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A Review of Observations of Floating Tar in the Sargasso Sea

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ABSTRACT. Floating tar balls are a product of weathering of crude oil in the marine environment. They have been found to be prevalent in the world ocean, particularly in the 1960s and 1970s before stricter controls on petroleum transport and handling were in effect. Much of the early research on the occurrence and composition of pelagic tar balls was conducted in the North Atlantic Ocean. Research and time-series assessments in the Sargasso Sea since that time have documented that floating tar balls sampled by neuston nets in the open ocean and washed up on shorelines have declined in the past two decades.

A tar ball washed ashore in Whalebone Bay, Bermuda, September 2013. *Credit: Harrison Specht, Cornell University*

Tar balls are lumps of solid or semi-solid tar resulting from the weathering of oil in the marine environment. When they form with a density lower than seawater, they become buoyant and float on the ocean's surface. They are generally irregularly shaped and come in sizes ranging from < 1 mm to tens of centimeters across. At the lower end of this size range, fragments produced during weathering and degradation cannot be sampled using neuston nets, which typically employ a mesh size in the range of ~ 300 μm and have been used extensively for studying pelagic tar balls (Morris, 1971; Butler et al., 1973; Wade and Quinn, 1975). Tar balls can achieve maximum masses on the order of hundreds of grams, and they have been reported to have sea surface mass densities as great as 500 mg m^{-2} (Horn et al., 1970; Butler et al., 1973; Joyce, 1998).

Floating tar balls result from petroleum inputs to the marine environment from onshore and offshore oil production, processing and handling, shipping operations, and natural oil seeps. Denser-than-water (i.e., non-floating) tar balls may also be formed and beached as a result of the inclusion of sand and other solids (Iliffe and Knap, 1979) or by wave action on subtidal nearshore oil deposits (Bernabeu et al., 2013). Because floating tar balls can be transported over large distances by ocean currents, their presence has been widely reported in the waters and on the shorelines of the world's seas and ocean (Kvenvolden et al., 1995; Coles and Al-Riyami, 1996; Joyce, 1998; Kornilios et al., 1998; Zakaria et al., 2001; Owens et al., 2002; Nemirovskaya, 2011; Suneel et al., 2013). The ultimate fates of pelagic tar balls are degradation via biotic or abiotic (e.g., photolysis) mechanisms, physical dissolution and disintegration, sedimentation, and beaching as a result of being washed ashore by wind, current, and tidal action (Butler et al., 1973; Butler, 1975; Iliffe and Knap, 1979; Sleeter and Butler, 1982). The residence time of floating tar balls in the ocean is uncertain. Morris (1971) estimated a half-life of 0.5 to 1 year for tar in the North Atlantic, based on known oil inputs for the late 1960s. In the early 1980s, Sleeter and Butler (1982) estimated a residence time of one to four months, based on the standing stock and input rates of tar at that time.

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Tar balls were commonly seen in the open ocean in the 1960s and 1970s as a result of tank and ballast water flushing at sea, a prevailing practice in oil tanker operations at that time (NRC, 1975). Much of the early research on the occurrence and composition of tar balls in the North Atlantic was conducted in the Sargasso Sea and the inshore waters of Bermuda, and was thoroughly summarized by Butler et al. (1973). The occurrence of tar balls in the North Atlantic Ocean has been reported in the scientific literature since 1965, with anecdotal evidence of their existence recorded from at least the mid-1950s (Butler et al., 1973). During the *Ra* expedition across the Atlantic led by Thor Heyerdahl in 1969, the presence of sometimes significant quantities of floating tar and oil were noted (Heyerdahl, 1971). Many other initial observations of tar balls were unanticipated results of neuston net tows used to sample zooplankton in the sea surface ecosystem (Blumer, 1969; Horn et al., 1970; Morris, 1971). Blumer (1969) reports that during sampling in the Sargasso Sea, neuston nets sometimes became so heavily fouled with tar that they were rendered unusable.

Early chemical analyses of tar balls sampled off the Atlantic coast of North Africa revealed that they had an alkane composition indicative of crude oil sludge, distinct from whole crude oil, suggesting a source from oil tanker operations (Brunnock et al., 1968). Hydrocarbon profiles of many other tar balls clearly indicated a predominantly crude oil signature (Butler et al., 1973; Butler and Harris, 1975). Others have subsequently undertaken detailed chemical analyses of tar balls, beyond the scope of this review (e.g., see: Kennicut and Brooks, 1983; Van Vleet et al., 1983; Kvenvolden et al., 1995; Kiruri et al., 2013; McKenna et al., 2013; Mulabagal et al., 2013). It is important to note that not all tar balls are anthropogenic. Biomarker and isotope analysis of tar balls from the coast of California showed that they were derived from shallow offshore oil seeps (Hostettler et al., 2004). While natural sources of tar exist in the Atlantic Ocean, none have yet been unequivocally identified as tar ball sources. Requejo and Boehm (1985) characterized hydrocarbons in a subsurface (~ 250 m water depth), oil-rich layer in the Sargasso Sea (centered on 20°N, 55°W). They detected a suite of hydrocarbons with molecular and isotopic compositions consistent with seepage from a fossil hydrocarbon source somewhere on the Venezuelan shelf. It also had a lower average molecular mass than that reported for pelagic or beach-stranded tar, suggesting crude oil was not the source.

Throughout the 1960s to 1980s, the occurrence of tar balls and oil on

Bermuda's beaches was significant, and it was often the subject of news coverage in the island's newspapers (see Butler et al., 1973). For example, in 1971 it was reported that "huge patches of oil—up to a foot square" were being washed up on local beaches (Anonymous, 1971). Knap et al. (1980) reported the geometric mean density of tar balls collected using uniform transect methods on a number of Bermuda beaches during the periods 1978–1979 and 1971–1972 as being 77 and 89 g m^{-1}, respectively. This difference was not statistically significant ($P = 0.05$), indicating that the quantities of beached tar during these periods had not changed, despite a reported decrease in operational discharges from oil tankers. By 1985, Smith and Knap (1985) reported a significant decrease in the amount of tar balls washed up on beaches in Bermuda compared with the earlier studies. They reported a decrease of ~ 80% in the geometric mean density of tar balls recorded on two Bermuda beaches between 1978/79 and 1982/83. This decline was attributed to the introduction of international conventions to reduce discharges of petroleum products by ships.

Joyce (1998) reported on floating tar in the western North Atlantic and Caribbean Sea, including the Sargasso Sea region. The data were derived from 2,786 neuston tows conducted between 1982 and 1996. During that time, the amount of tar detected decreased substantially over the whole area, though significant amounts were still present in the Sargasso Sea in 1996. The decrease in the amount of tar was attributed to "legal and economic forces that limit the amount of oil introduced into the ocean." Based on data from Sea Education Association cruises, author Siuda, in Laffoley et al. (2011), provides an update on the floating tar data reported by Joyce (1998). A further update, using 2012 data, is shown in Figure 1a (sampling locations) and Figure 1b (floating tar data) for the Sargasso Sea. These data document a decline in frequency of observation for tows containing tar balls over the period from 1977 to 2012. Concurrently, the number of tar balls per tar-containing tow decreased from an average of 29 (range: 1–244) prior to 1996, to 7 (range: 1–68) between 1996 and 2002, with never more than three tar balls collected in a single tow after 2003.

Butler et al. (1998) demonstrated a general correlation of the occurrence of beach tar in Bermuda with estimated anthropogenic inputs of petroleum to the North Atlantic Ocean over a similar time period, 1971–1996. These data also showed a significant decline. Furthermore, they suggested that the quantity of tar washing up on Bermuda beaches was time dependent and primarily governed by the mesoscale circulation of the Sargasso Sea. The circulation produces alternating periods of upwelling, clean water, and convergences containing floating detritus, including tar,

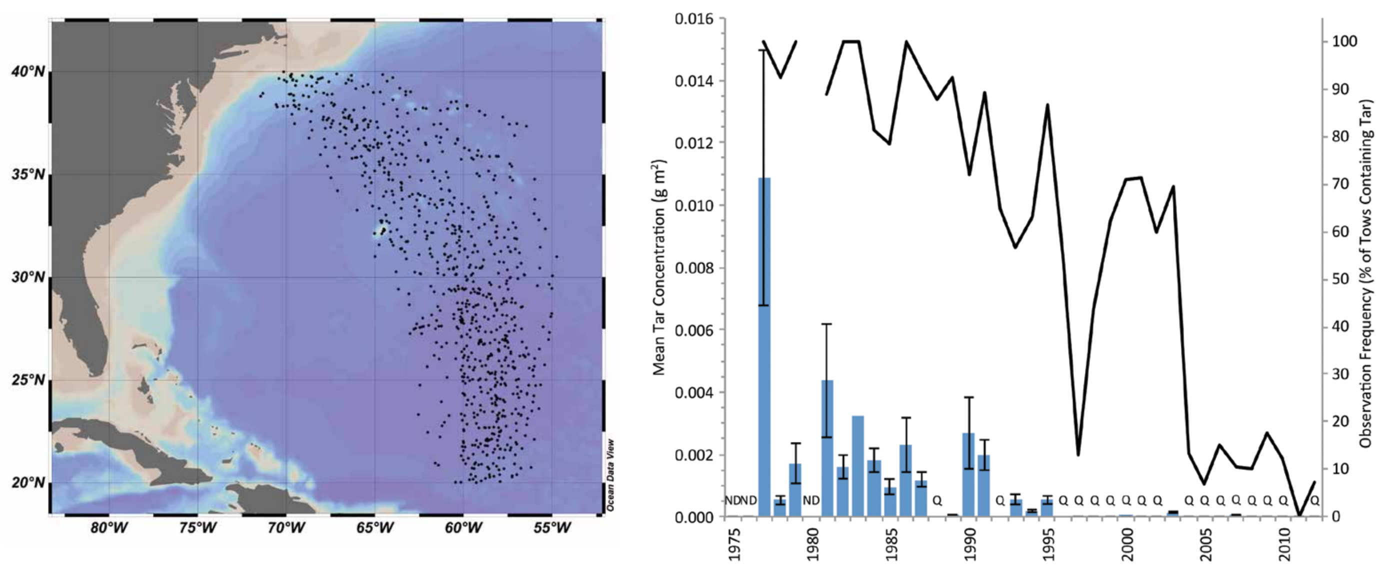

Figure 1. (a) Location of 1,145 neuston tow stations sampled during each October from 1977 to 2012 by the Sea Education Association. (b) Yearly mean neuston tar concentration (blue bars) and frequency of observation (black line) during October transects of the Sargasso Sea region. Target length for each tow was 1,852 m. Annual number of tows ranged from 1 in 1983 to 83 in 1991, with a mean of 32. Error bars represent standard error. ND indicates no data collected during that year. As tar concentration declined, mass was no longer regularly determined. Instead, presence or absence of tar was recorded, sometimes accompanied by a count of pieces. Q indicates record of these qualitative data. Funding for initial data analysis was awarded by the Sargasso Sea Alliance to author Siuda.

Neuston net tow sampling aboard an SEA vessel. *Credit: Sea Education Association*

which is deposited on and removed from beaches on a tidal cycle. The resulting residence times on beaches are six hours to a few days (Butler et al., 1998). The importance of ocean currents in distributing tar balls was also highlighted by Van Vleet et al. (1983), who estimated that approximately 7,000 tons of pelagic tar was discharged annually from the Gulf of Mexico by the Gulf Loop Current in the early 1980s. They also estimated that up to half of this load originated in the Gulf of Mexico, with the remainder originating in the Caribbean and transiting through the Gulf. The Deepwater Horizon oil spill in the Gulf of Mexico in 2010 has been a source of tar balls washing up on the shores of Alabama and Mississippi (Tao et al., 2011; Mulabagal et al., 2013), although no published quantitative data similar to the numerous tar ball surveys conducted elsewhere in the North Atlantic in the 1970s and 1980s are currently available.

Several investigators have examined the biological role and impacts of floating tar balls. The colonization of tar balls by some marine organisms such as barnacles, isopods, and hydroids (Horn et al., 1970; Butler et al., 1973) has been widely noted, as well as the potential for significant microbial colonization (Tao et al., 2011). Organisms can also ingest free-floating tar balls and pellets. Sleeter and Butler (1982) sampled zooplankton and their fecal pellets from Hydrostation S in the Sargasso Sea in 1979. They determined that the rate of zooplankton grazing of particulate hydrocarbons in surface waters appeared to be the same order of magnitude as the input of petroleum residues at that time, and the incorporation of particulate hydrocarbons into zooplankton fecal pellets could provide a mechanism for rapid sedimentation of hydrocarbons through the water column. Witherington (2002) reported that 20% of post-hatchling loggerhead turtles sampled in the slope water near the Gulf Stream front off the coast of Florida had ingested tar.

CONCLUDING REMARKS

The incidence of tar balls in the Sargasso Sea in the North Atlantic Ocean has significantly decreased since the 1960s and 1970s, as might be expected as a long-term result of the implementation of international conventions that reduced inputs from oil tanker cargo tank cleaning and discharges of the tank washings (NRC, 2003) along with the continuation of floating tar removal processes. However, contemporary sources of tar balls in the wider Atlantic region are still present, as shown by floating tar production following the *Erika* and *Prestige* oil tanker accidents (Mazeas and Budzinski, 2002; Bernabau et al., 2013) and the BP Deepwater Horizon spill in the Gulf of Mexico (Kiruri et al., 2013).

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