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Risk assessment reveals high exposure of sea turtles to marine debris in French Mediterranean and metropolitan Atlantic waters

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ABSTRACT

Debris impact on marine wildlife has become a major issue of concern. Mainy species have been identified as being threatened by collision, entanglement or ingestion of debris, generally plastics, which constitute the predominant part of the recorded marine debris. Assessing sensitive areas, where exposure to debris are high, is thus crucial, in particular for sea turtles which have been proposed as sentinels of debris levels for the Marine Strategy Framework Directive and for the Unep-MedPol convention. Our objective here was to assess sea turtle exposure to marine debris in the 3 metropolitan French fronts. Using aerial surveys performed in the Channel, the Atlantic and the Mediterranean regions in winter and summer 2011–2012, we evaluated exposure areas and magnitude in terms of spatial overlap, encounter probability and density of surrounding debris at various spatial scales. Major overlapping areas appeared in the Atlantic and Mediterranean fronts, concerning mostly the leatherback and the loggerhead turtles respectively. The probability for individuals to be in contact with debris (around 90% of individuals within a radius of 2 km) and the density of debris surrounding individuals (up to 16 items with a radius of 2 km, 88 items within a radius of 10 km) were very high, whatever the considered spatial scale, especially in the Mediterranean region and during the summer season. The comparison of the observed mean debris density with random distribution suggested that turtles selected debris areas. This may occur if both debris and turtles drift to the same areas due to currents, if turtles meet debris accidentally by selecting high food concentration areas, and/or if turtles actively seek debris out, confounding them with their preys. Various factors such as species-specific foraging strategies or oceanic features which condition the passive diffusion of debris, and sea turtles in part, may explain spatio-temporal variations in sensitive areas. Further research on exposure to debris is urgently needed. Empirical data on sea turtles and debris distributions, such as those collected aerially, are essential to better identify the location and the factors determining risks.

1. Introduction

Ubiquitous, anthropogenic debris are endangering marine ecosystems and the ecological services they provide (Derraik, 2002). Plastics, mostly originating from land-based sources, constitute the predominant part of marine debris (Derraik, 2002; Barnes et al., 2009; Andrady, 2011). Their resistance and lightness cause them to accumulate and diffuse in the marine environment (Andrady, 2011; Ryan et al., 2009) and thus to threaten a wide range of taxa (Rochman et al., in press). Many species become entangled or collide with broad items, or ingest fragmented debris, either because they may confuse them with their prey, and/or because they may not discriminate them in their food bowl (Mrosovsky, 1981; Laist, 1987). Beyond direct mortality, debris more frequently trigger sub-lethal effects related to habitat loss, alteration of movements, decreased absorption of nutrients or disruption of the endocrine system due to consumption of leached toxic substances. All of these impacts may decrease individual chances of survival and reproduction, and possibly disrupt the entire food chain (Derraik, 2002; Gregory, 2009).

The number of species identified to be impacted by marine debris is increasing: 267 species were listed in 1997 (Laist, 1987). Now more than 600 species are known to be affected (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF, 2012), including marine bird species (van Franeker et al., 2011), fish (Boerger et al., 2010) and

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cetaceans (de Stephanis et al., 2013). All seven sea turtle species, six of which are listed by the IUCN as threatened (The IUCN Red List of Threatened Species version 2015-4), are also concerned (Schuyler et al., 2014a; Nelms et al., 2015). Entanglement of sea turtles in macro-debris or fishing gear is a major and pressing issue of concern (Gregory, 2009; Wilcox et al., 2013; Vegter et al., 2014; Nelms et al., 2015). Cases of ingestion have been more widely studied, particularly in the loggerhead turtle *Caretta caretta* (Nelms et al., 2015). It has been shown that very small pieces of debris can result in the death of individuals (Bugoni et al., 2001; Santos et al., 2015). Otherwise, debris can accumulate in the digestive tract for several months (Lutz, 1990) and may lead to malnutrition, affected buoyancy and diminished swimming capacities, or to other chronic effects depending on the species' foraging strategy or on debris characteristics (Schuyler et al., 2014a; Nelms et al., 2015). These effects decrease turtles' chances to feed, or avoid predators or interactions with anthropogenic activities, and may have potential demographic consequences (Schuyler et al., 2014a; Nelms et al., 2015).

Marine animals which are exposed to floating debris can also be used as environmental sentinels, e.g. in the fulmar *Fulmarus glacialis*, the digestive content is used as an indicator of regional plastic pollution for the Convention for the Protection of the Marine Environment of the North-East Atlantic (The OSPAR convention), which aims to take all measures to protect the maritime area against pollution in the North-East Atlantic region (van Franeker et al., 2011). The complex life history of sea turtles leads them to use a wide range of habitats and marine compartments during their ontogenetic development, increasing their potential exposure to marine debris (Mansfield and Putman, 2013; Casale et al., 2007). Being widely distributed in the Mediterranean Sea and the European Atlantic Ocean and being prone to ingest debris, make them possible indicators of debris levels in surface and shallow waters at a large spatial scale. For these reasons, debris ingestion by *Caretta caretta*, which is higher in the Mediterranean compared to the Atlantic and the Pacific oceans (Tòmas et al., 2002; Dell'Amico and Gambaiani, 2013; Camedda et al., 2014), was proposed as an indicator of marine debris levels ashore or at sea for monitoring the Good Environmental Status (GES) as defined by the Descriptor 10 ("Marine Litter") of the Marine Strategy Framework Directive (MSFD) ("indicator 10.2.1", Galgani et al., 2013) and the Unep-MedPol convention ("indicator El 18"). In order to establish conservation measures for the protection of sea turtles and consider them as sentinels of their environment, identifying the sensitive areas where sea turtles are exposed to debris and where they thus risk to ingest them or to be entangled, is thus crucial.

Plastic is known to accumulate in ocean gyres, as in the so-called "ocean garbage patches" of the Atlantic and Pacific (Moore et al., 2001; Law et al., 2010; Eriksen et al., 2014; Ryan, 2014; van Sebille et al., in press). Dense human population accentuates pollution in the European waters, and the configuration of the Mediterranean Sea causes this area to be one of the most polluted worldwide (Cózar et al., 2015; Suaria and Aliani, 2014). Necropsies or observations of the faeces of live individuals performed in the last decade showed inter and intra-regional variations in debris ingestion by sea turtles (Dell'Amico and Gambaiani, 2013; Darmon et al., 2014; Nelms et al., 2015). For example, within the Mediterranean Sea, the occurrence of loggerhead turtles having ingested debris in the North Western Mediterranean area varies from less than 15% in Sardinia (Camedda et al., 2014) to more than 70% in Tuscany (Campani et al., 2013) and almost 80% in Spain (Tòmas et al., 2002). This suggests that the chance to encounter debris is not random and diffuse but rather concentrated in specific high risk areas (i.e. where the probability for sea turtles to be exposed to debris is higher). These high risk areas may be related to regional hydrological characteristics due to the convergence of currents and downwellings. They appear to be preferential foraging areas for sea turtles but also areas in which floating debris accumulate (Witherington et al., 2012; Cózar et al., 2015). As sea turtles are obligate air-breathers, they most likely occupy the surface waters, where they may actually encounter floating debris.

Our objective here is to assess where sensitive areas are situated and to evaluate the exposure of sea turtles to marine debris in the metropolitan French Mediterranean and Atlantic (the Channel, the Brittany and the Bay of Biscay) waters. Studies aiming to identify hazard areas, where turtles are likely to interact with debris, have recently been highlighted as crucial (Nelms et al., 2015). Such studies are only emerging, possibly because they require combined data, both on animal and debris spatial distributions, which may require heavy technologies for data collection on large spatial scales. Authors have generally used simulation-based approaches established from data on species and debris spatial distributions or debris ingestion found in literature (Schuyler et al., 2015; Wilcox et al., 2015), but rarely real data. Empirical data collected by ship and aerial surveys may yet provide valuable information in order to evaluate and locate sensitive zones, by targeting the areas where turtles and debris spatially overlap. In this study, we explore data collected during the Marine Megafauna Aerial Survey (SAMM) campaign carried out in winter and summer 2011–2012 on the 3 fronts of the French metropolitan maritime domain, during which sea turtles and marine debris were recorded (Pettex et al., 2014). We evaluated (i) debris and sea turtle spatial distributions and overlap, (ii) the probability of sea turtles to be exposed to debris and (iii) the quantity of debris surrounding them at close distances, i.e. where they may be susceptible to be in contact with, and thus ingest, collide or be entangled with debris. Sea turtles may select debris concentration areas, either directly if, for example they confound them with prey (Schuyler et al., 2014b), or indirectly, if debris drift into their displacement routes or are enmeshed within their food (Witherington et al., 2012). In order to examine this hypothesis, we tested (iv) if the observed degree of exposure was similar to a theoretical degree of exposure found with a random distribution of debris.

2. Material and methods

2.1. Study area and data collection

The study area included the 3 fronts of the metropolitan French Exclusive Economic Zone (the Mediterranean, the Channel and the Atlantic waters), extended to the adjacent waters (the English Channel, the Spanish waters of the South of the Bay of Biscay and the Italian waters in the Pelagos sanctuary). The area covers 559,000 km^2 (Fig. 1).

Aerial censuses were performed in winter and summer 2011–2012, the first from 3rd November 2011 to 15th February 2012, the second from 15th May to 15th August 2012. The observations were performed from a Britten Norman twin plane equipped with two side "bubble" windows. Two observers respectively noted the location and number of sea turtles and marine debris among the marine mammals and birds for which the sampling plan was first designed. The data were recorded by a third person on board. The plane flew 183 m above sea surface at a constant speed of 90 knots, along linear transects covering the entire zone. In order to take into account the influence of bathymetry on visibility, the transects were homogeneously distributed in zigzag over 4 strata (Fig. 1): the "coastline strata", extending from the coastline to the neritic area, covering 12 nautical miles; the "neritic strata" from the coastline to the 200 m isobath, corresponding to the continental shelf; the "continental slope strata" from the 200 m to the 2 km isobaths; the "oceanic strata" beyond the 2 km isobath, which includes abyssal plains. Three regions were differentiated: The Channel region, as part of the Greater North Sea, which comprises the entire North front as far as the North sea