Marine Pollution Bulletin, Vol. 11, pp. 161–164
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0025-326X/80/0601-0161 $02.00/0

Has the Amount of Tar on the Open Ocean Changed in the Past Decade?

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Quantitative surveys of beach tar on Bermuda during 1978–79 are compared with similar surveys in 1971–72. A 15% increase in the mean, while not significantly different from previously observed levels, is significantly higher than the reported 27% decrease due to improvements in tanker operations.

Quantitative measurements of petroleum residues on the open ocean have been made using neuston nets since 1969 (Horn *et al.*, 1970; Morris, 1971). The origin of these pelagic tar lumps in the North Atlantic Ocean is generally accepted as being primarily from operational discharges of tankers on the Europe–Persian Gulf route (National Academy of Sciences, 1975).

Systematic monitoring of pelagic tar for many years at a single location would seem to be a desirable way of detecting whether anti-pollution measures were being carried out; but no such survey has been done for more than two years (Butler & Morris, 1974), and for such a short period the effects of oceanic currents far exceed the changes in petroleum discharge.

An alternative sampling method is to collect tar lumps from oceanic beaches (Morris & Butler, 1973). These have the same chemical nature as tar lumps collected at sea. However, beach samples represent a cumulative collection of tar, while sampling at sea provides only an instantaneous level at a single location. Thus beach collections may provide a better assessment of the levels of oceanic tar. We report here the results of such a beach survey carried out during 1978–79, and compare it with results obtained in 1971–72 (Butler *et al.*, 1973).

Observations

Five beaches (Fig. 1) were selected for this study, including both windward and leeward sides of the island of Bermuda. It was not possible to use exactly the same locations as the 1971–72 study, because those beaches are now cleaned regularly by the Bermuda Department of Agriculture and Fisheries. The new sites were matched as closely as possible to the old sites in direction and hydrographic characteristics.

One exception was Whalebone Bay, a north-facing cove which provides the only break in a 4 km line of rocky cliffs. A current parallel to the shore causes floating material from this coast to accumulate in Whalebone Bay, resulting in tar levels four times as high as other beaches. No bay in the 1971–72 survey had a similar topography, and so the Whalebone Bay data were excluded from the representative set for 1978–79.

A 1 m wide transect was marked on the beach from surf zone to high tide mark and all tar lumps larger than a few millimetres were collected from the surface of the sand in that area. Whether the tide was high or low had little effect on the amount collected. In 1978–79, two samples were taken weekly on the sixth and seventh days. These were referred to as 'weekly samples' and '1-day samples', respectively. The ratio of weekly mean to 1-day was 3.2 for Vickers Bay, 3.1 for Surf Bay, 7.1 for NASA Long Bay and 3.7 for Whalebone Bay. Ratios of medians and geometric means were similar. Thus the residence time of tar lumps on the beach was of the order of days. This was confirmed by replacing marked tar lumps in a sampled transect: they often were completely dispersed after one tide cycle (Butler *et al.*, 1973).

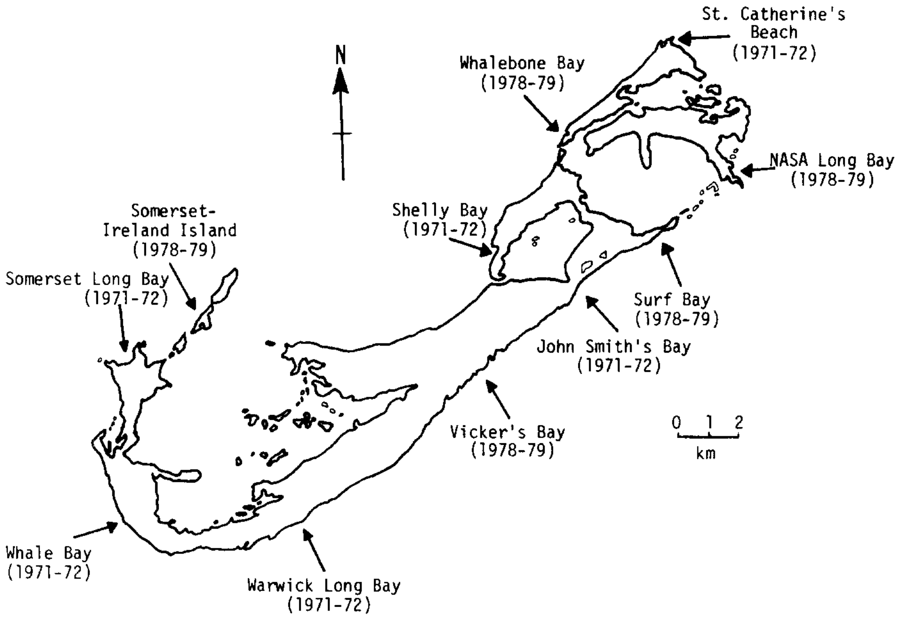

Fig. 1 Bermuda beaches sampled for pelagic tar.

Table 1 compares the mean quantity of tar found per metre of beach in both the 1971-72 and 1978-79 surveys. Since the geometric mean is less sensitive to occasional very high values and the median is less sensitive to both high and low values, these other measures are also included. Comparison of the selected data set for 1971-72 with the corresponding set for 1978-79 shows that the latter is slightly higher in all measures of central tendency (15% for mean, 21% for median, 16% for geometric mean).

TABLE 1

Quantities of tar on Bermuda beaches.

	No. of collections	Arith. mean ($g\,m^{-1}$)	Median ($g\,m^{-1}$)	Geom. mean ($g\,m^{-1}$)
1971-72 *series (weekly samples)**				
Somerset Long Bay (N)	35	220	143	107
Whale Bay (W) †	26	174	68	67
Warwick Long Bay (S)	35	98	65	62
John Smith's Bay (SE)	33	199	140	98
St. Catherine's Beach (E) †	22	111	50	38
Shelley Bay (NW)	32	207	108	98
Total distribution	183	171	84	77
1978-79 *series (weekly samples)*				
Somerset-Ireland Island (NW)	45	123	100	75
Vickers Bay (S)	48	115	36	43
Surf Bay (SE)	49	338	243	223
NASA Long Bay (E)	49	199	82	84
Whalebone Bay (NW)	44	1108	790	779
Total distribution ‡	191	195	102	89
1978-79 *Series (1-day samples)*				
Vickers Bay (S)	22	37	11	10
Surf Bay (SE)	26	109	86	69
NASA Long Bay (E)	24	28	12	10
Whalebone Bay (NW)	20	300	255	212
Total distribution ‡	72	60	27	20

*Reported in Butler *et al.* (1973). The 1971-72 series includes all data except when beaches were sampled more frequently than weekly – in such cases only the first measurement was included. When two or more transects were made on a beach at the same time, the results were averaged.

† Incomplete series because St Catherine's Beach began to be cleaned in August 1972, and Whale Bay was frequently washed out by storms or high tides (Butler *et al.*, 1973).

‡ The 1978-79 series total does not include Whalebone Bay.

The distributions of these two samples are shown in Fig. 2. They are neither normal nor log-normal, but roughly approximate the tail of a normal distribution. We therefore expected that the t-test might give a realistic appraisal of whether the two distributions were different. We found $t = 0.995$ with 372 degrees of freedom and P about 0.33, indicating that the two distributions are not significantly different.

The non-parametric chi-square test was applied to the data by arranging the two data sets in increasing numerical order and pooling them. The pooled distribution was divided into 17 categories each containing 22 data points, and the ranges of each category were used to find the frequency of occurrence in each sampling year. When the normalized distributions were compared, we found chi-square = 20.1 and $P = 0.22$. The same calculation with five categories containing 75 points each, and with 22 categories containing 17 points, both gave similar results, but slightly higher probability (0.4–0.45). Similar conclusions were drawn using the Kolmogorov–Smirnov and Mann–Whitney tests. The Kolmogorov–Smirnov test indicated that the maximum absolute difference in the cumulative normalized distributions is $D_{\text{max}} = 0.074$. For level $\alpha = 0.1$, $D_{\text{max}} = 0.09$ would be required (Keeping, 1962). The Mann–Whitney parameter u_s was 18601, giving $t_s = 1.26$ and $\alpha = 0.19$.

Conclusion

Could we have seen quantitative changes in beach tar reflecting increases or decreases in oceanic oil pollution during the past decade? The rapid exchange of beach tar with the ocean implies that it is a useful substitute for the neuston net. Estimates of the annual input of petroleum to the marine environment and the total standing stock of tar lumps on the world oceans implies a residence time for tar lumps of the order of months to years (Butler *et al.*, 1973; Morris & Butler, 1973; Butler & Morris, 1974; National Academy of Sciences, 1975), after which they appear to

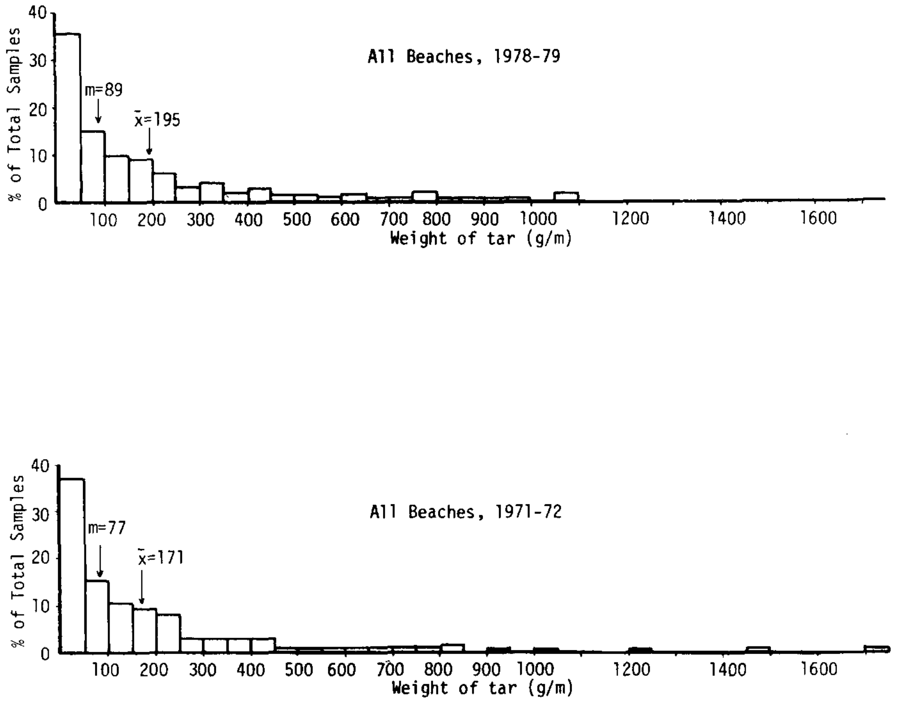

Fig. 2 Weight of tar (g m^{-1} wide transect) sampled weekly.

disintegrate to particles dispersed in the water column (Morris *et al.*, 1976). Therefore, it would be expected that significant changes in either the pattern or the amount of discharge in the currents that feed the Sargasso Sea would influence the amount of beach tar within a year.

Table 2 gives estimates of the total amount of oil transported by sea, as well as the input from accidental oil spills and operational discharges. Recent statistics on large oil spills (Butler, 1978) and total amount transported (United Nations, 1978) are fairly well known, but no comparable way of monitoring operational discharges exists (McKenzie, 1979). Unfortunately the latter source appears to be the major input, especially to the Sargasso Sea: the well-publicized increase (by a factor of 1.6) in spills from tanker accidents during 1973–77 is overwhelmed by the possible decrease of operational discharges by 27% during the same period.

The differences we observe in the mean amount of beach tar on Bermuda between 1971-72 and 1978-79 might be expected to reflect differences in oil spilled in the Sargasso Sea and its contributing currents during the period 1970–72 and 1977–79, respectively. If this input actually decreased by approximately 27%, the mean tar quantity found in 1978–79 might have been as low as 171 (1–0.27) = 125 g m^{-1}. The probability that we have actually observed such a decrease is of the order of 1% ($t = 2.69$, 372 d.f., $P = 0.007$).

Thus we conclude, in spite of reports to the contrary, that during the present decade the input of petroleum residues to the Sargasso Sea did not decrease significantly, and may have increased.

We thank volunteers K. Binkley, I. Holm, D. Ikeda, and J. McLohne who assisted with the field work; F. Mosteller and M. Fiering of Harvard University and L. Ireland of the Bermuda Biological Station for Research who suggested some of the statistical techniques used and J. Cadwallader for assistance with diagrams. This work was supported by grants from the Bermuda Government, Esso Bermuda, and the Zemurray Foundation. This is Contribution No. 822 from the Bermuda Biological Station for Research.

TABLE 2

Inputs of petroleum to the oceans (10^{12} g yr^{-1})

Year	Total oil transported by sea (United Nations) 1978)	Accidents		Operational discharges	
		(Butler, 1978)	(McKenzie, 1979)	(McKenzie, 1979)	(National Academy of Sciences, 1975)
1970	1440	0.4		3.85*	
1971	1526	0.24		4.08*	1.2–2.3
1972	1654	0.23		4.42*	
1973	1873	0.05	0.084	5.01	
1974	1837	0.06	0.067	4.07	
1975	1644	0.13	0.188	3.62	
1976	1797	0.23	0.204	4.09	
1977	N.A.		0.213	3.65	
1978	N.A.		0.260	N.A.	

* Extrapolated assuming ratio of operational discharges to total oil transported by sea was constant for 1970–73: 1.67×10^{-3}.
N.A. = Not available.

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