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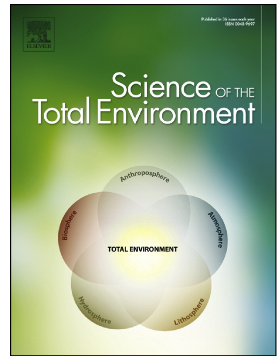

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Massive Coastal Tourism Influx to the Mediterranean Sea: the Environmental Risk of Sunscreens

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Abstract

The Mediterranean region is, by far, the leading tourism destination in the world, receiving more than 330 million tourists in 2016. This tourism is undertaken mostly for seaside holidays, and during the summer season concentrates between 46% and 69% of the total international arrivals; this is equivalent to a density of 2.9 tourists per meter of Mediterranean coast, or double this number taking into account the local/permanent population in addition. Previous studies have reported not only the presence of sunscreen in the various environmental compartments (water, sediments and biota) of the Mediterranean Sea (MS) and other regions, but also show that sunscreen products are toxic for marine biota and are accumulated and biomagnificated. Here, we highlight that the environmental risk of these chemicals is likely to be exacerbated in the MS due to the massive influx of tourists and its densely populated coasts, the basin's limited exchanges with the ocean, the high residence time of surface waters, and its oligotrophic waters.

The Mediterranean Sea

The Mediterranean Sea (MS) presents a number of physical, chemical, biological and socioeconomical peculiarities that make it different from other marginal seas: it is a semi-enclosed basin where evaporation exceeds precipitation and river discharges. This has generated a hydric deficit that is partially compensated with a limited water exchange with the Atlantic Ocean through the narrow Strait of Gibraltar (12.8 km width and over 300 m depth), that is the only connection with the open ocean. The Strait limits exchanges with the ocean, resulting in extended residence times of surface waters (3.8 and 7.7 years for the Western and Eastern Mediterranean, respectively) (Powley et al., 2016), a tidal signal of the order of centimeters (Tsimplis et al., 1995) and higher salinity (up to 39.1 PSU) and temperature (up to 28 ºC) in the upper water columns of the MS than in the Atlantic Ocean (36.0 - 36.5 PSU; 13.5 – 20 ºC, respectively) (Said et al., 2011). These unique characteristics make the MS an important "hot spot" of marine biodiversity, with approximately 17,000 marine species (many of them endemic) (Coll et al., 2010, and references therein).

Higher biodiversity occurs in coastal areas and continental shelves of the MS with unique and endangered habitats such as seagrass meadows and vermetid reefs (Coll et al., 2010). The most important community sheltering sediments in the MS are the *Posidonia oceanica* meadows. This marine phanerogam endemic of the Mediterranean, included in Annex II of the Protocol of the Barcelona Convention 1996 as an endangered marine species, plays a critical role in the coastal ecosystems, and is considered to be the key controlling the natural equilibrium in the MS.

The concentration of inorganic nutrients in the water mass of the MS is low, especially for phosphorous, with the main inputs coming from continental weathering, wet and dry atmospheric deposition (Bethoux et al., 1999). The low availability of nutrients in the MS prevents high primary productivity, leading to oligotrophic conditions that give a blue and crystalline appearance to their waters. The climate is mild and wet during the winter and hot and dry during the summer and has 250 days of sunshine a year (Sain et al., 2002). All this, together with a rich cultural heritage and favorable sociopolitical situation, create the idyllic scenery of the Mediterranean Sea coastal regions that attract millions of tourists every year and make Europe the worldwide leader in international tourism.

Coastal Tourism in the Mediterranean Sea

Since the end of 2nd World War international tourist arrivals in the European Union (EU) have increased every year, reaching 1,239 million arrivals in 2016 (compared with 25 million in 1950). The EU thus accounts for 40% of total global tourist arrivals and 50% if we include arrivals from the EU countries themselves. This yields a ratio of 680 international arrivals per 1000 inhabitants (World Tourism Organization (UNWTO), 2018). With a Gross Domestic Product (GDP) of € 14,900 billion in 2016, the EU constitutes the second largest economy in the world. This tourism generated € 1,108 billion in international tourism receipts. The most visited countries are those with coastal areas around the MS; and although they benefit economically, they are also exposed to an intense tourism pressure (Batista e Silva et al., 2018). International arrivals during 2016 to the countries on Mediterranean region reached 329.2 million in total: France (82.6 million), Spain (75.6 million), Italy (52.4 million), Turkey (39.5 million in 2015), Greece (24.8 million), Croatia (13.8 million), Morocco (10.3 million), Tunisia (5.7 million), Egypt

(5.3 million), Albania (4.1 million), Cyprus (3.2 million), Slovenia (3.0 million), Israel (2.9 million), Malta (2.0 million), Montenegro (1.7 million), Algeria (1.7 million in 2015), Bosnia-Herzegovina (0.8 million), and Monaco (0.3 million) ("UNWTO Tourism Highlights, 2017 Edition | Tourism Market Trends UNWTO,") (Figure 1). These extremely high numbers of international visitors, comparable to the population of the third most populated country in the world, the USA with 327 million in 2018, together with the local population living in the coastal regions (143 million in 2000 and estimated in 174 million by 2025) (UNEP, 2015), is certain to be generating an enormous pressure of unpredictable effects on the coastal ecosystems of the Mediterranean.

The Mediterranean tourism takes the form, mostly, of seaside summer holidays; consequently the months from June to September concentrate between 46-69% of the total nights spent at tourist accommodation establishments in coastal areas, that is a measure of tourist visits (data from 1991 to 2011 for Spain (46%), Italy (49%), Greece (57%), Croatia (69%), Cyprus (51%) and Slovenia (48%); Figure 2) (data available from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tour_occ_ninatc&lang=en). Considering the 46,000 km of Mediterranean coastline and assuming that 132 million tourists (that is, a conservative estimate of 40% of the total visitors) stay during their summer vacation on or near to the coast, this is equivalent to a density of 2.9 tourists per meter of coast during summer season. And if we include 143 million holiday-makers of the local/permanent population, this density may be double.

Sunscreens as a new coastal threat

There are many identified impacts on the Mediterranean marine environment associated with coastal tourism, such as marine litter (UNEP/MAP, 2015), aquifer overexploitation, insufficient sewage treatment capacity (Kent et al., 2002), and loss of biodiversity (Habibullah et al., 2016), among others. However, intimately linked to the growth of coastal tourism and awareness of the risks associated with exposure to ultraviolet radiation (UV) is the use of sunscreens, an everyday skincare products used in modern society, and its release into the environment.

Sun protection is the most important segment of the sun care market with expenditure of more than € 7.0 billion forecasted in 2014, and Europe accounts for 32 % of the total world market (Osterwalder et al., 2014). Given the large and widespread consumption of these products and the multitude of chemical ingredients included in their formulation, sunscreens have recently been identified as emerging contaminants in coastal waters (Tovar-Sánchez et al., 2013; Tsui et al., 2014). One of the major components of sunscreens are organic and inorganic UV filters, substances with a range of light protection in the range of 320-400 nm (UVA) and 280-320nm (UVB) and with almost zero absorption of visible radiation (Díaz-Cruz and Barceló, 2009; Salvador and Chisvert, 2005). These UV filters are used in the formulation of many everyday products by modern society.

Organic UV filters have been detected and quantified in Mediterranean seawater (Giokas et al., 2004, 2005; Cuderman and Heath, 2007; Tarazona et al., 2010; Vidal et al., 2010; Nguyen et al., 2011; Amine et al., 2012; Magi et al., 2012; Tovar-Sánchez et al., 2013; Benedé et al., 2014) and in Mediterranean sand and sediments (Sánchez-Brunete et al., 2011; Tarazona et al., 2014; Benedé et al., 2018). Furthermore, organic

UV filters have been detected in biota from the Mediterranean coast, including in species of commercial importance such as mussels, clams and fish (Bachelot et al., 2012; Cunha et al., 2015, 2018).

The presence and/or toxicity of the organic and inorganic UV filters included in the formulation of these skincare and cosmetic products has attracted special attention in recent years. Some organic UV filters (such as 2-hydroxy-4-methoxybenzophenone, 4-methylbenzylidene camphor, isoamyl 4-methoxycinnamate or 2-ethylhexyl salicylate among others) have been found to be bioaccumulated in mussels (Castro et al., 2018; Vidal-Liñán et al., 2018), corals (Tsui et al., 2017), crabs, shrimps, prawns, squids and fish (Peng et al., 2017; Molins-Delgado et al., 2018); these chemicals have also been detected in the liver of dolphins from the coast of Brazil (Gago-Ferrero et al., 2013), in cormorants from Switzerland (Fent et al., 2010), and in unhatched eggs of birds species from the Natural Park of Doñana (SW of Spain), thus proving the biomagnification of these substances (Molins-Delgado et al., 2017). Moreover, these compounds cause a variety of different biological and toxicological responses, affecting survival, behavior, growth, development and reproduction, and these responses have been observed at various trophic levels: algae (Paredes et al., 2014; Giraldo et al., 2017; Mao et al., 2018), corals (Downs et al., 2014, 2016), mussels (Paredes et al., 2014; Giraldo et al., 2017; Moschino et al., 2017; Sureda et al., 2018), sea urchins (Paredes et al., 2014; Giraldo et al., 2017), copepods (Chen et al., 2018), shrimps (Paredes et al., 2014) and fish (Araújo et al., 2018; Molins-Delgado et al., 2018). Some studies have also revealed the effects of endocrine disruption caused by some of these organic UV filters in aquatic biota (Wang et al., 2016; Lorigo et al., 2018).

With regard to inorganic UV filters (i.e. TiO_2 and ZnO, mainly used as nanoparticles), many studies have assessed their environmental impact on marine organisms. Some of the responses studied are oxidative stress in abalones (Zhu et al., 2011), Zn accumulation in microalgae (Zhang et al., 2016), immune responses in mussels (Barmo et al., 2013), DNA and cellular effects in sea urchins (Manzo et al., 2017), bleaching in corals (Corinaldesi et al., 2018) and genotoxicity in fish (Vignardi et al., 2015).

Nevertheless, the majority of these studies have employed only individual UV filters in isolation, rather than the complete sunscreen product which contains a mixture of organic and inorganic UV filters with other significant ingredients (e.g. surfactants, emollients, film formers, etc.). The combination of these ingredients in the sunscreen composition may enhance or alter the toxic effects of each component on its own. Only a few studies have considered sunscreen as a complex matrix with the potential to release harmful substances to the marine ecosystem (Danovaro and Corinaldesi, 2003; Danovaro et al., 2008; Tovar-Sánchez et al., 2013; Sánchez-Quiles and Tovar-Sánchez, 2014; Corinaldesi et al., 2017; Díaz-Gil et al., 2017; Sendra et al., 2017; Sureda et al., 2018).

Taken together, these findings have demonstrated clearly the risk that the use of these skincare and cosmetic products is presenting to the marine environment, and several reviews have been published highlighting the potential for bioaccumulation and/or biomagnification of their ingredients through the trophic chain on aquatic ecosystems (Brausch and Rand, 2011; Tsui et al., 2014; Baker et al., 2014; Kim and Choi, 2014; Sánchez-Quiles and Tovar-Sánchez, 2015). As a direct consequence of the harmful impact on coral reefs of some organic UV filters contained in sunscreens (Downs et al., 2016), the US state of Hawaii has passed a bill banning the use of sunscreens containing

Benzophenone-3 and Ethylhexyl methoxycinnamate. And the Western Pacific nation of Palau is set to become the first country to ban many types of sunscreen to protect its vulnerable coral reef (http://www.palaugov.pw/wp-content/uploads/2018/08/Proposed-Legislation-re.-Responsible-Tourism-Education-Act-of-2018.pdf). In the MS, warnings about the environmental implications of sunscreen products released to the coastal waters have been published (Misic et al., 2011; Sánchez-Quiles and Tovar-Sánchez, 2015), but these implications are yet to be properly evaluated.

Perspectives for the Mediterranean Sea

Marine coastal areas, and those of the MS in particular, provide the human population in general with a multitude of benefits including an abundance of natural resources that sustain economies and societies. These benefits and opportunities have reinforced our economic reliance on coastal resources in the EU, where tourism is now one of the biggest and fastest-growing industries, generating a significant proportion of total GDP in many of the maritime countries. Nevertheless, coastal ecosystems are also coming under increasing pressure from the damage and pollution caused by the massive influx of visitors, threatening the environmental resources on which the economic growth depends. Indeed, tourism may become a victim of its own success if it is not developed in a sustainable manner.

To date, the investments that have been made in the tourism sector by the Public Authorities of the countries located around the Mediterranean coast (especially Spain, France, Italy and Croatia) have focused mostly on establishing a network of services to cover the heavy, fast-growing, and sometimes uncontrolled, tourist demand of recent years. However, other aspects of vital importance, particularly the ecological effects of chemical products associated with tourism (sunscreens being the case in point) remain without reliable scientific assessment. While other emerging contaminants (e.g. microplastics) have been identified as an ubiquitous marine problem in the Mediterranean (UNEP/MAP, 2015), the magnitude of the environmental risk of sunscreens in the Mediterranean waters has not yet been addressed. Moreover, in the MS and its densely populated coasts, the environmental risk of these chemicals could be greatly exacerbated not only by the massive influx of tourists, but also by the basin’s limited exchanges with the ocean, high residence time of surface waters, and its oligotrophic waters. All these factors produce a rapid biological response to coastal inputs in the MS.

The current lack of knowledge of the impacts of sunscreen on the Mediterranean marine ecosystems may be masking serious adverse effects on populations of marine organisms (including those of commercial importance) and causing a deterioration of the quality of its waters, its rich biodiversity and its natural resources in general. As is being done for the key ecological organism, the coral reef, studies are urgently needed on the main and most important community-sheltering sediments in the MS, the *Posidonia oceanica* meadows, that paradoxically are directly responsible for the high quality of the marine environment that serves as a ‘trade mark’ attracting tourists to the Mediterranean coasts. Aware of this, the European Union has considered it a priority to optimize the sustainable use of our oceans and seas, to ensure the development and sustainable growth of the coastal regions, and thus to enable us to maintain and consolidate Europe as the world's leading tourist destination.

Future prospects for international tourism arrivals to the MS countries promise a continuing increase in the influx of visitors: taking into account only the international arrivals to the European countries of the Mediterranean region, these are expected to increase by an average of 2.6 million a year through 2030 (World Tourism Organization (UNWTO), 2017). Given the current massive influx of visitors to the Mediterranean coast and the increasing trends, actions are urgently needed to understand the occurrence, residence time, behavior, fate, aging, ecotoxicological impact and, not least, the potential transfer to the food chain, of this everyday product being released into the MS. In addition, other actions such as the development of new ecofriendly cosmetic formulations and new or optimized technologies able to remove UV filters from wastewater treatment plants would be also necessary.

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Figure 1. International tourist arrivals to countries bordering the Mediterranean Sea during 2016 (for Turkey and Algeria data is from 2015). Source: (World Tourism Organization (UNWTO), 2017)

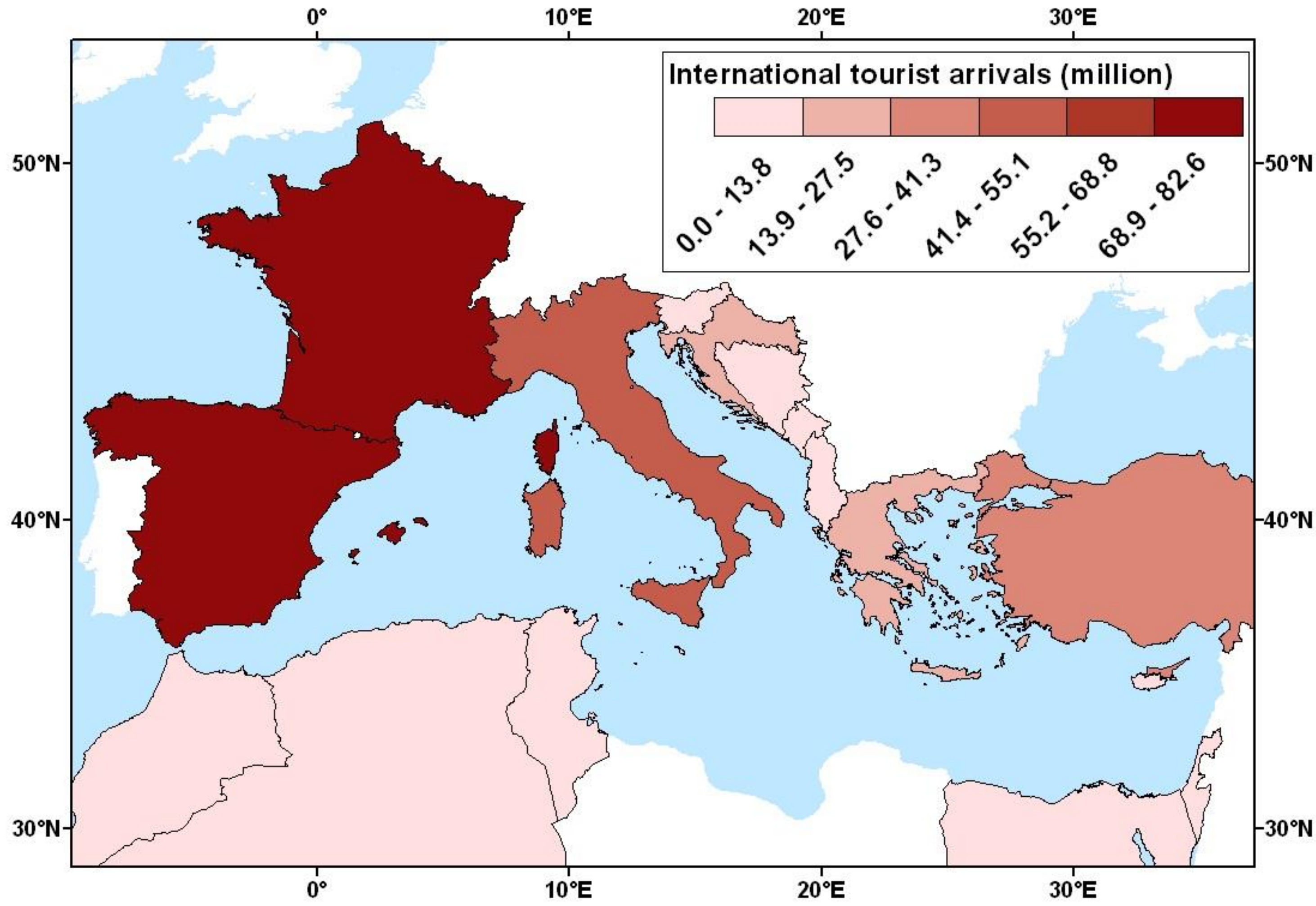

Figure 2. Nights spent at tourist accommodation establishments in coastal areas (from 1991 - 2011). (http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do).