LONG-TERM PERSISTENCE OF BUNKER C FUEL OIL AND REVEGETATION OF A NORTH-TEMPERATE SALTMARSH: MIGUASHA 1974-1985.

J.H. Vandermeulen
Marine Ecology Laboratory
Department of Fisheries and Oceans
Bedford Institute of Oceanography
Dartmouth, N.S., Canada B2Y 4A2

and

J.R. Jotcham *
Department of Biology
Acadia University, Nova Scotia, Canada

INTRODUCTION

Low-energy mariane coastal environments are generally considered to be highly susceptible to long-term persistent contamination from coastal oilspills because self-cleaning by wave action and tidal flushing is very low, and because the spilled hydrocarbons tend to become entrapped in depressions and within beach interstices.

These processes have been documented for several such environments (Vandermeulen and Gordon, 1976; Baker et al., 1984; Vandermeulen et al., 1981). Within this context, saltmarshes and other coastal wetlands are particular problems because traditional cleanup or countermeasure operations (booming, manual or mechanized cleanup) invariably aggravated the problem, either by forcing more of the spilled oil into the wetland sediments or by drastically damaging the wetland ecosystem.

One alternative to oil spill cleanup, in the special case of wetlands, is a nil response in which the spilled oil is left untouched in the marsh, and is left to natural albeit very slow natural weathering and decomposition processes. The oiling and subsequent setting aside of the oiled saltmarsh near Miguasha, Quebec, provided an opportunity to monitor the long-term fate of such an uncleaned marsh environment. The present paper documents persistence of stranded eleven-year old Bunker C oil, and the revegetation of marsh areas impacted by the spilled oil in 1974.

MATERIALS AND METHODS

Vegetation surveys and sediment sampling were carried out in September 1985. In addition to the original test plots laid out in 1975, three transects were laid out across the marsh, with sampling stations marked out along them (Figure 1).

Present Address: Balsam Research, Box 900, Berwick, N.S. BOP 1E0

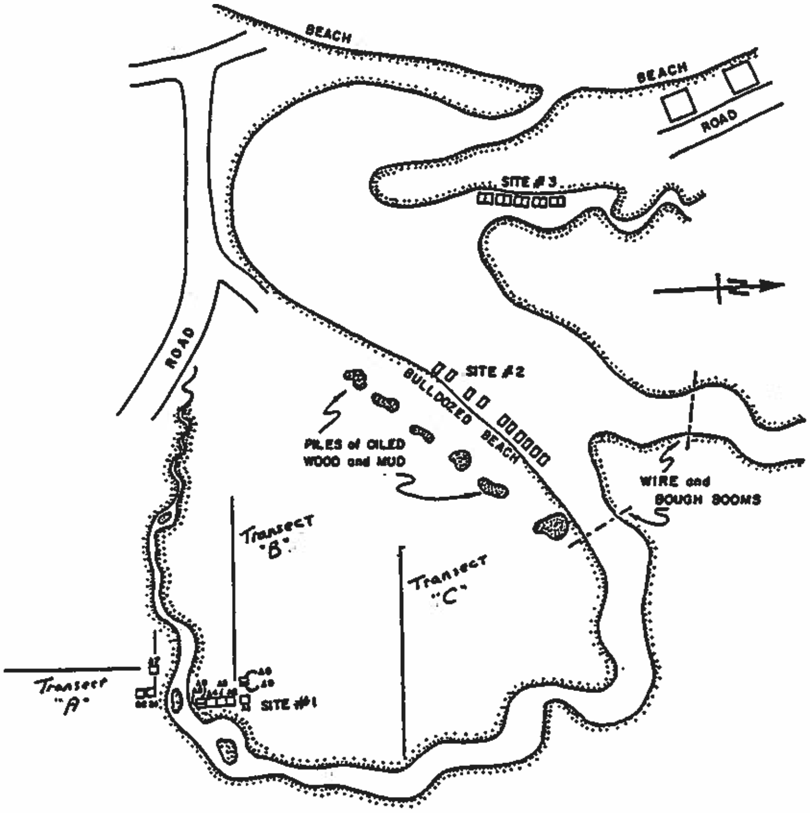

Figure 1. Schematic representation of Miguasha saltmarsh showing location of 1975 test plots, and of the 1985 vegetation transects.

Vegetation Surveys

Vegetation was studied using a 1 M^2 quadrat, divided into 100 10x10 cm^2 squares. Species composition, rooted frequency, and percent cover were inventoried for each sample. Each of the original test plots were sampled in this way, as well as were stations along the three transects. The data were then analyzed objectively by quadrat, regardless of their location in the marsh. For identification of quadrat number, see Table 1. Data were averaged for the species within each sample, and the averages were relativized to obtain importance values (IV's). Multivariate analysis was done using Decorana (Hill, 1979a) and Twinspan (Hill, 1979b). Both methods group individuals according to their similarities, Decorana providing a graphic presentation, application of Twinspan resulting in a two-way table. Statistical analyses were performed on the CDC Cyber at Acadia University.

Hydrocarbon Analysis

Both surface (0-2cm) and subsurface (-2cm) sediment samples were collected into hexane-rinsed glass sampling jars, and stored frozen

(-10°C) until extraction and analysis.

Sediment aliquots were extracted by alkaline digestion, and partitioned into n-alkane solvents. Quantitative analysis was by UV-fluorescence (UV/F) (310nm excitation, 374nm emission), with results expressed as oil equivalents using a sample of buried Bunker C as reference material. Qualitative analysis was by the method of Lloyd (1971), using synchronous excitation-emission UV/F scans and peak-height analysis as detailed in Vandermeulen et al. (1981). Glass capillary-chromatography was done on aliphatic and aromatic fractions (F1, F2) (HP-5730A), following liquid chromatographic separation

All solvents used in sediment-hydrocarbon analysis were double distilled in glass from ACS-grade reagent stock.

SPILL BACKGROUND

On September 14, 1974, the tanker Golden Robin ran aground in the Baie de Chaleur, just off Dalhousie, New Brunswick. The Baie forms the mouth of the Miramichi estuary which marks the border between New Brunswick and the province of Quebec. At this point the estuary is approximately 2 km wide. Approximately 1,000 barrels (159,000 litres) of Bunker C fuel oil were spilled into the estuary, resulting in extensive intertidal oiling of both the New Brunswick and opposite Quebec shorelines.

In the course of this, the small marsh of Miguasha, located on the Quebec side of the estuary, became oiled also. Despite efforts to contain the incoming oil within the mouth of the main marsh drainage channel by booming off two small secondary marsh channels, a substantial but undetermined amount of spilled Bunker C oil reached the marsh interior. During subsequent high tides the oil spilled over the banks onto the adjacent high marsh vegetation. Oiling of the marsh itself was not extensive, and was restricted largely to lower lying portions of the marsh, and the channel banks.

Although cleanup of the bay was effected immediately, the oiled saltmarsh was left uncleaned until the following spring, 1975. Several cleanup approaches were attempted, primarily in the back portion of the marsh where oiling had been heaviest and where spilled stranded oil and oiled vegetation was still very much evident. These included manual removal of oiled vegetation, digging and spading of oiled vegetation and surface sediment layers and various burning methods, as well as mechanized plowing and removal of oiled sod with a motor-driven sod-cutter (Table 1, Figure 1). None of the methods was highly successful, and the mechanized methods especially disturbed the marsh sediment greatly. Results are summarized in Cejka (1975).

A subsequent field survey, and chemical analysis of sediments from the various testplots, done in 1976 and 1977, revealed chronic poor recovery of vegetation in all test plots, and the presence of varying large amounts of hydrocarbons within the sediments (Vandermeulen and Ross, 1977). In all test plots, hydrocarbons had penetrated to at least 10 centimetres, and in some down to 20 cms.

Table 1. Marsh test plots and 1975 test treatments. For location of test plots refer to Figure 1.

Test plot	Condition in 1974	Treatment in 1975
A1	Oiled	non-cleaned control
A3	Oiled	manual cleanup
A4	Oiled	cleanup by cutting and removing vegetation
A5	Oiled	cleaned by burning with propane torches
A6	Oiled	burned with varsol
A7	Oiled	burned with gas/No.2 fuel oil mixture
A8	Oiled	digging out oiled sod with spade
A9	Oiled	removal of oiled sod with hand-saw
B1	Oiled	sodcutter
B2	Oiled	plowed with farm plow

RESULTS

General Marsh Vegetation

1. General Marsh Morphology

The Miguasha saltmarsh is located on the north shore of the Baie de Chaleur, across from Dalhousie, New Brunswick. The marsh is small, ca. 1 km^2, and lies protected behind a gravel spit. It is drained by a simple drainage network of two small secondary channels which drain into a single main channel. In the absence of freshwater stream input, main water input from the landward side is by surface runoff from the surrounding more elevated land, a mixture of farmland and pine/spruce forests.

The front part of the marsh bordering the main or primary channel is in fact well above mean high tide, formed of sand deposits that are overgrown with typical dune vegetation.

The typical marsh environment is found in the back portion of the system, drained by the secondary channels, and constitutes a typical Atlantic coast marsh, with characteristic and visually distinct vegetation zones. Zone 1, at the water's edge and along the edge of marsh drainage channels, was dominated by generally pure stands of _Spartina alterniflora_. Zone 2, evident just above zone 1, was dominated by _Spartina patens_. This zone also contained occassional _Arenaria lateriflora_, _Plantago maritima_, _Limonium nashii_, _Salicornia europaea_, _Suaeda maritima_, _Atriplex patula_, and _Glaux maritima_. Zone 3, well away from the water's edge, was co-dominated by _Plantago maritima_ and _Glaux maritima_, with occasional _Suaeda maritima_ and _Salicornia europaea_. _Solidago sempervirons_ was relatively rare, found primarily on raised hummocks immediately beside the drainage channels. Marsh pannes on the upper marsh often contained a luxuriant growth of _Ruppia maritima_.

2. Vegetative Recovery

Overview 1975-1984

Photographic documentation of the test plots, first oiled in 1974 and subsequently subjected to various cleanup trials in 1975, show very heavy oiling of all vegetation, with both cleanup crew and equipment mired in masses of oiled vegetation and surface sod.

Observations made during 1976 and 1977 field trips showed dry deposits of tar over the various test plots, generally in the form of an asphaltic layer of from one to several cms in thickness, and generally broken up by drying and cracking into circa one decimeter square flakes. The two test plots that had been either dug out (A8) or had the sod removed with a hand-saw (A9) were both filled with water, with tar submerged.

Over the subsequent period, 1978-1984, vegetation gradually reinvaded the various test plots. The process was most rapid in the test plots that had been treated either manually (A3, A4) or by burning the oiled vegetation (A5, A6, A7). By 1984 the vegetation in these plots, and in the two plots treated with sodcutter (B1) and farm plow (B2) appeared visually restored, and not differing from the surrounding vegetation. The exceptions were the two test plots A8 and A9 which had had the surface sod removed by either digging or hand-cutting. In both of these revegetation was slow, and from a distance the vegetation appeared more yellow in color than vegetation in adjacent test plots, or in surrounding non-oiled areas.

At the same time the areas of dried tar residue disappeared from view, mainly by slow invasion of marsh vegetation. One extensive oiled area remained evident for several years, but had disappeared from view during a four-year period (1978-1982) when no visits were made to the marsh.

1985 Survey

Of the various test plots marked out in 1975, the general locations of plots A1 through A6, A8 and A9 were relocated. Test plots B1 and B2 were no longer identifiable, or distinguishable from the surrounding marsh. Test plot A7, originally located on the edge of a secondary drainage channel, was not identifiable by vegetative abnormalities _per se_ . However, the bank of the drainage channel at this point was marked by a discharge of greyish-white material that had been noted on previous visits, which served to identify the location of A7.

Only one test plot, #A7 (quadrat 7 in the numerical analysis), was markedly different from its surroundings. The vegetation and surface root mass in this plot had, in 1975, been dug out with a spade to a depth of several centimeters. At the time of sampling for the present study, 1985, the test plot was a small pond, with _Spartina alterniflora_ along its edges.

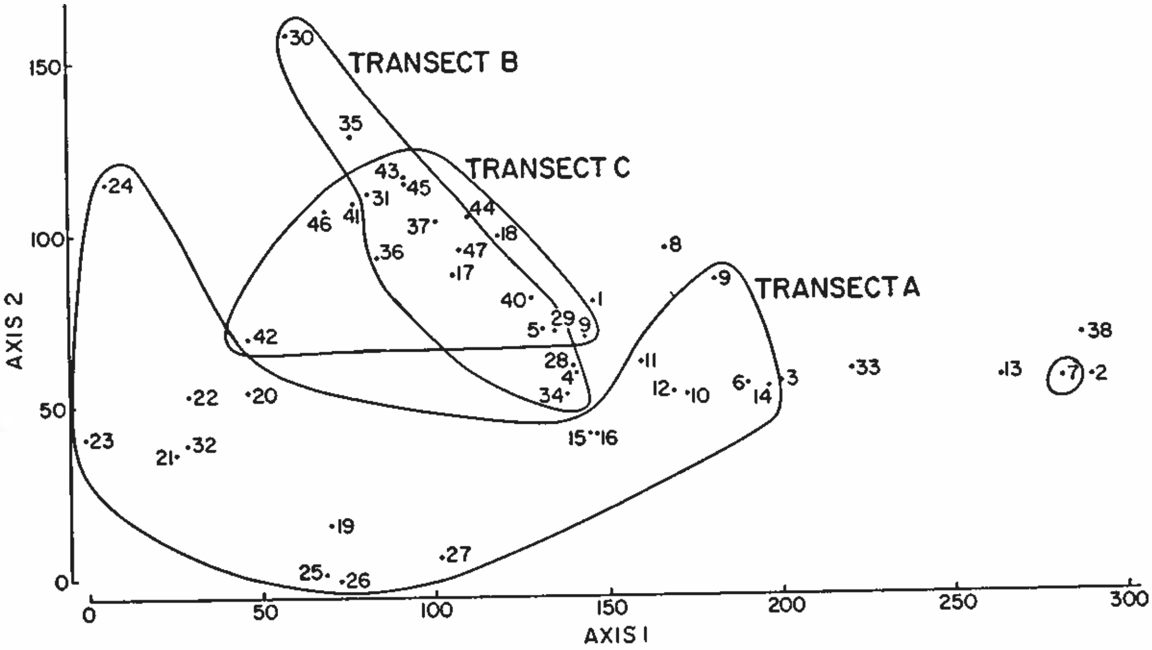

Figure 2. Decorana ordination of the vegetation data from the Miguasha salt marsh. Forty seven quadrats are shown, clustered according to their floristic similarities. The axes are mathematical abstractions, determined by Decorana.

Table 2. Twinspan analysis of the vegetation data from the Miguasha salt marsh. Quadrat numbers (1-47) are along the top, and species names are on the left. The values in the matrix show relative importance of species. The dichotomous divisions made by Twinspan are shown for species on the right, and for quadrats along the bottom.

```
             22222234144234131133 3234 2443  4111  1113  2 3
             04123522961660718545499755837018410636234372798

GLAUX        55555555533542222-11----1-------11----------5--  000
PLANTAGO     55555155255255555-2534455435554552--111112-----  001
S. PATENS    5-553555-5555555555555555555555555555554553-55-  0100
LIMONIUM     -------1-12-12313--1112133222-2111--11-------22  01010
SALICORNIA   ----------------2------------2---------------3-  01011
SOLIDAGO     ----------------------------1------------------  011
SUAEDA       ---------------------1-----------------------1-  100
RANUNCULUS   ---------------------------------------------1-  10100
ATRIPLEX     ----------------1----------------------------23  10101
ARENARIA     2------------31------------------3------1----4-  1011
S. ALTERN.   ----111--11333--2--223222-11--45444155455555445  11

             00000000000000000000000000000011111111111111111
             00000000000001111111111111111100000000000000011
             00000000000110000111111111111100001111111111101
             000000011110100010000011111111000100000000001
             01111110011  011 0011100000001011 0000000011
              0111110101   01 010110001111  01 0011111101
```

The vegetation survey data were assembled into a matrix of relative importance values. Analysis of these data using Decorana resulted in the ordination shown in Figure 2. Tidally inundated quadrats dominated by *Spartina alterniflora* are found on the extreme right (#2, 7, 13, 38), while *Glaux* dominated high marsh quadrats are grouped on the extreme left (#21, 22, 23, 24, 32, 42). Between these extremes, *Spartina patens* dominated quadrats tend to lie on the right, and *Plantago maritima* quadrats on the left. Hence the first axis is similar to the initial zonation visualized before the analysis, except that here the *Glaux maritima* quadrats were separated from the *Plantago maritima* quadrats, which was not visually apparent in the field. Most of the quadrats from the various 1975 test plots were similar to surrounding quadrats, and quadrats from similar areas generally grouped together. The exception was quadrat 7 (1975 test plot A8) which grouped with the *S alterniflora* dominated plots 2, 13 and 38.

Table 2 shows the two-way table produced by the Twinspan analysis on the same data. The hierarchical divisions on the quadrats are shown along the bottom, and the divisions on the vegetation species are shown along the right. Generally the groupings are similar to those from the Decorana ordination. Again quadrat 7 is grouped at the far right, among the plots dominated by S. alterniflora. The only anomaly is quadrat 9, which is clustered with quadrat 38 on the same branch in Table 2, but is separate from #38 in Figure 2. Quadrat 38 was located on the bank of the main secondary drainage channel in this portion of the marsh, and was dominated by S. alterniflora. The Twinspan diagnostics indicated that #9 and #38 were clumped together mainly by the total absence of Glaux maritima and Plantago marina.

3. Hydrocarbon Survey

Hydrocarbon Characterization

Qualitative examination by UV/F synchronous scanning (SEES) revealed the usual UV pattern expected with a bunker C contaminated sediment, with a major peak at 360nm, pronounced fluorescence at 380 nm and 408 nm, and tailing off subsequently to near zero at 480 nm. The latter region, 380 nm and above, corresponds to the fluorescence response region for 5-ring compounds and larger (Lloyd, 1971). This characteristic pattern was found in samples of buried Bunker C deposits, and in several surface and sub-surface sediment samples (top trace, Figure 3).

Most sediment samples, however, elicited a differing SEES profile. While generally resembling that of standard whole oil with the major fluorescence peak at 360 nm, these differed in a markedly lower fluorescence response above 360 nm, corresponding to reduced numbers of 5-ring and larger aromatic hydrocarbons (middle traces, Figure 3).

A third and differing SEES profile was found in a number of samples, primarily in deeper subsurface sediments and in remote unoiled areas of the marsh. In these the main fluorescing region was shifted to the left, with a major peak at 347 nm that was either equal to or dominated the diagnostic hydrocarbon peak at 360 nm (bottom trace, Figure 3). SEES scans of such samples also frequently showed pronounced peaks at 432nm and 457 nm. These differences were quantified and confirmed using the peak-height analysis of UV/F SEES scans that has been described elsewhere (Vandermeulen et al, 1981).

GC-chromatograms of the F1 (aliphatic fraction) and F2 (aromatic fraction) of a buried Bunker C sample showed a highly degraded pattern of peaks overlying a large unresolved envelope, consistent with the weathering of stranded oil for several seasons (Figure 4). Similar GC analysis of sediments that had been indicated as contaminated by UV/F analysis also showed such patterns, with a large unresolved envelope underlying a pattern of peaks consistent with the continued presence of n-alkanes and aromatic hydrocarbons.

Hydrocarbon Concentrations

Quantitative examination by UV/Fluorescence (310 nm excitation, 374 nm emission) of sediment samples extracted for hexane solubles suggested widely varying concentration of fluorescing materials, presumed to be hydrocarbons, in all samples. Levels varied between 48.6 ug/gm in a

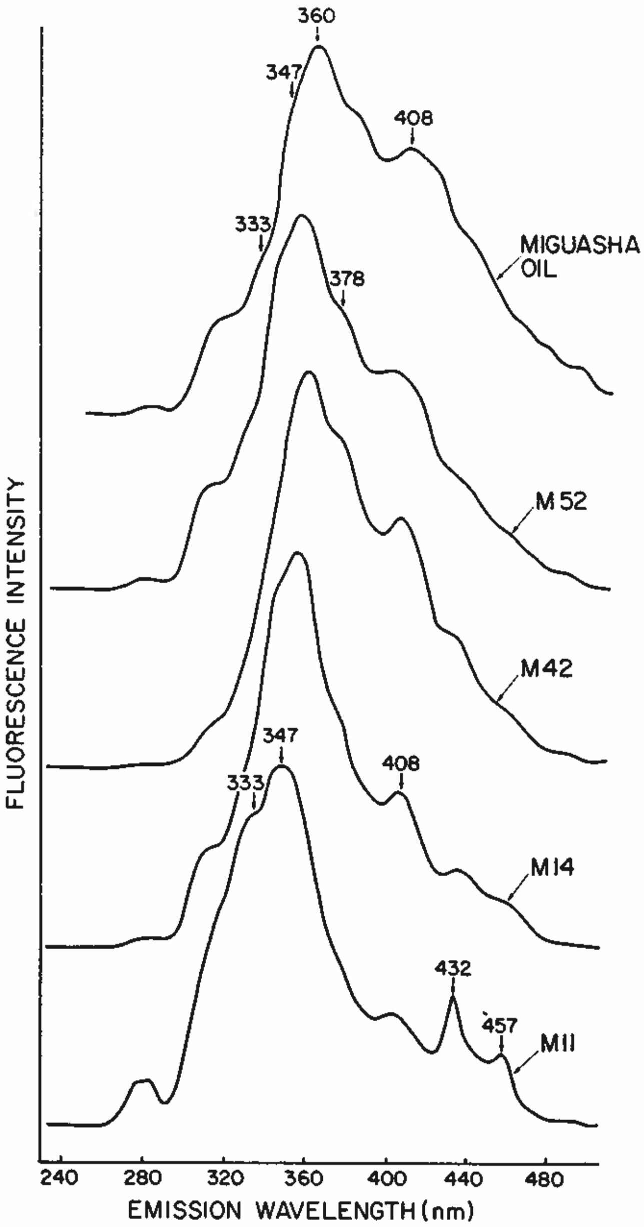

Figure 3. Simultaneous excitation-emission scans (SEES) of Miguasha buried oil, heavily tarred sub-surface sediments (M52), contaminated surface sediment (M42), newly deposited sediment (M14), and a -20 cm sub-surface sediment (M11).

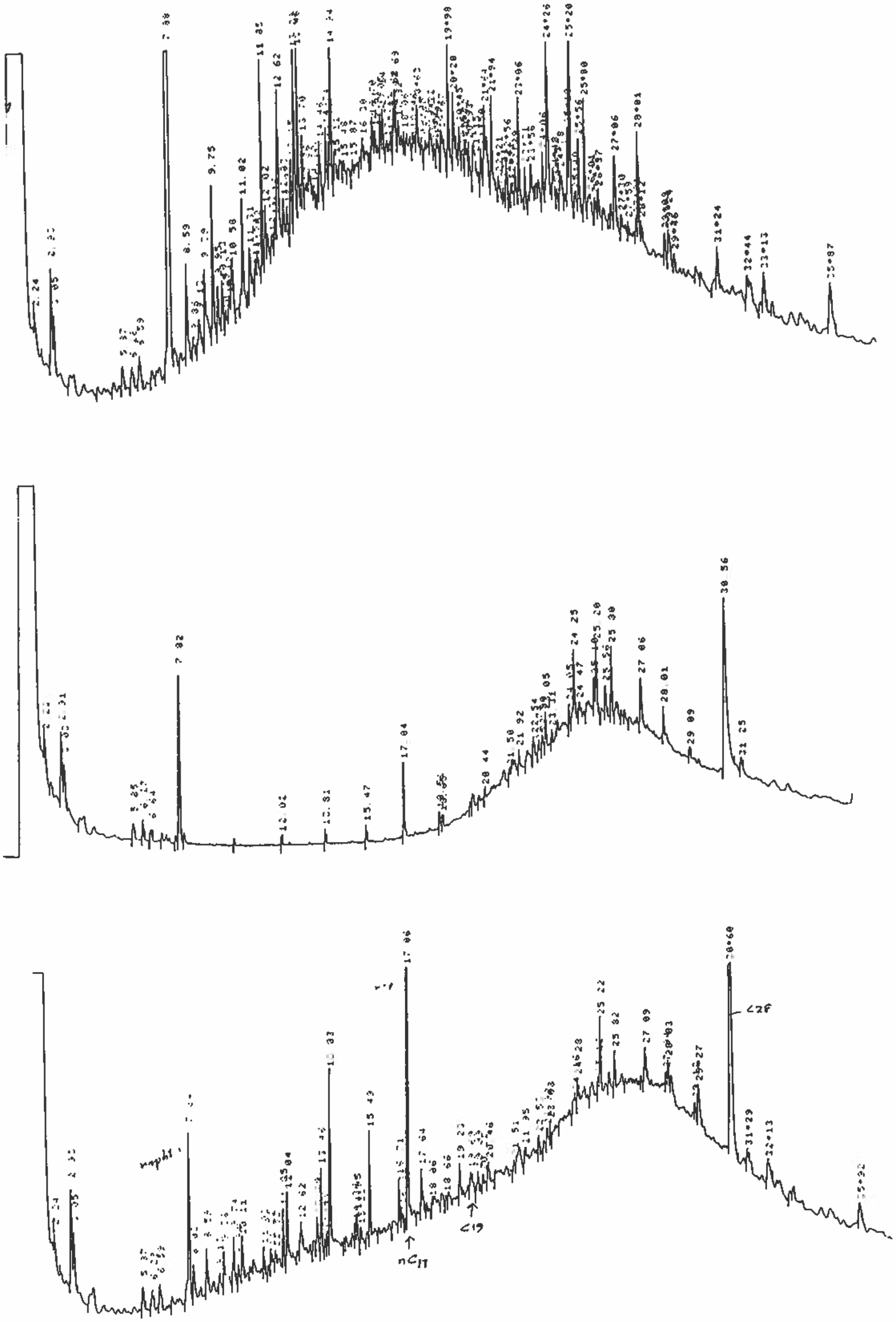

Figure 4. Gas chromatograms of F1 fractions from new sediment overlying a buried tar layer (top), surface sediment sample near oiled region (middle), and from buried tar layer (bottom). (Peaks at 7.8 and 30.6 are internal standards.)

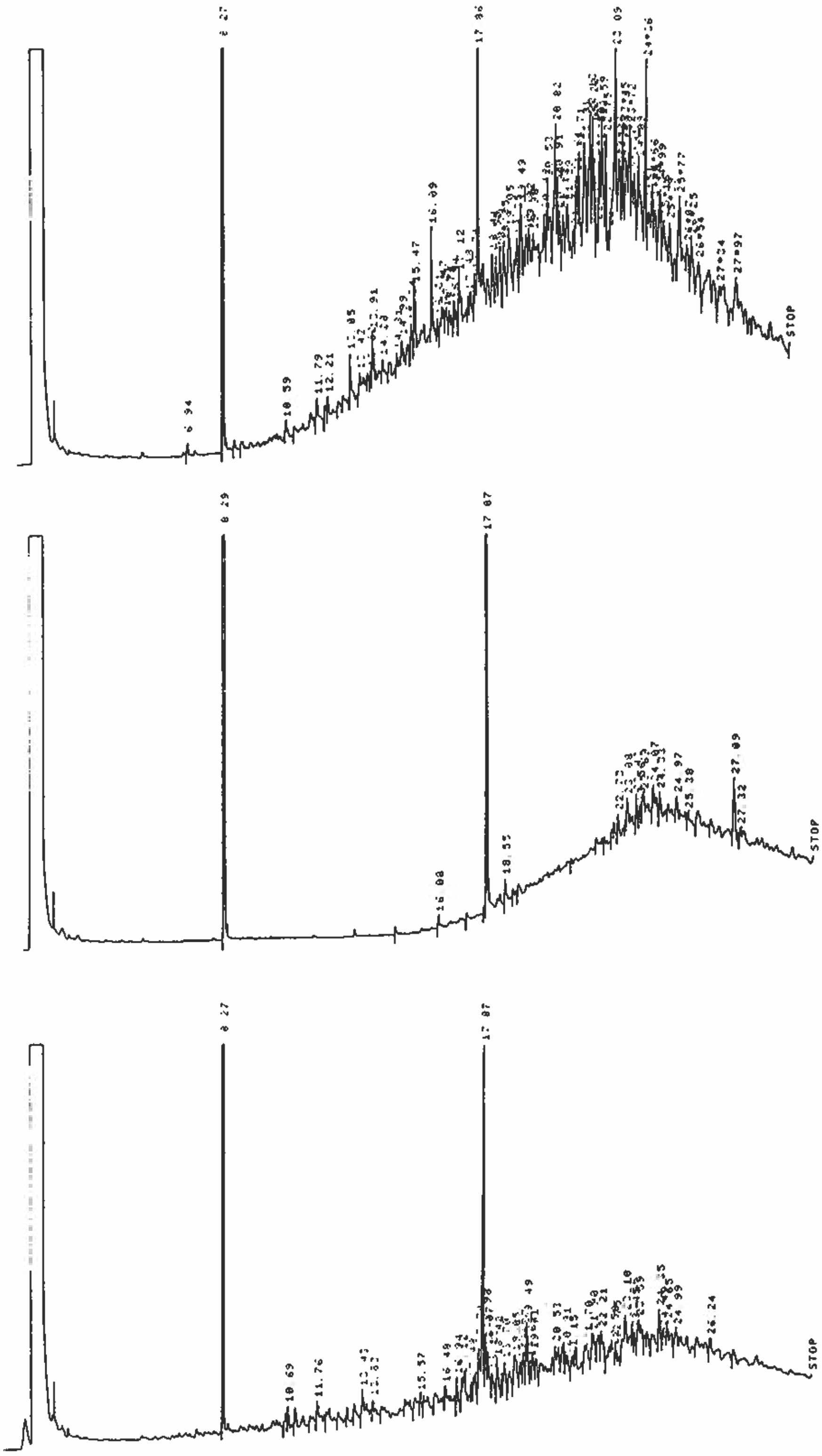

Figure 4 continued. Gas chromatograms of F2 fractions from new sediment layer overlying a buried tar layer (top), surface sediment sample near long-term oiled region (middle), and from buried tar layer (bottom). (Peaks at 8.2 and 17.8 are internal reference standards).

Table 3. 1985 sediment oil equivalents (ug/gm), determined by UV/Fluorescence, in 1975 test plots in Miguasha marsh. Values shown represent total fluorescing materials, and are not corrected for native, indigenous fluorescence. Values marked * judged to be background values, based on UV/F SEES spectra.

			Core depth			
			0-5cm	5-10cm	10-20cm	-20cm
Quadrat	1	1975 test plot A1	1,125.3	1.776.3		
	2	A2	340.5	3,621.9	3,188.7	359.6*
	5	A6	1,354.9			144.2*
	5B		435.6	21,180.3*	384.2*	
	6	A7	1,941.8			48.6*
	6B		703.4			61.3*
	8	A9		6,805.8		

Table 4. Hydrocarbon equivalents (ug/gm) in sediment samples from transect A in Miguasha marsh, September 1985. Determinations by UV-fluorescence represent total fluorescence, and are not corrected for native fluorescing materials. Values marked * judged background from UV/F SEES spectra.

Transect station	A(0-5cm)		B(0-5cm)	
A7-1	1941.8	48.6* (-20cm)	703.4	61.3* (-20cm)
A7-2	399.7		1557.8	
A7-3	319.0		369.7	
A7-4	392.4		177.7	
A7-5	544.7		516.3	
A7-6	508.7		457.6	
A7-7	1793.2		3142.5	
A7-8	156.5		424.8	
A7-10	109.7			
A7-13	226.6			
A7-15	558.6			

- 20cm sediment sample to 58,697 ug/gm in a sample of buried tar deposit. Most samples varied between 150 to 10,000 ug/gm.

Representative fluorescence intensities for extracts from sediments from the 1975 test plots, resurveyed in 1985, are shown in Table 3. Surface and near surface sediments generally ranged between 340 and 6806 ug/gm oil equivalents. One sample, taken from 5-10cm in test plot A6, was an anomaly at 21,180 equivalents. Deeper, -20cm, sediments generally ranged between 49 and 360 ug/gm oil equivalents.

Representative values for oil equivalents from one of the main marsh transects, transect A originating from 1975 test plot A7, are shown in Table 4.

DISCUSSION

Most of the 1975 test plots appeared indistinguishable from the surrounding marsh areas, and this was supported by the analyses of the vegetation surveys. However, there were some analytical problems that could have been overcome if the test plots had been selected slightly differently in 1975. A major problem was that the cleanup or test plots were not blocked originally to allow for vegetation zonation. Second, no initial plant inventory was taken. And third, there were no replicate plots, sothat no statistical analysis was possible. Hence, no detailed conclusions may be drawn about the succession of vegetation after the oil spill or after the subequent cleanup trials.

No morphometric data were collected in 1985, but as pointed out, the vegetation appeared normal, consistent with that in other salt marshes at that time of year. Except for test plot 7, there were no visible outlines of any of the old test plots, and vegetation was continuous throughout the marsh. The one exception to this was test plot A8 (quadrat 7), located on the high marsh, but which was dominated by <u>Spartina</u> <u>alterniflora</u>. The latter is characteristic of low marsh areas that are regularly inundated by saltwater. This test plot had been used in 1975 to assess the usefulness of digging out and removing oiled sod mass, lowering the level of the marsh back to the <u>S</u>. <u>alterniflora</u> level. The vegetation for this particular location was therefore normal in terms of its zonation, although it was surrounded on all sides by <u>S</u>. <u>patens</u>.

The value of the numerical analyses was in the association of similar plots based on floristic composition. The test plots treated with cleanup procedures were not outliers from the non-treated test plots. Their relative position with respect to other areas in the analyses correlated well with their actual location in the marsh, with the obvious exception of test plot A8. That is, there were no unexplained anomolies between the perceived zonation and the subsequent analysis.

From an oiling point of view, the 1975 test plots remain foci of ongoing hydrocarbon contamination for the marsh. In this respect the data from UV/Fluorescence is used primarily to screen extracts for presence of hydrocarbons or for native fluorescing material, in particular using the SEES profiles. The presence of large amounts of native fluorescing materials in the marsh sediments, e.g. plant pigments, becomes a significant interfering factor in these fluorescence data, especially where hydrocarbons are present in low concentrations. While in regions of high concentrations, such as in surficial oiled sediments, the oil hydrocarbons over-ride fluorescence due to native materials, this becomes less significant as the concentration of oil hydrocarbons relative to native pigments decreases. We suspect in fact that in table 3, the value of 21,000 mg/gm reported for the -5/-10 cm sample for quadrat 5B is due largely to background fluorescence, based on the presence of the dominant background fluorescence maximum at 347 nm which is found to be characteristic of native fluorescence. Similar SEES spectra were also found in the -20 cm samples for quadrats 2, 5, 6 and 6b, which are all relatively free of hydrocarbons when examined by GC.

It is interesting to note, however, that most of the profiles for the surface sediments indicate deficiencies in 5-ring and larger aromatic materials (decreased peak intensities above 360nm) when compared with SEES profiles on whole Bunker oil. Instead, we see a predominance of lower molecular weight, one to three and four ring, materials. This suggests that much of the present surficial contamination may be the result of water-borne cross-contamination.

In sub-surface sediments, hydrocarbons continue to persist in the original oiled areas, but are rarely found in large amounts below 15 cm. Even in heavily oiled areas there was little evidence of high concentrations, except where strata or zones of intact oil or oiled vegetation had become buried by subsequent siltation and marsh buildup.

Most remarkable was the finding of the buried oil layer along Transect B. The circumstances suggest that this particular region of the marsh was and remains an area of rapid sediment deposition and marsh growth. This also suggests that under certain conditions of high sedimentation rates the easiest and least damaging countermeasure approach to oiling of a saltmarsh may be to simply leave the marsh to natural revegetation.

In terms of marsh recovery by revegetation, the overall impression from the long-term followup suggests two processes were at work here. The first consists of two stages - weathering of the stranded oil slicks with concommittant impregnation with sediment, followed by reinvasion by marsh vegetation. The latter originates either from already existing rootmasses under the weathered tar layer, or by lateral reinvasion. The latter has also been observed at the site of the oiled Ile Grande marsh, in north Brittany, France.

The second process consists mainly of total burial by deposition of imported fine sediments over the layer of oil and oiled marsh vegetation. In this case the newly deposited layer of sediment was up to 15 cm in depth, and indicates a high rate of deposition for this region of the estuary. Interestingly, there was no evidence of new vegetation embedded within this new sediment layer suggesting perhaps that new root formation had not occurred until a sufficiently deep sediment layer had been formed over the buried and relatively unweathered oil layer. Certainly no roots of the new marsh vegetation were found to penetrate down into and through the buried oil horizon.

CONCLUSION

The Miguasha saltmarsh has generally recovered, with few signs that either the oil itself or any of the cleanup procedures, except for oiled sod removal, has either helped or hindered the revegetation.

Sediment samples taken from the initial oiled marsh areas, however, retain significant and identifiable amounts of Bunker C derived hydrocarbons. These are found primarily in the upper 15cm.

Surface sediments generally show low level hydrocarbon contamination consisting mainly of lower molecular weight hydrocarbons presumably transported and redistributed during tidal inundations of the marsh.

In areas of low sedimentation the recovery pattern is that of oil weathering and vegetative invasion. In areas of high sedimentation and marsh buildup, the recovery was by burial of the spilled oil and oiled vegetation layer, followed by subsequent regrowth of vegetation above the subsurface oiled layer.

ACKNOWLEDGEMENT

We express our thanks to C.W. Ross, G. Sergy and K. Meikle for financial and general support during the various stages of this study. T.P. Ahern provided the chemical analytical support. S. Vandermeulen assisted in the bulk of the field work and collections. We acknowledge the financial support of the Department of Fisheries and Oceans, and a research grant from the Environmental Emergencies Branch of the Environmental Protection Service, Department of Environment.

REFERENCES CITED

Baker, J.M., J.H. Crothers, D.I. Little, J.H. Oldham and C.M. Wilson. 1984. Comparison of the fate and ecological effects of dispersed and non-dispersed oil in a variety of intertidal habitats. In Oil Spill Chemical Dispersants: Research, Experience and Recommendations. (Allen, T.E., ed.) Amer. Soc. Test. & Mat'ls, Phil. #STP 840. pp. 239-279.

Cejka, P. 1975. Study of various cleanup methods for a bullrush marsh polluted by oil. Report No. UE-1R (July/August 1975). Res. and Dev't Div'n, Envir'l Emerg. Brnch, EPS DOE

Hill, M.O. 1979a. Decorana. A fortran program for detrended correspondence analysis and reciprocal averaging. Cornell University, Ithaca.

Hill, M.O. 1979b. Twinspan. A fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Ithaca.

Lloyd, J.B.F. 1971. The nature and evidential value of the luminescence of automobile engine oil and related materials. III. Separated luminescence. J. Forensic Sci. 11:235-253.

Vandermeulen, J.H. and Gordon. 1976. Re-entry of five-year old stranded Bunker C oil from a low-energy beach into the water, sediments and biota of Chedabucto Bay, Nova Scotia. J. Fish. Res. Bd Canada 33:2002-2010.

Vandermeulen, J.H. and C.W. Ross. 1977. Assessment of cleanup tests of an oiled saltmarsh - the Golden Robin spill in Miguasha, Quebec. Report EPS-8-EC-77-1. Can. Dept Fish's & Envir't.

Vandermeulen, J.H., B.F.N. Long and T.P. Ahern. 1981. Bioavailability of stranded Amoco Cadiz oil as a function of environmental self-cleaning: April 1978 - January 1979. In Amoco Cadiz: Conse quences d'une pollution accidentelle par les hydrocarbures. CNEXO, Paris. pp. 585-597