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Floating macro-litter along the Mediterranean French coast: Composition, density, distribution and overlap with cetacean range

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ABSTRACT

This study investigated the composition, density and distribution of floating macro-litter along the Liguro-Provençal basin with respect to cetaceans presence. Survey transects were performed in summer between 2006 and 2015 from sailing vessels with simultaneous cetaceans observations. During 5171 km travelled, 1993 floating items were recorded, widespread in the whole study area. Plastics was the predominant category, with bags/packaging always representing >45% of total items. Overall mean density (14.98 items/km^2) was stable with significant increase reported only in 2010–2011; monthly analysis showed lower litter densities in July–September, suggesting possible seasonal patterns. Kernel density estimation for plastics revealed ubiquitous distribution rather than high accumulation areas, mainly due to the circulation dynamics of this area. The presence range of cetaceans (259 sightings, 6 species) corresponded by ~50% with plastic distribution, indicating high potential of interaction, especially in the eastern part of the area, but effective risks for marine species might be underrepresented.

1. Introduction

Marine ecosystem is affected by various pressures related to human activities, such as coastal urbanisation, commercial and recreational maritime traffic, resources exploitation by fishery or drilling operations (Coll et al., 2012; Halpern et al., 2008). Anthropogenic pollution is a by-product of all these activities, representing an input of unnatural substances in the ecosystem. The Mediterranean Sea represents a particularly sensitive ecosystem for the coexistence of high impacts and biodiversity richness (e.g. Coll et al., 2012; Pérès, 1978); indeed, the strong anthropogenic pressure, represented by the surrounding industrialised countries and high shipping levels, can jeopardize the fragile ecological balance of this semi-enclosed basin.

Marine litter is defined as any persistent manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (Coe and Rogers, 1997; Galgani et al., 2013). The complex path of marine litter includes sources, dispersal, fragmentation, degradation and release of new chemical compounds, deposition: thus, besides aesthetic impacts, debris represents hazards for marine life as it can interact with all levels of the trophic chain spoiling the normal ecosystem functioning (Baulch and Perry, 2014; Coe and Rogers, 1997; Cole et al., 2011; Derraik, 2002; Gall and Thompson, 2015; Gregory, 2009; Laist, 1997; Simmonds, 2012). For example, floating litter can help the dispersion of small invertebrates over broad ranges, potentially favouring also the distribution of alien species (Aliani and Molcard, 2003; Barnes, 2002; Derraik, 2002; McKinney, 1998); the accumulation on the seabed can provoke hypoxia in the benthic communities (Derraik, 2002; Goldberg, 1994). Interactions between litter and marine organisms have been reported for 693 different species, mainly occurring through entanglement and ingestion (Gall and Thompson, 2015): physical wounds, reduction of mobility, limitation of feeding success, blockage of the intestinal tract are among the detrimental consequences (e.g. Derraik, 2002; Gregory, 2009; Laist, 1997; Mato et al., 2001). Among all debris, plastic is the most ubiquitous and long-lasting material (Barnes et al., 2009; Derraik, 2002; Moore, 2015): it represents up to 80% or sometimes more of the waste that accumulates on land, shorelines, ocean surface or seabed (Barnes et al., 2009). Its slow degradation after ingestion by a variety of species causes an increased exposure to chemicals, enhance the availability and accumulation of persistent pollutants in the food chain (Carpenter and Smith, 1972; Cole et al., 2011; Davison and Asch, 2011; Engler, 2012; Fossi et al., 2016, 2014; Mazzariol et al., 2011; Ryan et al., 1988; Simmonds, 2012), besides playing a role in transporting other toxic substances (Endo et al., 2005; Mato et al., 2001; Teuten et al., 2007; Thompson et al., 2004).

Given the exponential increase in use of artificial polymers, therefore in waste production (PlasticsEurope, 2015), research has been

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expanding regarding this topic, especially to better understand sources, patterns and potential effects on ecosystems and human health in the long-term. In Europe, marine litter is included in the descriptors of the Marine Strategy Framework Directive for the evaluation and monitoring of ecological status of marine waters (MSFD), requiring the characterisation of the trends in the amount of litter in the water column, including floating at the surface (EC, 2008; Galgani et al., 2013, 2010). Accordingly, high trophic level organisms are considered as indicators for monitoring the effects of litter in marine ecosystems (Fossi et al., 2012a; Galgani et al., 2014, 2010).

Surveying marine litter at surface can provide reliable estimate of its abundance and distribution patterns before it meets its unpredictable fate. Monitoring programmes of floating litter have been developed over wide geographical areas, reporting higher abundances generally related to shipping routes (Carić and Mackelworth, 2014; Ryan, 2013), urbanised coastal regions (Hinojosa and Thiel, 2009; Matsumura and Nasu, 1997; Thiel et al., 2013, 2003) and oceanic currents systems (Law, 2010; Shiomoto and Kameda, 2005; Yamashita and Tanimura, 2007).

The Mediterranean Sea has been indicated as one of the areas of highest concentrations of marine waste in the world (Barnes et al., 2009; Eriksen et al., 2014; Jambeck et al., 2015; van Sebille, 2014), comparable to the levels of the five large oceanic accumulation patches (Collignon et al., 2012; Cózar et al., 2015; Suaria et al., 2016). Many studies have been focusing on beach litter (Ariza et al., 2008; Golik and Gertner, 1992; Munari et al., 2016; Poeta et al., 2014), seafloor (Galgani et al., 1996, 1995; Galil et al., 1995; Pham et al., 2014; Stefatos et al., 1999; Tubau et al., 2015) and floating macro-litter (Aliani et al., 2003; Kornilios et al., 1998; McCoy, 1988; Morris, 1980; Suaria and Aliani, 2014). However, different techniques, sea compartments and periods of research prevent uniform assessments of pollution loads (Deudero and Alomar, 2015; Ryan, 2013; Suaria and Aliani, 2014). Besides, litter distribution is strongly influenced by the variable circulation patterns of the basin where high energy systems, like the Liguro-Provençal Current, play a determinant role in redistributing floating particles (Mansui et al., 2015; Millot, 1999).

Interactions with plastic have been reported in the Mediterranean Sea for many cetacean species of both oceanic and coastal habitats (Cuvier's beaked whale (*Ziphius cavirostris*), fin whale (*Balaenoptera physalus*), sperm whale (*Physeter macrocephalus*), striped dolphin (*Stenella coeruleoalba*), bottlenose dolphin (*Tursiops truncatus*)) (e.g. De Stephanis et al., 2013; Deudero and Alomar, 2015; Fossi et al., 2014; Gomerčić et al., 2006; Levy et al., 2009; Mazzariol et al., 2011), mainly using data obtained from stranded animals, then representing only the small portion of detectable impacts (Baulch and Perry, 2014). For example in the Mediterranean Sea, the death of a sperm whale of 4.5 t, was attributed to 7.6 kg of plastic debris in its stomach, which was ruptured probably due to the large plastic load (De Stephanis et al., 2013) and one bottlenose dolphin died due to nylon filaments wrapped around his larynx (Levy et al., 2009). Given the widespread exposure of animals to this threat, focusing studies on regions of high biodiversity and richness takes on a significant meaning from a conservation point of view (Fossi et al., 2012a; Galgani et al., 2014), as well as reporting about the areas where overlap between pollution and wildlife occurs and is detected at an early stage (Coll et al., 2012; Fossi et al., 2016). For all these reasons, in this study we wanted to investigate the presence of floating macro-litter in the Liguro-provençal basin in relation with the presence of cetaceans. Indeed, the Liguro-provençal Sea is characterised by high offshore primary productivity, which attracts a variety of predators, including six species of cetaceans (*Tursiops truncatus*, *Stenella coeruleoalba*, *Globicephala melas*, *Grampus griseus*, *Physeter macrocephalus*, *Balaenoptera physalus*) (Laran et al., 2016; Notarbartolo di Sciara and Birkun, 2010). This area is important for the feeding and reproduction of cetaceans and especially during the summer period (from the end of spring to the autumn) when the six species of cetaceans are present in large quantities. We therefore wanted to know if the aggregation zones of floating macro-litter were those where the majority of cetaceans were observed. For this we provided a robust assessment conducted between 2006 and 2015 by contemporary observation on litter and marine life, in particular cetacean species. Data were collected during various campaigns conducted by EcoOcéan Institut (Nouvel Horizon, IMPACT-CET), and supported by WWF-France (Cap cétacés) and the Nicolas Hulot Foundation (Objectif cétacés). Aims of this research were: 1) to characterise floating macro-litter by composition, abundance and density over the whole study period; 2) to verify monthly (2007–2008) and yearly variations in composition, abundance and density; 3) to investigate distribution patterns of plastics and cetacean species, in order to provide a preliminary indication of areas of co-occurrence and potential risk.

2. Material and methods

2.1. Study area

Surveys were carried out in the Liguro-Provençal basin within different campaigns conducted along the Mediterranean French region of Provence-Alpes-Côte d'Azur and Principality of Monaco. Some surveys extended in open sea and towards the Corsican coast, but for more detailed analysis we selected only an area of about 100 km width were the majority of effort was performed (Fig. 1).

The Ligurian Sea is characterised by narrow continental shelf and steep descending slope reaching up to 2000 m depth. As for the whole northern Mediterranean, water dynamics is influenced by the permanent cyclonic circulation of the Liguro-Provençal Current, with its minor branch entering the continental shelf of the Gulf of Lion. Marked atmospheric forcing due to dominant north-westerly winds can affect general circulation, inducing vertical mixing, local enrichment and production activity (Béranger et al., 2010; Millot, 1999).

The study area is partially included in the Pelagos Sanctuary for the protection of marine mammals (Notarbartolo di Sciara et al., 2008), with which shares ecological importance and species richness. Seven cetacean species are considered regular in this basin: striped dolphin, fin whale, sperm whale, long-finned pilot whale, Risso's dolphin, bottlenose dolphin and Cuvier's beaked whale (Laran et al., 2016; UNEP, 2013). Nevertheless, this area suffers high levels of anthropic pressure: in particular, it is crossed by shipping routes depending on the major port movements of Marseille, Toulon and Nice, but also seasonally characterised by pleasure boats traffic (Campana et al., 2015; David et al., 2011). The coastline is in fact dotted with famous touristic destinations (cities, islands, parks) which become particularly busy in summer months.

2.2. Survey methodology

Visual surveys of floating macro litter (>1 cm) were conducted from sailing vessels between 2006 and 2015, mainly during summer months (Fig. 1). Surveys were performed simultaneously with transects looking for cetaceans during 98 days at sea: marine litter surveys were interrupted when cetaceans were sighted and registered, then resumed as the observations were over. Sampling was carried out in standard conditions at a speed around 6 (± 0.5) knots with three observers standing at the bow of the boat, approximately 3 m above sea level. They continuously scanned 180° ahead of the vessel, sighting all floating macro-litter and reporting it to a fourth person who recorded the time, type, size and number of objects seen. In parallel, information on sea state, light conditions as well as wind force were taken down, and a GPS continuously recorded the boat's position. For this study we only considered marine litter from anthropogenic sources and it was classified in three main categories: “Plastics”, “Styrofoam” and “Other items”. The Plastics category included: Bags (packaging, films, wrappings, sheets, divided in small, medium and large fragments), Bottles, Cans and Other plastic. In order to reduce the bias due to bad visibility, in our analysis we only took into account the surveys conducted in sea state ≤2 Beaufort.

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