts of such mortality (Nelms et al., 2016). In this sense, although this study has not allowed to obtain of a mortality rate, the proportion of loggerhead turtles killed because of entanglement has been assessed: 13.3 % of the entangled loggerhead turtle specimens died, most of them dying once at the Rescue Centre of the Fundación Palma Aquarium and a few, as already mentioned, found directly dead. In addition, it must be considered that entanglement may cause long-term suffering and a slow deterioration (Blasi et al., 2016), which could contribute to the fact that directly observed mortality is rather reduced. Furthermore, the fact that there is a great lack of knowledge around the cause of stranding, as important as the number of entanglement cases, could be causing part of the entanglement cases and their impacts to be omitted and, consequently, underestimated. In connection with impacts on the entangled loggerhead specimens analysed, although no case where the weight of the entanglement material was greater than the weight of the affected specimen was found, severity of the injuries was mainly severe, followed by medium, extreme (death) and finally, a few cases of minor severity. Nonetheless, again, an important number of cases where no information in this regard is available was found. In any case, from the known records, entangled *C. caretta* specimens were characterized by suffering significant effects. In fact, from 9 to 300 days (68.51 ± 53.13) were needed for these individuals to recover from those severe impacts that altered their natural condition and hampered them in many senses: in their ability to move, feed, and breathe (Kühn et al., 2015). This, together with the fact that for the most part of the cases (87.51 %), the weight of the entanglement is doubled and even more when posed inside the water, it is not surprising that most of the entangled loggerhead specimens were found at sea (87.5 %) in comparison with cases in which turtles reached the coast and were found stranded (5.8 %). To end with the impacts, it should be noted that most of the entanglements occurred in the front flippers, predominantly in the right. For the rest of the cases, turtles became entangled or injured at the neck, the whole body, and posterior limbs, which is not so far from what Anastasopoulou & Fortibuoni (2019) evidenced in cases of loggerhead turtles interacting with debris of FADs.

Finally, with respect to social aspects, a significant lack of knowledge has been detected in many senses. First, of all known entanglement cases, almost 26.0 % were not correctly reported, and, second, only 26.7 % of the entangling material was given to the Fundación Palma Aquarium Rescue Centre and was able to be collected for its study. This facts, together with a great proportion of strandings recorded by unknown cause, the number of entanglement cases possibly missed in the stranding network and the great rate of entanglement cases classified as unknown for many of the studied variables, confirms that entanglement is an under-reported threat to marine turtles (Duncan et al., 2017). Despite turtle entanglement is being recognised as one of the major sources of turtle mortality in many areas including the Mediterranean with *C. caretta* having the highest number of entanglement records in the Mediterranean Sea (Blasi et al., 2016), a quantitative knowledge gap exists with respect to the entanglement rates and their potential implications in terms of global populations (Duncan et al., 2017; Nelms et al., 2016). In this context, the present study has given a general picture of the characteristics of this type of events in the Balearic Islands in many senses. First, rates of entanglement between loggerhead turtle populations in the islands has been obtained, what emphasises the importance of long-term stranding records and highlights the importance of a collaborative programme with the Marine Fauna Recovery Centres which, in addition to contributing to the recovery of injured animals, displays a wide collection of information on stranded specimens ((Duncan et al., 2017; Febrer-Serra et al., 2018). In fact, since population trends are difficult to measure in these migratory species, studies on stranding registers provide very important information on threat factors and demographic parameters, which is very useful in the management for the conservation of this species (Febrer-Serra et al., 2018). Second, valuable information has been gathered about this type of event, the characteristics of the material involved and, finally, the affected loggerhead turtles. Obtaining this type of information is of great importance to better understand this threat and its magnitude, as well as the vulnerability of this species, which is essential to set conservation priorities, advise management decisions, and develop appropriate mitigation measures (Nelms et al., 2016). The polymeric characterization, for example, is of paramount importance to identify sources and sinks of plastics and to better understand fate and impacts of different polymers, so that knowledge-based reduction and prevention measures, as well as specific solutions and alternatives, can be effectively implemented (Suaria et al., 2016). And third, the present study has made it possible to identify those areas where information is lacking, which allows the determination of the way forward as part of future strategies to improve knowledge about this problem and to fill the gaps. In any case, the collaboration between stakeholder groups such as strandings networks, recovery centres, fisheries, scientific community and research institutions and navigators is crucial to aid in producing urgently needed research to fill knowledge gaps, providing mitigating actions and improving education for the issue of entanglement (Duncan et al., 2017). In fact, in the context of the Balearic Islands, efforts are already being made in this regard by several organizations and institutions. The Fundación Palma Aquarium, for its part, has an environmental education programme from which it is carrying out a great task of dissemination for the awareness by talks in schools, clean-up days, collaboration with events of other entities and dissemination in social networks. As part of this important mission, emphasis is placed on citizen collaboration for the registration of entanglements, as well as the correct response when finding a turtle in this situation (Annex 1). For its part, *Observadores del Mar,* a citizen science platform for marine research and conservation, together with Marilles Foundation and the *Consejo Superior de Investigaciones Científicas* (CSIC), has developed a project called "Ghost fishing" that allows the integration of reports and cases of entanglement in a platform for collecting data. For the moment, several collaborators have provided data on this type of events: Fundación Palma Aquarium, Equinac, *Oceanogràfic de Valencia*, *Centros de Gestión del Medio Marino Andaluz* (CEGMA), *Confederación Española de Pesca* (CEPESCA), Sea Shepherd, *Alianza de Pesca Española Recreativa Sostenible* (APERS), and technicians of the Cabrera National Park among others (Alnitak Research Institute, 2022). Furthermore, training and resources for collaborating entities and individuals are provided by this project. Despite that the problems created by marine debris are difficult to address (Gregory, 2009) and will very much depend on future waste governance (Duncan et al., 2017), all the mentioned efforts, together with European Union tools like the 2008/56/EC Marine Strategy Framework Directive (MSFD; European Commission, 2008) (Camedda et al., 2014), intentional conventions like MARPOL with Annex V prohibiting the dumping of plastics into the ocean (NOAA Marine Debris Program, 2014), and monitoring platforms and projects that gather standardized information at both international and national levels like INDICIT II, look after an improvement in the situation caused by this problem, which is currently affecting loggerhead turtle populations.

4.1. Future improvements and considerations

There are several considerations that future studies in this line of work could contemplate. First, it should be noted that several study variables proposed by the INDICIT II protocol could not be studied in this research (body condition and body condition index of the turtle, animal size range, main injuries, mesh size and twine characteristics of litter coming from fisheries). In that sense, a possible improvement would be to also consider these variables as part of the study, which would allow characterizing in more detail the entanglement events. Secondly, it is important to recognise the biases associated with using stranding specimens for data collection since within and between stranding sites there are differences in turtle foraging ecology, life stages and proximity to human habitation and, therefore, they are exposed to different levels and types of potential entangling materials (Duncan et al., 2017). For that reason, the collection of standardized data by collaborating stranding networks from different regions would mean a substantial improvement. Third, since, as mentioned above, entanglement may be associated with other problems or threats such as ingestion, it would be of great interest to study and understand the interaction and relationship between the different problems affecting *C. caretta* specimens. And finally, considering that the level of biofouling could indicate the age of ghost gear or other materials entangling marine turtles (Duncan et al., 2017), it would be very useful to study the fauna associated with both the entanglement material and turtle's carapace to estimate the approximate time from the entanglement. This could be related with the consequences suffered by the affected specimen and the severity of their injuries, what will be useful to better understand vulnerability.

5. Conclusions

- The results obtained in the present study have demonstrated that entanglement is the main threat affecting loggerhead turtles in the Balearic Islands for the last few years.

- Both the spatial and temporal distribution of entanglement events corresponds to what was expected according to previous studies, but larger rates of entanglement of early juveniles suggested a need for further research.

- Debris sizes and ratios according to turtle sizes pointed out different vulnerability among life stage groups.

- Entanglement materials showed a resemblance to both global and regional characteristics of marine litter in terms of polymer type and colour, but not as clearly in relation to sources.

- As a consequence of entanglements, mainly affecting front flippers of the turtles, a proportion of moderate mortality but high severity in the injuries was found.

- Despite stranding records have been demonstrated to be a useful tool to obtain important results about entanglement, a generalized lack of knowledge and underestimation emphasises the need for more studies and greater collaboration from various areas to better understand this threat.

6. References

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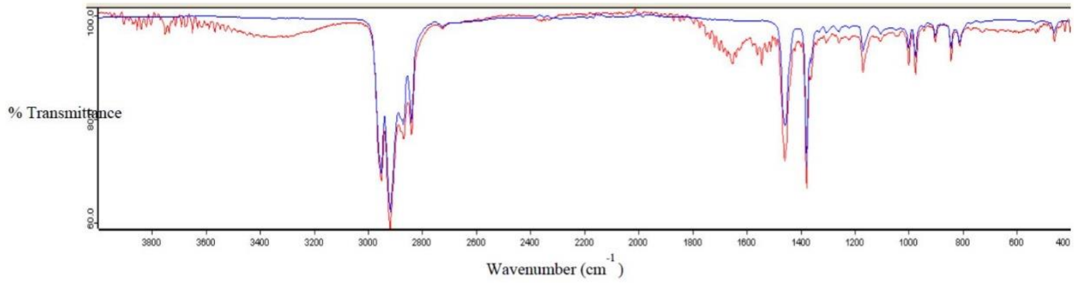
8. Annexes

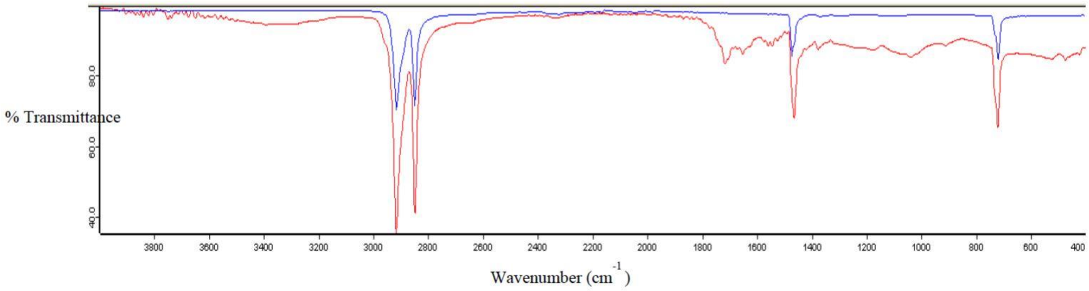
8.1. Annex 1 – Established protocol by the Fundación Palma Aquarium Rescue Centre in case of finding a stranded sea turtle.

8.2. Annex 2 – FT-IR spectrum examples of (A) Polypropylene and (B) High Density Polyethylene. The red spectrum corresponds to the spectrum of the analysed plastic and the blue spectra come from a spectral database or library.

A.



B.



8.3. Annex 3 – Special permit given from the *Servei de Protecció d'Espècies of the Conselleria de Medi Ambient i Territori* of the Balearic Islands with the purpose to carry out the present research work.

GOIB CONSELLERIA
MEDI AMBIENT
I TERRITORI
DIRECCIÓ GENERAL
ESPAIS NATURALS
I BIODIVERSITAT

AUTORITZACIÓ ESPECIAL PER A LA CAPTURA D'ESPÈCIES PROTEGIDES

Referència: CEP 10/2022

Titular	Rita Font de Benito
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E-mail	info@fundacionpalmaaquarium.o
Entitat	UIB
Aval	Fundació Palma Aquarium
Espècie/s	*Caretta caretta*
Quantitat	Indeterminada
Illa	Mallorca
Zona	Indeterminada
Finalitat	Estudis de material d'emmallament i epibionts a tortugues marines (TFM)
Mètode captura	n.a.
Condicions	1.- L'ús d'aquesta autorització en Espais Naturals Protegits requereix l'autorització prèvia de l'organisme gestor de l'espai. Així mateix, s'organitzarà amb aquest la logística de les visites. 2.- Abans d'un mes finalitzada la vigència de l'autorització, cal remetre informe detallat del seu ús al Servei de Protecció d'Espècies i al Servei d'Espais Naturals (CMAIT-CAIB) 3.- L'autorització és personal i intransferible, i el seu titular és responsable del seu ús 4.- Cal tenir accessible l'autorització mentre se'n faci ús i presentar-la si és requerida
Condicions particulars	
Normativa	Article 61.1.d del text refós de la Llei 42/2007 del Patrimoni Natural i la Biodiversitat

Vista la sol·licitud de l'interessat i la normativa aplicable, inform favorablement la petició formulada

Palma, 03 de març de 2022

El cap del Servei de Protecció d'Espècies,
Ivan Ramos Torrens

Vista la proposta, s' APROVA L'AUTORITZACIÓ
El director general d'Espais Naturals i Biodiversitat,
Llorenç Mas Parera

CONSELLERIA DE MEDI AMBIENT I TERRITORI
GOVERN DE LES ILLES BALEARS

Data inici 03/03/2022 **Data caducitat** 31/12/2022

INFORME A REMETRE DESPRÉS DE LA DATA DE CADUCITAT:
Dates i localitats on s'ha fet ús de l'autorització
Espècie i nombre d'exemplars capturats o recol·lectats, en el seu cas
Destí del material (en cas d'espècies catalogades, s'han de dipositar prioritàriament en col·leccions públiques
Observacions o suggeriments en relació amb l'autorització o les espècies autoritzades

En cas que el titular publiqui resultats a l'empara de l'autorització, cal incloure a la publicació referència Expressa a aquesta autorització, i el Servei de Protecció d'Espècies agraira que se n'hi envii còpia.

C/Gremi Corredors, 10 1er pis Polígon Son Rossinyol 07009 Palma
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