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Tar ball frequency data and analytical results from a long-term beach monitoring program

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Abstract

Following the spill of fuel oils from the New Carissa in February 1999, approximately 300 km of beaches on the Pacific coast of North America were surveyed. A long-term observation program focused on the documentation of stranded tar balls in the vicinity of the spill site. Systematic beach surveys which were conducted over the period March 1999 to April 2001 and semi-logarithmic scale, time-series plots proved the most useful format for identifying trends. Beach monitoring continued through to August 2001, by which time 212 tar balls had been analyzed by GC/MS for their chemical characteristics. The samples of tar balls collected between February 1999 and August 2001 were qualitatively compared with New Carissa source oils (NCSO) and 101 (48%) were not consistent with NSCO. The presence of tar balls that are not related to an incident can confound attempts to define cleanup or endpoint criteria and to assess possible injury to natural resources.

Keywords: Oil spills; Tar balls; Chemical characterization; Oregon

1. Introduction

The wood-chip carrier M/V New Carissa ran aground on the outer shore of North Spit, near Coos Bay, Oregon, at approximately 124°18′ W and 43°24′ N (Fig. 1), on 4 February, 1999, carrying an estimated 400,000 gal (9520 barrels) of fuel oils. The total amounts of oils released from the vessel were estimated to be on the order of 95,000–265,000 l (25,000–70,000 gal) of IFO 280 and MDO. This coast has very high wave-energy levels (Tillotson and Komar, 1997) and complex nearshore current patterns. The affected shoreline is characterized by long, straight sand beaches that are interrupted by bedrock headlands and tidal river inlets.

The Unified Command instigated an in situ burn when it appeared that the grounded vessel was about to break up. During the burn, the forward two-thirds of the vessel (bow section) separated from the stern. The bow section was successfully refloated and towed out to sea on 2 March, but the tow broke during a storm and the bow drifted to the northeast. The Unified Command estimated that up to 48 barrels (2000 gal) of oil were released when the bow grounded near Waldport (Fig. 1). The bow was removed and scuttled at sea on 11 March. The stern section remains (as of October 2001) at the site of the initial grounding.

Shoreline Cleanup Assessment Team (SCAT) procedures were developed during this operation for the description and documentation of the stranded tar balls and a field form was designed to record appropriate observations (Owens et al., 2000). A number of data output formats were used to summarize the information (Owens et al., 2001).

The field survey and sample analysis results are presented and discussed in two general phases: (a) the initial

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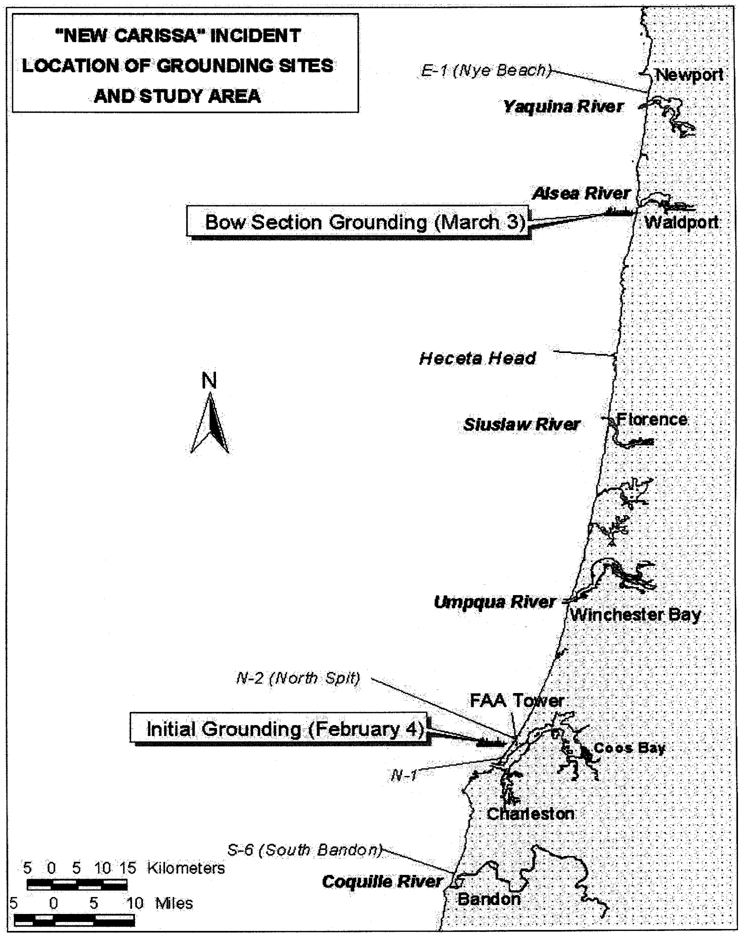

Fig. 1. Location of study areas.

period of oil stranding in the North Spit area (Segments N1 and N2) and as far north as Heceta Head (segment N13), over the period up to 3 March, 1999 (Polaris Applied Sciences, 1999); and (b) the period of the long-term beach observation program, for which data are presented from 4 March, 1999 through the end of April 2001. This discussion focuses on the second phase of tar ball observations after 3 March, 1999.

Concern for the impact of tar balls on shore birds, specifically the Western Snowy Plover (*Charadrius alexandrinus nivosus*), listed by the US Fish and Wildlife Service as a regionally threatened species, led to a long-term beach monitoring and tar ball collection program. It was noted that many of the tar balls encountered during this program did not appear to be visually consistent with oil from the New Carissa. Additionally, there were several days when larger quantities of oil were observed that were inconsistent in time and space with those typically associated with and expected from the New Carissa. For these reasons, a program of chemical analysis was instituted to evaluate the source of the tar balls (Mauseth et al., 2001).

When it had become evident by the end of the summer of 1999 that a large number of the tar balls that had been analyzed did not have chemical characteristics that matched the known New Carissa source oils (NCSO) an evaluation program was initiated. This program, which began in November 1999, consisted of surveying three beaches, one with suspected continued New Carissa oiling, and two distant beach locations. These beaches were the North Spit (segments N1 and N2) in the vicinity of the vessel, a portion of Nye Beach (E1) at Newport, adjacent to the Yaquina River, and a portion of Bullards Beach (S6) north of Bandon, just to the north of the Coquille River (Fig. 1). The two distant beach segments, each approximately 1000 m in length, were selected based on their similar coastal geomorphology and their geographic proximity to an adjacent jetty-inlet system, just as the wreckage of the New Carissa was to the North Spit jetty and Coos Bay inlet. The Nye Beach area to the north of the spill site had been affected by oil from the New Carissa during the months following the incident, whereas, little oil was transported to the south of the spill site, and none had been observed or reported at any time from the Bandon area. Beach observation surveys and tar ball sample collection were conducted at intervals on these three beaches from mid-November 1999 through April 2001.

2. The beach observation program

A SCAT program was initiated on 8 February, 1999 following standard procedures developed over the past ten years (NOAA, 2000; Owens, 1999). Field surveys were conducted daily from 9 to 18 February. As the amount of oil on the shore decreased after 18 February, spot observations were provided on a daily basis primarily by personnel who were conducting wildlife surveys along the affected coast. Most of the SCAT team members were demobilized on 27 February. As the tar balls were transported along the outer Oregon coast to the north, after 15 February the affected sections of the coast were divided into 56 segments, which covered approximately 300 km of shoreline.

2.1. Field observations up to 2 March, 1999

The initial field methods applied in February followed standard SCAT reporting procedures. The SCAT method proved to be too insensitive to accurately describe the amounts and types of oil observed after 23 February as the amounts of oil observed on the shoreline diminished significantly and so it became necessary to modify the reporting methodology. At that time, most of the beached oil took the form of oil pellets of various sizes, also called "tar balls". The standard SCAT method resulted in evaluations of oil quantities that were invariably too high (Owens et al., 2000), primarily due to the following factors:

1. Standard SCAT procedure reports the degree of oiling in terms of a per cent coverage, width, and thickness. Reported in these terms, the area covered by tar balls was generally less than 1% (and thus approximated to 1%), and the thickness category always a *Cover* (>1 mm and <1 cm).
2. The width of the area covered by tar balls was often reported as the width of the beach. As a result, the oiling category was always reported as "light", and the estimated volumes tended to be uniformly too high.
3. In addition, over time an increasing number of observers who had little or no experience with the SCAT method were involved in beach surveys.

For these reasons, a new "Beach Assessment Reporting" (BAR) form was introduced on 23 February to provide an appropriate method for recording the frequency and character of stranded tar balls. This form has been adopted by Environment Canada and NOAA as suitable for tar ball surveys (NOAA, 2000; Owens and Sergy, 2000).

2.2. Field observations between March 1999 and September 2001

Concern for the potential impact of tar balls on the Western Snowy Plovers in the area adjacent to the spill site prompted a long-term monitoring and sampling program. Beach surveys to locate tar balls were conducted daily from 3 March to 3 September, 1999, and thereafter on a less frequent basis through to the summer of 2001. The segmented area to the north of Heceta Head was surveyed systematically only until 26 May, 1999. As time went on, surveys were almost exclusively performed by cleanup crews, who would report both oiling conditions and pick up tar balls, and occasionally by scientific support staff. In most cases, the observations were noted by the cleanup teams and reported using field notes or verbally to the cleanup crew supervisors, who completed the BAR form. Beginning in late July 1999, the cleanup crews were requested to also report the weight of the collected tar balls.

Initially, during March 1999, observations were obtained from at least ten, and often as many as twenty segments, each day. With time the observed shoreline oiling conditions decreased and, consequently, the level of beach observation activity was reduced in late March 1999. After late March 1999, between five and ten segments were visited each day, and this number was reduced further in mid-May, after which observations were recorded only from three to seven segments daily and were confined primarily to segments N1 through N13, between the vessel location and Heceta Head, approximately 80 km to the north. After 3 September, 1999, observations were limited to N1 and N2, with occasional observations in segment N3 and in the two remote locations, Nye Beach (E1) and Bandon (S6). The data from these four segments are the focus of this discussion.

2.3. Tar ball survey data analysis

Field observations were entered into a data base and a series of summary tables and maps were produced, initially on a daily basis and later on a weekly schedule until September 1999. This data base was used to generate information on the concentration (g/m^2) and volume of oil within each segment (Owens et al., 2001).

Simple histograms of oil volume were used to identify large oiling or re-oiling events but, as the data spanned as many as nine orders of magnitude, these high values masked smaller changes in oil on the shoreline and this format provided very little useful information about oil conditions between the larger events. The solution to

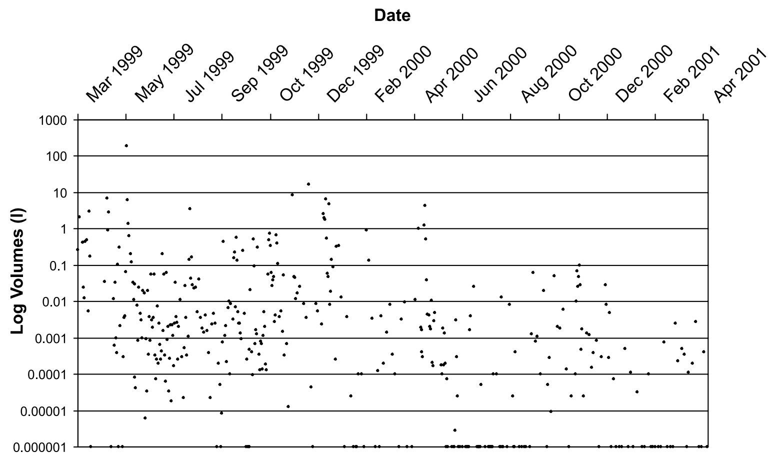

Fig. 2. Segment N2: calculated daily tar ball volume, in liters, for the period March 1999–April 2001, plotted on a semi-logarithmic format (a plotted value of 0.000001 is used to indicate that the volume is zero).

this effect was applied by plotting the same data on a logarithmic scale (Fig. 2). In this plot the value of 0.000001 is used to indicate a value of zero. This semi-logarithmic format permits a more refined visual analysis of the temporal changes in oiling conditions that takes into account all of the tar ball data, regardless of the volume. The data are plotted as a scatter diagram and not as a histogram or a bar plot as (i) the area underneath each bar is not directly proportional to the value on the logarithmic axis, which can lead to a misleading interpretation, and (ii) there is a large variation in values so that smaller values tend to be masked.

A second method for representing oiling conditions was a histogram of the normalized tar ball concentration per unit area. This format has been commonly used for reporting tar ball concentrations on beaches (e.g., Asuiquo, 1991; Corbin et al., 1993; Iliffe and Knap, 1979; Romero et al., 1981; Sen Gupta et al., 1993). The total calculated oil volume for a segment, as discussed above, does not give an accurate indication of the frequency of oil distribution along the shorelines. Oil concentration, expressed as weight of oil per unit area, can be calculated by dividing an estimated oil weight, derived from oiling observations, by the oiled area (Owens et al., 2001). The normalized concentration histogram suffers the same advantages and limitations as that of oil volume histogram as it provides little information about the distribution of concentrations of smaller amounts of oil. A semi-logarithmic plot (Fig. 3) provides a better depiction of changes in small amounts of oil.

The monthly mean tar ball size is computed by dividing the total tar ball size by the total number of tar balls, or tar ball density, recorded in a given month. The sum of the total tar ball size is computed by multiplying the reported tar ball size by the estimated or observed

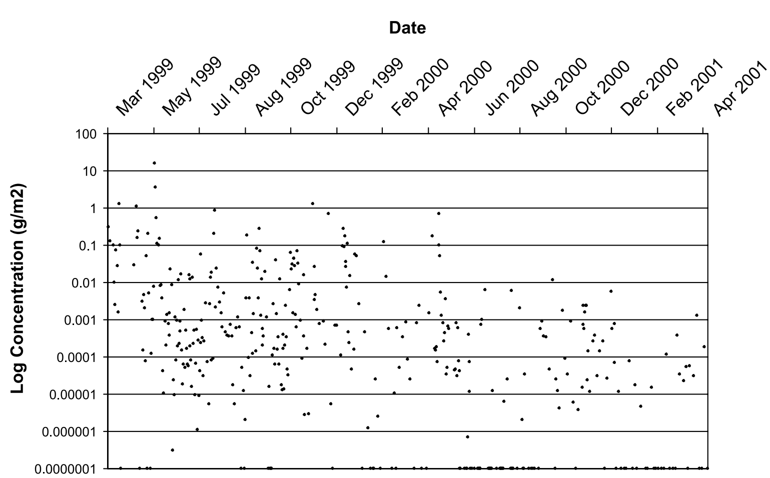

Fig. 3. Segment N2: calculated daily tar ball concentration, in g/m^2, for the period March 1999–April 2001, plotted on a semi-logarithmic format (a plotted value of 0.0000001 is used to indicate that the concentration is zero).

Table 1
Summary of tar ball size observations, in centimeters, for segments E1, N1, N2 and S6: March 1999–April 2001

Month	Segment							
	E1		N1		N2		S6	
	Mean (*n*)	Max	Mean (*n*)	Max	Mean (*n*)	Max	Mean (*n*)	Max
Mar1999	1.57 (34)	15.24	0.65 (13)	3.81	0.66 (16)	7.62		
Apr 1999			0.52 (52)	10.16	0.46 (30)	10.16		
May 1999	2.54 (2)	5.08	1.03 (95)	7.62	1.14 (62)	10.16	0.95 (1)	0.95
Jun 1999			0.44 (84)	7.62	0.38 (63)	7.62		
Jul 1999			1.51 (54)	7.62	0.95 (38)	6.35		
Aug 1999			0.57 (41)	8.89	0.65 (31)	8.03		
Sep 1999			0.37 (146)	8.89	0.64 (55)	7.62		
Oct 1999			0.26 (90)	6.35	0.48 (72)	7.62		
Nov 1999	0.55 (2)	1.27	2.86 (36)	22.86	1.03 (78)	17.78		
Dec 1999	0.50 (3)	1.91	0.74 (24)	6.35	3.03 (17)	8.89	1.27 (2)	1.27
Jan 2000	0.95 (2)	2.54	0.43 (41)	25.40	0.87 (54)	12.70		
Feb 2000	1.02 (2)	1.91	0.67 (11)	15.24	1.04 (14)	5.08		
Mar 2000	0.64 (1)	0.95	0.91 (15)	5.08	1.76 (18)	7.62		
Apr 2000	0.95 (1)	0.95	1.26 (16)	5.08	0.75 (13)	5.08		
May 2000			0.61 (34)	2.54	0.54 (40)	2.54	0.94 (2)	1.91
Jun 2000			0.42 (24)	2.54	0.43 (30)	13.91		
Jul 2000			1.27 (20)	0.00	2.47 (18)	10.16		
Aug 2000			0.55 (16)	7.62	1.93 (17)	7.62		
Sep 2000			1.30 (13)	3.81	0.53 (13)	2.54		
Oct 2000			0.43 (13)	1.59	0.61 (12)	4.92		
Nov 2000			0.38 (21)	7.62	0.55 (23)	3.81		
Dec 2000			0.39 (14)	1.27	0.75 (19)	6.35		
Jan 2001			0.37 (9)	0.64	0.28 (9)	1.27		
Feb 2001			0.83 (7)	1.27	0.64 (7)	1.91		
Mar 2001			0.91 (9)	3.81	0.56 (9)	1.27		
Apr 2001	0.92 (3)	3.11	1.59 (7)	2.54	0.91 (9)	2.54	0.64 (1)	0.64

number of tar balls for each set of observations and the sum of the tar ball sizes for a month is then divided by the total number of reported tar balls (Owens et al., 2001). The results of these calculations are provided in Table 1, which also indicates the number of observations and size of the single largest tar ball observed for each survey month, and are presented in Fig. 4. Thus, for segment N2, the mean tar ball size was calculated as 1.03 cm in November 1999, from a total of 78 observations. The largest single observed tar ball for that month had a diameter of 17.78 cm.

The monthly tar ball volume was calculated by dividing the total tar ball volume by the total segment length surveyed during a given month, then multiplied by the segment length (Owens et al., 2001). The results of these calculations are reported in Table 2, which also shows the number of observations for each survey month. Thus, for segment N2, the mean tar

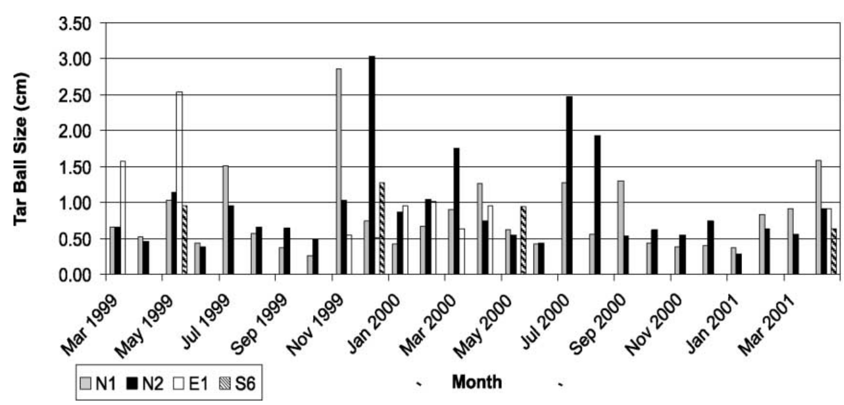

Fig. 4. Monthly median daily observed tar ball size, in centimeters, for segments E1, N1, N2 and S6: March 1999–April 2001.

Table 2
Summary of calculated tar ball volume data, in liters, for segments E1, N1, N2 and S6: March 1999–April 2001

Month	Segment			
	E1 (*n*)	N1 (*n*)	N2 (*n*)	S6 (*n*)
Mar 1999	0.119 (34)	0.901 (13)	0.985 (16)	
Apr 1999		20.289 (52)	0.852 (30)	
May 1999	0.002 (2)	10.405 (95)	8.925 (62)	tr (1)
Jun 1999		0.088 (84)	0.013 (63)	
Jul 1999		0.362 (54)	0.160 (38)	
Aug 1999		0.332 (41)	0.004 (31)	
Sep 1999		1.434 (146)	0.126 (55)	
Oct 1999		0.165 (90)	0.129 (72)	
Nov 1999	0.001 (2)	3.068 (36)	0.654 (78)	– (1)
Dec 1999	0.001 (3)	0.018 (24)	1.817 (17)	tr (2)
Jan 2000	0.001 (2)	0.181 (41)	1.161 (54)	– (2)
Feb 2000	0.001 (2)	0.615 (11)	0.118 (14)	– (1)
Mar 2000	tr (1)	0.003 (15)	0.017 (18)	– (1)
Apr 2000	tr (1)	0.007 (16)	0.003 (13)	– (1)
May 2000	– (2)	0.166 (34)	0.522 (40)	tr (2)
Jun 2000		0.001 (24)	0.000 (30)	
Jul 2000	– (1)	0.002 (20)	0.002 (18)	– (1)
Aug 2000	– (1)	0.000 (16)	0.002 (17)	– (1)
Sep 2000		0.022 (13)	0.009 (13)	
Oct 2000	– (1)	0.002 (13)	0.015 (12)	– (1)
Nov 2000		0.062 (21)	0.026 (23)	
Dec 2000		0.000 (14)	0.008 (19)	
Jan 2001		0.000 (9)	0.000 (9)	
Feb 2001		0.001 (7)	0.000 (7)	
Mar 2001		0.002 (9)	0.001 (9)	
Apr 2001	0.001 (3)	tr (7)	0.001 (9)	tr (1)

tr: Less than 0.001 l (or trace), –: No tar balls observed in the segment.

ball volume was calculated as 0.65 l in November 1999, from a total of 78 observations. Again, the presence of a few high values masks the low values so that a semi-logarithmic presentation (Fig. 5) provides a more meaningful format to depict the full range of data points.

3. The sample analysis program

It became evident early in the long-term monitoring and sampling program that the pattern of tar ball distribution on the beaches, in time and space, was not consistent with trends of oil releases from the New Carissa. As a result of this observation a key component of the study became to verify the source of the tar balls that were being observed and collected from the beaches. Criteria used for selection of tar ball samples to be analyzed for chemical fingerprinting were that they: (1) were representative of the tar balls observed on the beach, (2) appeared to be anomalous or different to those from the New Carissa incident in terms of timing or distribution, or (3) were anomalous or different in appearance. In total, 885 tar ball samples were collected between February 1999 and August 2001, and 212 were selected randomly from within each category for analysis using a combination of Modified EPA 8015—gas chromatography flame ionization detection (GC/FID) and modified EPA 8270—gas chromatography/mass spectrometry (GC/MS) methods.

3.1. GC and GC/MS analysis

Tarball samples were analyzed for saturated hydrocarbons and total petroleum hydrocarbons by GC/FID similar to the methods described in Douglas et al. (1994). The GC column used in this analysis provided baseline resolution of *n*-alkanes from *n*-C8 to *n*-C40 and the *n*-C17/pristine and *n*-C18/phytane pairs. Quantification of the compounds was based on the internal standard compound, which was spiked into the sample prior to analysis. Concentrations were calculated versus the average response factor of a five-point instrument calibration of *n*-alkanes. Each of the selected tar ball samples was also analyzed for polycyclic aromatic hydrocarbons (PAH) and sterane and triterpane biomarkers by GC/MS in the selected ion mode based on Douglas et al. (1994) and Page et al. (1995). The target PAH compounds included parent PAHs and alkylated homologues groupings. The concentrations of the individual PAH and biomarker compounds were calculated versus the internal standards, which were spiked into the

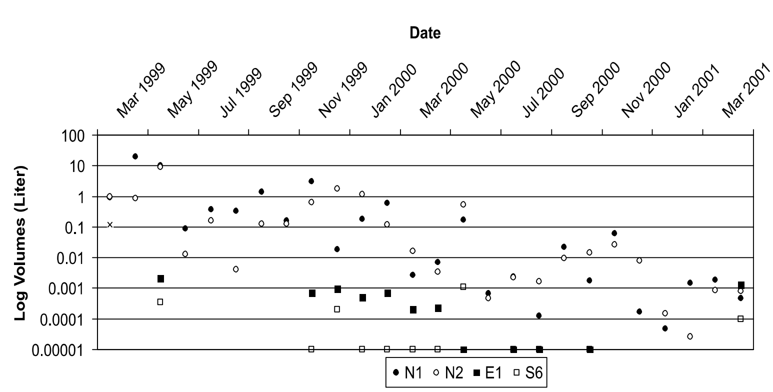

Fig. 5. Mean monthly tar ball volumes, in liters, for segments E1, N1, N2 and S6 (March 1999–April 2001), plotted on a semi-logarithmic scale (a plotted value of 0.00001 is used to indicate that the volume is zero).

sample extracts prior to analysis. The analyte concentrations were not corrected for the surrogate recoveries. The target biomarker concentrations were quantified using average response factors (RF) generated from the four-point calibration curve. The target PAH concentrations were quantified using average RF generated from the five-point calibration curve. Concentrations of the alkylated PAH compounds were determined using the RF of the corresponding parent PAH compound.

3.2. Source identification

The chemical fingerprinting evaluation involved comparison of field sample data to that of the New Carissa reference materials collected. The evaluation included use of GC/FID data and chromatograms; PAH distributions and internal source ratios; and biomarker distribution patterns. Data were also evaluated by statistical and graphical means using the methods of Brown and Boehm (1993), Boehm et al. (1995), Douglas et al. (1996), and Page et al. (1995). Comparisons were made using 18 source oils collected from the New Carissa, from the beach or water immediately adjacent to the ship while and soon after it was breaking up. These NCSO included samples from fuel tanks prior to, and after, the in situ burn. Engine room oils included mixed fuel, lube and neat oil samples at the ships last two fuelings. A tar ball that matched any one of these 18 samples was considered to be a match of the oils from the New Carissa.

4. Results

4.1. Beach observations

The data presented in Figs. 2 and 3 cover the period March 1999–April 2001 and are based on 772 observations in segment N2. Between November 1999 and April 2001, E1 located just to the north of Newport was visited on 15 occasions and S6, near Bandon, also was surveyed on 15 occasions (Table 2).

The variations in tar ball size (Table 1 and Fig. 4) indicate that:

- the majority of tar balls were less than 1 cm in diameter,
- the mean did not exceed 1.27 cm in S6 and exceeded 2 cm on only one month in E1 and N1, and in two months in N2 during the entire study period,
- at no time was the observed mean tar ball size less than 0.5 cm in segments E1 or S6, but, in the two "N" segments, it was below 0.5 cm in 1999 in April (N2), June (both), September (N1), and October (both), and in 2000 in January (N1) and June (both), and
- there are no evident trends in size within or between segments based on a visual inspection of the data.

The variations in monthly tar ball volume (Table 2 and Fig. 5) indicate that:

- the data for N1 and N2 reflect a large input from the stern until the end of May 1999, after which the mean daily tar ball volume only exceeded one liter on four occasions,
- over time in these two segments after May 1999, the calculated daily volumes appeared to be higher during the winter months (September 1999–January 2000) and lower in the summer months in 1999 (June–August 1999: June–August 2000),
- in segment E1, the mean daily volume exceeded 0.1 l only in March 1999, and thereafter was always less than 0.01 l, with no reported tar balls on four surveys during May through August 2000, and
- in segment S6, no tar balls were observed on 8 of the 12 occasions this beach was surveyed and on the three occasions when they were present the calculated daily volume was less than 0.01 l.

4.2. Sample analyses

Over the period February 1999–August 2001, 111 (52%) of the 212 tar ball samples that were analyzed for chemical fingerprinting were considered to be a positive match for NCSO.

During the first three months of the spill response (February–April 1999), when sampling was directly related to determining the extent of New Carissa oiling, all (100%) of the 11 samples analyzed from the immediate vicinity of the vessel (from the north jetty to 5 km north of the vessel) were positively matched to NSCO (Table 3). From approximately 5 km north of the vessel to Heceta Head (≈85 km to the north), 9 of 11 sample analyses (82%) were consistent with NCSO. Further to the north, from Heceta Head to Yaquina River (≈135 km north of the vessel), only 4 samples were submitted for analysis and 2 (50%) were matched to NCSO. North of Yaquina River, only 2 of 10 samples submitted (20%) were identified as matching the NCSO. South of Coos Bay, where only small amounts of oil were observed, no samples were submitted for analysis. All samples collected during this time period were considered representative of the oiling conditions observed.

During the period between May 1999 and August 2001, 105 samples were analyzed from the segments immediately adjacent to the New Carissa of which 73 (70%) were qualitatively matched to NCSO (Fig. 6). The occurrence of New Carissa tar balls decreased substantially in the next segments monitored to the north. From 5 km north of the vessel to Heceta Head, only 14 (34%)

Table 3
Frequency of tar ball matches to NCSO: February 1999–August 2001

Coastal area	Representative		Anomalous in time and/or space		Anomalous in appearance		Total	
	C-NCSO[a]	NC-NCSO[b]	C-NCSO[a]	NC-NCSO[b]	C-NCSO[a]	NC-NCSO[b]	C-NCSO[a]	NC-NCSO[b]
February 1999–April 1999								
North of Yaquina River	2 (20%)	8 (80%)						
Heceta Head to Yaquina River	2 (50%)	2 (50%)						
N3 to Heceta Head	9 (82%)	2 (18%)						
North spit: N1 and N2	11 (100%)	0						
South of Coos Bay	–	–						
May 1999–August 1999								
North of Yaquina River	0	8 (100%)	0	1 (100%)	–	–	0	9 (100%)
Heceta Head to Yaquina River	0	12 (100%)	–	–	–	–	0	12 (100%)
N3 to Heceta Head	10 (42%)	14 (58%)	4 (27%)	11 (73%)	0	2 (100%)	14 (34%)	27 (66%)
North spit: N1 and N2	47 (65%)	25 (35%)	24 (89%)	3 (11%)	2 (33%)	4 (67%)	73 (70%)	32 (30%)
South of Coos Bay	0	4 (100%)	0	5 (100%)	–	–	0	9 (100%)

Segments N1 and N2 are immediately adjacent to the New Carissa spill site.
[a] C-NCSO = Consistent with NCSO.
[b] NC-NCSO = Not Consistent with NCSO.

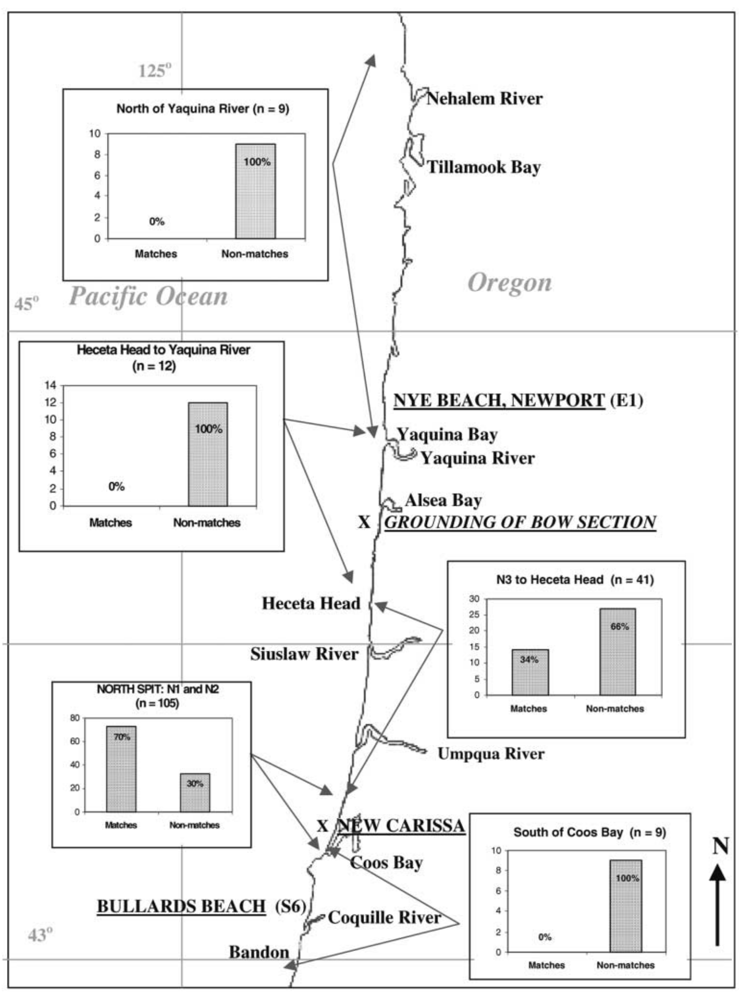

Fig. 6. Qualitative matches of tar balls to NCSO: May 1999–August 2001.

samples out of a total 41 samples analyzed had positive matches to the New Carissa. During this same time period, all (100%) of the 30 samples collected to the north of Heceta Head and south of the entrance to Coos Bay were determined to be not consistent with NCSO: 12 samples were collected from Heceta Head to Yaquina River; 9 samples from Yaquina River northward; and 9 samples from the Coos Bay jetties southward. Table 3 shows the number of tar balls selected for each of the criteria in the sampling program, and the qualitative match results.

Background oiling on the central Oregon coast is also supported by the occurrence of mystery spills. These spills were either reported to the US Coast Guard (USCG) and cleaned up, or they were noted as anomalous oiling events by the New Carissa beach cleanup crews and later determined to be other than New Carissa oil by chemical analyses. The USCG responded to at least four incidents other than the New Carissa on the Oregon coast during the study period.

5. Discussion

Pelagic tar balls and stranded tar balls have been reported from many oceans and coasts worldwide (Clark and MacLeod, 1977). The presence of pelagic tar in the Pacific Ocean is well known (Wong et al., 1974, 1976; Shaw and Mapes, 1979). Wong et al. report average tar ball concentrations on the order of 0.03 mg/m^2 at 25° N and 0.4 mg/m^2 at 35° N, for the Northeast Pacific, whereas, for the same general region, the latter authors report concentrations of surface pelagic tar in the range 0.0–0.3 mg/m^2. The presence of tar balls on the shore, from pelagic sources, in the area affected by the spill from the New Carissa is therefore to be expected.

The numerous pelagic tar ball studies reported in the literature indicate a high variability of tar ball concentrations in time and space. "Concentrations may vary by a factor of 10 or more at a single station during the course of a single day and by as much as a factor of 500 in the course of a year" (Payne and Philips, 1985). This variability may be partially attributable to sample collection, however, the net result would be a variability in the distribution and concentration of stranded pelagic tar balls. In their study of tar ball distribution on the ocean surface after a spill, Eagle et al. (1979) note that mean values for tar ball concentrations should be treated with caution as tar ball sampling is both "variable and erratic".

The distribution of tar balls on a beach along the Oregon coast is affected by the dynamic nature of the shore zone. The beach surface undergoes a constant change as sand is redistributed by waves and wind during each tide. Erosion and deposition occur at the same time within short distances (a few meters) and at the same location within a matter of hours. Thus, any materials that are stranded at the water line are constantly subject to removal (erosion) or burial. The seasonal pattern of sand migration on and off the beaches causes changes that may be on the order of hundreds of cubic meters at one location (Aguilar-Tunon and Komar, 1978). Such changes are most significant during the transition seasons (April–May and September–November). The concentration of tar balls at any one time or location would be expected to vary with changes in tidal or wind-induced water levels or in response to sediment redistribution. One survey conducted at one tide stage may not produce the same observations as a second survey conducted at a different tide stage on the same day, even with the same observation crew.

Romero et al. (1981) also note that (1) tar ball deposits are not cumulative and represent only the material deposited in the intertidal portion of the beach during the last tidal cycle, and (2) the amount of tar in the supratidal zone is dependent on recent winds which constantly redistribute sand to alternately expose and bury tar balls. In this spill in Oregon, tar balls observed in segments N1 and N2 were removed by the field crews so that these tar ball observations must be treated as individual records of the oiling condition on a section of shore at that time. The dynamic nature of tar ball distributions and concentrations limit the use of the observations, and the data derived from the field surveys should be regarded as primarily descriptive information, or semi-quantitative at best.

Based on a detailed tar ball survey over a one-year period at 26 locations, Romero et al. (1981) indicate that the standard deviation often is of the same magnitude as the mean value for observations at a given location (see also Corbin et al., 1993) and that differences between beaches or changes on any one beach are "not significant unless they are close to an order of magnitude difference".

Previous studies of stranded tar generally report concentrations in terms of:

- tar ball count per length of beach (e.g., g/m) (e.g., Corbin et al., 1993),
- weight by area (e.g., g/m^2) (e.g., Asuiquo, 1991; Gabache et al., 1998; Romero et al., 1981; Sen Gupta et al., 1993), or
- weight by volume (e.g., g/ml).

Corbin et al. (1993) provide a classification for tar ball levels on beaches (Table 4). The values used in this classification are numbers that refer to a single line of tar balls (g/m). This swash-line approach approximates the situation during the tar ball surveys reported in this discussion. If this classification is applied to the data discussed in this study, only 5 days fall into the "low,

Table 4
Tar ball concentration level classification (from Corbin et al., 1993)

0–1.0 g/m	negligible
1.0–10.0 g/m	low, background
10.0–100.0 g/m	moderate
>100.0 g/m	high, unusable for recreational purposes

background" category (1–10 g/m^2) (Fig. 3). All other days have values in the "negligible" category (<1 g/m^2).

6. Conclusions

The quantity of oil on Oregon beaches following the initial cleanup was very small. The level of effort expended on searching for and removing very small tar balls in the New Carissa case was unusually high due to concern for shorebirds. The accuracy of tar ball surveys when small sizes are involved is largely a function of the effort, particularly when false positives are common and burial is an important factor. In these situations it is difficult to accurately estimate the actual concentrations and volumes, and most tar ball observations likely underestimate the true concentration and volume. Semi-logarithmic, scale time-series plots proved the most useful format for identifying trends as the data spanned as many as nine orders of magnitude.

In this study, oil not consistent with NCSO often was similar in appearance and could only be differentiated through laboratory analysis. The chemical analyses show that, throughout the course of the New Carissa beach cleanup operations, there was a level of background oiling independent of the spill incident. Tar balls not consistent with NCSO were observed, sampled and analyzed on approximately 300 km of central Oregon coastline. The existence of background oiling is also supported by the occurrence of "mystery" spills during the study period. The occurrence of background oiling on the shoreline generally goes largely unrecognized by the public due to the relatively small size and concentration of the ambient tar balls. This study did not attempt to execute a thorough randomized search of beaches to develop statistical estimates of density. It was intended to replicate search efforts performed by cleanup personnel in this incident.

The study to document the background tar ball distribution is considered successful based on two of the results. The background concentrations were similar at both of the distant beach locations and, secondly, no New Carissa oil was observed at either of these two beaches. It is likely, therefore, that these two beaches define a consistent minimum level of background oiling that is not associated with specific known events. The Oregon coast is not a high traffic region as are the major west coast ports in the Seattle–Vancouver, San Francisco–Oakland, and Los Angeles–San Diego areas. Nevertheless, there exists a background tar ball level that must be factored into the development of cleanup criteria. Given the demonstrated existence of background oiling, the application of zero tolerance shoreline cleanup goals can be an impractical, if not impossible, cleanup endpoint in this coastal environment.

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