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Sources, composition and spatial distribution of marine debris along the Mediterranean coast of Israel

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ABSTRACT

Marine debris (litter) is a complex problem that affects human activities and the marine environment worldwide. The Clean Coast Program in Israel has had some success in keeping most of the coasts clean most of the time, but without understanding the mechanisms of accumulation of marine debris on the coasts of Israel. In 2012, we initiated a study to characterize the types of marine debris, its origins and spatial distribution. Nineteen surveys were done from June 2012 to March 2015 on eight beaches that spanned the coast of Israel. Average debris density was 12.1 items per 100 m² and 90% of the items were plastic. The top debris categories were food wrappers and disposables, plastic bags and cigarette butts. However, there was variation in the top debris categories among the beaches indicating that a flexible approach with multiple options will be important when addressing the marine debris problem.

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1. Introduction

Marine debris (litter) is a complex problem that affects human activities and the marine environment worldwide. Marine debris is a consequence of poor or inadequate solid waste management practices; unsustainable product design and consumer choices; accidental loss or intentional discarding of fishing gear, cargo or ship-generated debris; lack of infrastructure; indiscriminate human activities; and the public's poor understanding of the potential consequences of their actions (Jambeck et al., 2015). Therefore the effects of marine debris are wide-ranging. Waste at sea can cause serious damage to vessels and negatively affect fishing catch and gear (Mouat et al., 2010). Marine debris affects animals such as seabirds, marine mammals and fish through entanglement and ingestion and can cause changes in marine ecosystems through transportation of invasive species (Gregory, 2009; Morét-Ferguson et al., 2010; Vegter et al., 2014). The economic value of littered coasts is low, reducing tourism and thus affecting local economies (McIlgorm et al., 2011) and the price of cleaning a kilometer of beach can be as much as €97,300 per year in Europe (Mouat et al., 2010). Recognized as an international problem, marine debris is in the scope of many recent global declarations such as The Honolulu Strategy (UNEP/NOAA, 2011), an output from the Fifth International Marine Debris Conference, and "The Future We Want" (United Nations General

Assembly, 2012) from the UN General Assembly "Rio + 20". These declarations call for a reduction in marine debris inputs into the sea using various measures, improving scientific understanding of the sources, amounts and impacts of marine debris, and identifying ways to better coordinate and improve marine debris data collection.

The Mediterranean Sea is a mid-latitude, partly closed sea, connected to the Atlantic Ocean by Gibraltar Straits, to the Black Sea by Dardanelle Straits, and to the Red Sea through the Suez Canal. The Mediterranean Sea is characterized by a weak tide system, with a maximum range of 80 cm (Klein et al., 2004). The coastline and catchment area is home to 427 million inhabitants (7% of the world's population) and 25% of the international annual tourist trade; 30% of global shipping traffic passes through the Mediterranean Sea (UNEP/MAP, 2011). Similar to other parts of the world, Mediterranean beaches tend to have high debris densities owing to the combination of a densely populated coastline and shipping in coastal waters along with limited dispersal of plastics due to limited tidal flow or water circulation (Barnes et al., 2009). According to UNEP/MAP (2011), marine debris in the Mediterranean Sea is generated as a result of urbanization and rising living standards as well as economic activities and poor infrastructure throughout the region, particularly in the southern and eastern Mediterranean Sea, where >80% of landfill sites are not supervised. Success in keeping beaches clean is limited along the Mediterranean Sea. The main obstacles are poor public awareness, problems of administrative coordination, lack of funding and weak enforcement. There is no cross-border cooperation on marine debris (UNEP/MAP, 2011). These conditions

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make it particularly prone to the accumulation of significant amounts of marine litter at surface, water column and seabed levels (Tubau et al., 2015).

Located in the southeastern Mediterranean - the Levantine sub-basin, most of the Israeli coast suffered for years from marine debris. Until 2005, local authorities in Israel regularly cleaned only authorized bathing beaches which are under the authority of the Ministry of the Interior affairs, and therefore are operated according to the law and its ordinances (including services such as life guards and medic first aid stations, sanitary facilities, parasols and garbage bins). These beaches constitute only ~11% of the Israeli Mediterranean coastline (~20 km). As a result, debris accumulates mainly on the unauthorized beaches, which are outside the public's awareness and treated as the municipalities' backyard. Accumulations of marine debris deteriorated the quality of Israel's coast in the beginning of the new millennium. As a result, in 2005, the Israeli Ministry of Environmental Protection (MoEP) launched the "Clean Coast" program in cooperation with the Israel Nature and Parks Authority (NPA). The program improved unauthorized beaches cleanliness by using a combination of activities: routine cleaning of unauthorized beaches by local authorities, partly funded (70%) by the program; developing educational activities for all levels (from kindergartens to schools and youth movements); and better enforcement against beach littering and non-cooperative municipalities who's coasts were not found clean.

Variation in debris composition and geographical and seasonal composition along the Israeli coast was previously examined by Golik and Gertner (1992) and Bowman et al. (1998), and the cleanliness of 60 unauthorized beaches has been monitored since 2005 (Alkalay et al., 2007). In recent years, marine debris has been monitored mainly on the western Mediterranean coast (e.g., Poeta et al., 2014; Suaria and Aliani, 2014) while there is no information about marine debris from the southeastern coast of the Mediterranean.

The objective of the present study was to determine the abundance, spatial distribution and composition of marine debris along the Mediterranean coast of Israel as well as to investigate the possible sources of marine debris in order to determine options for better future management of marine debris in Israel.

2. Methods

2.1. Study area

The Mediterranean coast of Israel stretches about 195 km from Rosh HaNikra, near the Lebanese border in the north, to Zikim near the Gaza strip in the south (Fig. 1). More than five million people (about 60% of the Israeli population) and much of the country's marine economic and commercial activity (e.g. ports, harbors, power plants, desalination plants, coal jetties and offshore oil terminals) as well as related industries (e.g. refineries, warehouses) are concentrated in the coastal zone. In addition, some areas are military firing zones closed for public access, leaving only approximately 130 km of coastline open to the public for recreational activities (e.g. marinas, authorized bathing beaches, nature reserves) and very few beaches are left in their natural state with no development. Beaches in Israel are relatively narrow; mostly 20 to 30 m wide. Around river mouths, beach width can reach 100–300 m. Most coasts are gently sloping, dissipative, sandy beaches; a few are steep rocky reflective coasts (Lichter et al., 2010, 2011). Thirty-two small rivers and ephemeral streams cut the Israeli coastal zone and flow westward to the Mediterranean Sea. Some of these streams have extremely small drainage basins of only a few square kilometers, while others have drainage basins exceeding 1000 km² (Lichter et al., 2010, 2011). The Israeli coast, with the exception of the Haifa Bay, the Carmel headland and a few rocky coasts, is characterized by a straight shoreline that gradually changes its orientation from northeast to almost north towards its northern border (Fig. 1).

2.2. Field methodology

Eight sandy beaches along the Mediterranean coast of Israel were selected for the current study (Fig. 1) based on the Clean Coast Program list of beaches (Alkalay et al., 2007) using the criteria in Cheshire et al. (2009):

1. Betzet beach - located in the Rosh HaNikra Nature Reserve area, about 4 km south of the Israeli-Lebanese border, and belongs to Mateh Asher Regional Council. This is the northern-most sandy coast in Israel, almost 3 km long. The maximum width, from water front to the sandy dune in the border of the coast, is 50 m. Expected debris sources are from Betzet authorized beach in the north, popular with vacationers and fishermen, from the sea, perhaps from the nearby Lebanese coast, and perhaps from the Betzet stream which flows to the coast in the winter.
2. Naharia beach - An urban beach in the northern part of the city of Naharia. This beach is approximately 2 km long, with a maximum width from waterfront to dunes of 30 m. Expected debris sources were local vacationers and fishermen and from the sea.
3. Akko (Acre) beach - An open-coast beach in the south of the town of Akko, which stretches between the Palms beach in Akko and Raphael (security facilities). This beach is approximately 4 km long, with a maximum width from waterfront to sand dunes and the vegetation of the Na'aman River estuary of 65 m. Expected debris sources are from Akko authorized beaches on the north, the Na'aman River which flows to the coast, vacationers and fishermen as well as from the sea.
4. Kiryat Haim beach - This beach, located in the southern part of Haifa Bay, belongs to Haifa City Municipality. A relatively isolated beach, extending from the authorized beach of Kiryat Haim to Israel Shipyards, it is located at the north-eastern end of the industrial area of Kiryat Haim. This beach is approximately 2 km long with a maximum width of 40 m from waterfront to sand dunes. The main sources of debris are expected to come from the open sea, and the nearby Haifa Port, with some addition from the industrial area at the back of the coast, the Kishon River that flows year round through the Shipyard, and from fishermen.
5. Maagan Michael beach - The beach belongs to Hof HaCarmel Regional Council, and stretches from Tel Dor in the north to the Taninim Stream in the south. The beach is approximately 6 km long, with a maximum width of 60 m from waterfront to sand dunes, and is less frequently used. Expected debris sources are vacationers and fishermen and from the sea. Two streams flow year round (but dominant during winter floods) to this beach - Taninim stream in the south end of the beach and Dalia stream in the northern part.
6. Poleg Stream beach - located in the Poleg Stream Nature Reserve. The beach stretches from the authorized Poleg beach to Hof Hasharon National Park with the Poleg stream flowing year round to the beach. This beach is approximately 1 km long, with a maximum width of 80 m from waterfront to sand dunes or limestone cliffs near the Wingate Institute facility. Expected sources of debris are the authorized beach nearby and the Poleg Stream, mainly during winter floods.
7. Nitzanim beach - Belongs to the Hof Ashkelon Regional Council, and stretches from the city of Ashdod to the authorized Nitzanim Beach. This beach is approximately 2 km in length with a maximum width of 65 m. The expected sources of debris were the authorized beach users, fishermen, and from the sea.
8. Zikim beach - Belongs to the Hof Ashkelon Regional Council also, and stretches from the authorized beach in the north to a military closed zone near the Gaza Strip border in the south. This beach is approximately 2 km long with a maximum width of 70 m. Expected debris sources are the authorized beach users, fishermen and from the sea - with especially large deposits from Gaza Strip and even Egypt.

We relied on the local municipalities and the Israel Nature and Parks Authority to regularly clean the beaches as part of the Clean Coast Program (Alkalay et al., 2007). In 2012, only municipalities inhabited by

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