RECOVERY OF BRITTANY COASTAL MARSHES IN THE EIGHT YEARS FOLLOWING THE *AMOCO CADIZ* INCIDENT

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ABSTRACT: *The salt marshes on the Brittany coast of France have undergone a number of changes and have been influenced by man-made and natural factors since the* Amoco Cadiz *spill of March 1978. This work catalogs the ecological changes which have occurred over the past eight years and presents original data on the present state of these marshes.*

The recovery of Brittany coastal marshes began following cleanup operations which were often damaging to marsh and marsh substrate. The physical and toxicological properties of the oil also were damaging in the short term, especially to annual species. Natural recovery began primarily by invasion of exposed areas with annuals and rhizome spreading of perennials. Within four years, an almost logarithmic recruitment process was begun by annuals followed by perennials. Pioneer and opportunistic species increased, facilitated by partially vegetated substrates available for seed and seedling retention and by increased seed and rhizome production. Man-induced restoration was also important and was done largely by planting wild or cultured stock. The final stage of marsh recovery, as existing today, is the emergence of perennial species of high and low marsh at elevations and tidal exposures typical for their growth.

These successional changes in a marsh following a major oil spill (and various other man-made impacts) provide an understanding of the complex processes involved in marsh recovery. This understanding allows the formulation of planning guidelines to predict the long-term impacts of future incidents and to make proper recommendations for cleanup and restoration to aid the recovery process.

The duration of impacts of oil spills on marshes is dependent on the amount and type of substance spilled and on the levels of protection and cleanup efforts. Very large spills where very intense cleanup has occurred offer opportunities for studying the stages and rates of marsh recovery and the results can be applied to other spills for planning and mitigation purposes. The *Amoco Cadiz* (March 1978) spill on Brittany marshes has been studied over time by various researchers and thus provides such an opportunity for long-term study of marsh recovery.

Marshes on the Brittany coast were oiled by the *Torrey Canyon* in 1967 and provided some of the first information on marshes impacted by large spills. In general terms, researchers learned that marshes were severely damaged by oiling; that cleanup could be quite damaging; and that various ecological and physiological processes were influenced by the oil. Particularly relative to Brittany coast marshes, researchers found that certain plants were more sensitive to oiling and others were either resistant or more prone to rapid recovery. Follow-up studies of Brittany marshes since the *Amoco Cadiz* spill of 1978 have added much additional information on the details of recovery and the impacts of oiling and cleanup. Following is a chronology of Ile Grande marsh work through the present.

1978. Observations on the initial oiling of Brittany marsh and the level of cleanup were made by D'Ozouville, et al., NOAA/EPA, and others.[4,10] Seneca and Broome reported on artificial restoration activities and prespill conditions.[13] Relative to marsh ecology, the annuals (*Salicornia* and *Suaeda*) were considered most sensitive, although large die-offs of perennials were reported. (Later work showed that mainly leaves died and that intact roots undamaged by cleanup quickly produced aerial portions.) Also, the high tide deposited oil on the highest marsh elevations which affected the efficiency of natural cleanup.

1979. Long and Vandermeulen[9] reported erosion in secondary channels and deposition in channels and tidal flats which were attributed to "massive cleanup." Seneca and Broome[13] reported mixed results of plantings because of choosing improper planting elevations and because of the lingering effects of the oil and/or the cleanup.

1980. Vandermeulen et al.[15] reported increased erosion and suggested reduction in tidal prism and mass planting to restore the marsh. Without this, they predicted the recovery might "require centuries."

1981. Through this year, Seneca and Broome[13] reported planting 9,700 transplants in the Ile Grande marsh, and optimum species and techniques were determined. The condition of the marsh was reported as improving in many cases.

1982. Gross[5] began the first quantitative studies of the marsh using transects and coverage. He concentrated on artificial plantings but found the natural marsh to be in a state of successful recovery. Levasseur and Jory[7] reported a significant increase in vegetation since 1980.

1983. Gross[6] completed his study and his results were published by Levasseur.[8] Gross made a number of observations and developed conclusions from his data. He determined that the annuals (*Salicornia* and *Suaeda*) contributed considerably to the vegetation coverage in warmer months but died out in the winter, thus giving misleading interpretations. He also proposed a succession based on pioneering annuals which gave rise to perennial grasses (*Puccinellia*) and ultimately to broad-leafed perennials (*Halimione*). He reported areas of excellent recovery, but listed problems of bare spots and unplanted areas, and increased species diversity as due to the spill and the cleanup activities.

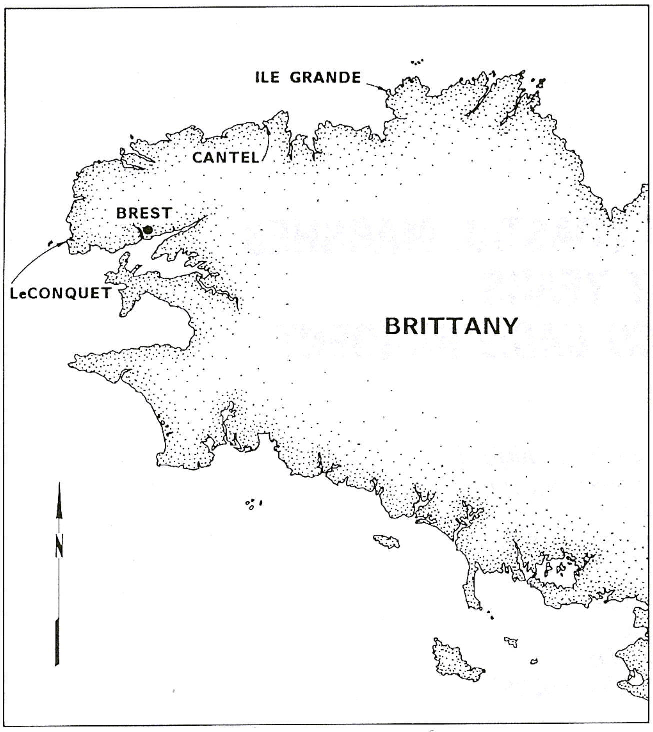

Figure 1. Location map showing three major survey sites along the Brittany coast

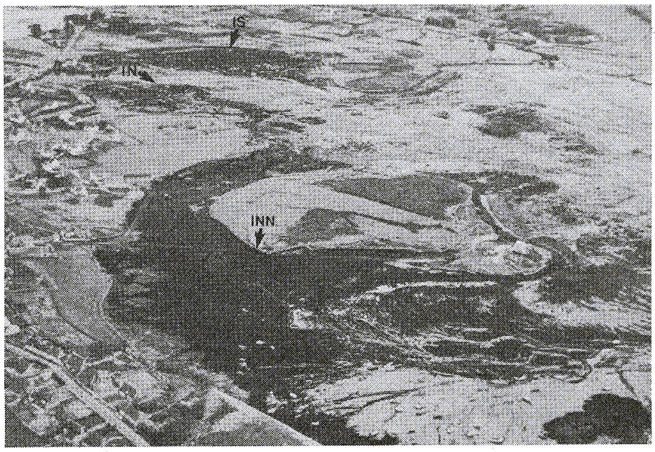

Figure 2. Aerial photograph taken in March 1978 showing extensive oiling of the three Ile Grande marshes used in the present study (arrows)

To study the present status of the Ile Grande and area marshes, quantitative surveys were conducted in late summer and early winter seasons. Comparisons were made of marsh with heavy cleanup, marsh without cleanup, and marsh without oiling to determine the following:

- the relative "state" of recovery of the impacted marshes;
- vegetation patterns of succession and ecological changes in marsh recovery;
- the long-term impacts of heavy cleanup versus no cleanup on marsh recovery;

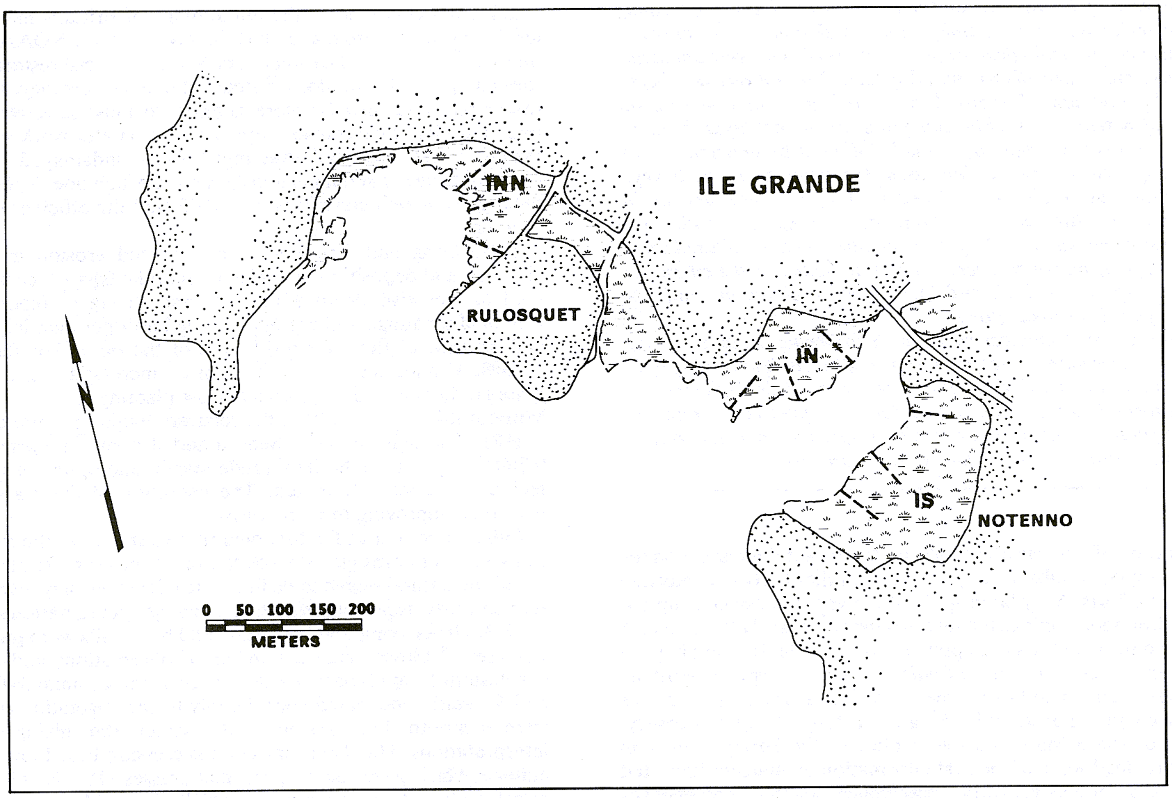

Figure 3. Map drawn from 1978 aerial photograph depicting the three marshes surveyed at Ile Grande (INN, northernmost marsh; IN, central marsh; IS, southern marsh)—The approximate locations of the transects are shown by dashed lines.

Table 1. Common species quantified in the transects and plot samples

Juncus maritimus	Perennial monocot found at higher marsh elevations; spreads by rhizomes
Halimione portulacoides	Large, perennial, broad-leafed dicot found at moderate marsh elevations and along creeks; a climax species which dominates many areas and reproduces quickly by seed
Puccinellia maritima	Perennial grass which spreads by seed and rhizome, and forms dense turfs at moderate elevations; frequently co-dominant with *Halimione*
Triglochin maritima	Perennial, producing a tap root and common at moderate elevations; also spreads by seed
Spartina maritima	Perennial grass, uncommon and found in lower elevations; a taller and more robust species, *S. anglica,* was quantified in several plots
Limonium vulgare	Perennial dicot and opportunistic in cracks and crusts at moderate elevations; reproducing by seed
Aster tripolium	Perennial dicot, uncommon in upper and moderate elevations of the marsh
Suaeda maritima	Annual, reproducing by seed and common in lower elevations
Salicornia spp.	Several species of annual, reproducing by seed and colonizing exposed areas in lower and moderate elevations

- the restoration procedures necessary for enhancement of marsh recovery over the long term; and
- planning guidelines for avoiding or reducing long-term impacts to marshes.

Methods

Study sites along the Brittany coast are shown in Figure 1. The Cantel marsh was used as a control site which had been oiled but not cleaned. Marshes at Le Conquet were used as control sites having been neither oiled nor impacted by cleanup.[2,10] The Ile Grande site (Figure 2) was heavily oiled during the spill and was also subjected to intense cleanup operations. Belt transects, 50 meters (m) in length and 0.5 m wide, were run at random intervals in the northernmost marsh at Ile Grande (INN), the central marsh at Ile Grande (IN), and the southern marsh at Ile Grande (IS) as shown in Figure 3. Similar transects were conducted at Cantel and Le Conquet. The total of 15 transects covered 450 square meters (m^2) of marsh. In addition to the transects, plot sampling was conducted at each site using 0.25 m^2 quadrats. Three plots were thrown at random in each of three marsh elevations—low, intermediate, and high.

Vegetation and geomorphology were noted along each transect and within each plot. In the transects, the presence of common species was noted for the entire length. The size and location of pannes (unvegetated, shallow pool) and creeks encountered were noted and they were photographed. Any bare spot or unvegetated crust (extremely weathered oil) in excess of 100 square centimeters (cm^2) was also noted. The data were recorded in percent occurrence and m^2 coverage of each species, concentrating on the major marsh species listed in Table 1. Percent occurrence and m^2 coverage in the plot samples were determined by using dot overlays with photographs of the plots.

Statistical analyses included means and standard deviations for occurrence of species in transects and plots within each site. Site intercomparisons were made by T-test and analysis of variance (ANOVA).

Figure 5. One of three transects run at the Cantel marsh (site C)—The higher overall elevation and steep grade to the water precluded the existence of *Salicornia;* the vegetation present is predominantly *Halimione, Triglochin,* and various grasses.

Figure 4. Sample transect at Ile Grande (one of three at IN) showing starting location (first ten meters of the total 50 m transect; line added to show orientation of 15 m × 0.5 m belt transect) and various features recorded for intersite comparison (A, beginning of *Salicornia* zone; B, bare spot; C, beginning of zone of *Triglochin, Puccinellia,* and *Salicornia;* D, crust (only one encountered in the transects); E, *Halimione* and *Puccinellia* zone; F, creek lined with *Salicornia* and with *Halimione* on the edges; G, beginning of *Juncus* zone 39.3 m from the beginning of the transect)

Figure 6. One of six transects run at the control marsh at Le Conquet (use key in Figure 4 for reference)—The *Juncus* zone occupied a narrow band far beyond the transect sites in this broad marsh and was sampled only by plots. The crust "D" is missing in this photo.

Table 2. Mean percent occurrence and standard deviations of species and geomorphological features compared between sites

	Marsh[1]				
Species/Feature	INN	IN	IS	C	LC
Salicornia	64.8 ± 22.0	50.7 ± 12.0	36.8 ± 30.7	0.9 ± 1.6	54.1 ± 24.1
Triglochin	28.3 ± 25.9	37.9 ± 9.3	2.1 ± 7.6	64.5 ± 21.9	0.0 ± 0.0
Limonium	12.0 ± 14.4	44.0 ± 34.8	29.8 ± 4.3	0.0 ± 0.0	0.0 ± 0.0
Puccinellia	32.7 ± 12.1	36.0 ± 9.6	19.4 ± 17.6	0.0 ± 0.0	29.3 ± 24.4
Halimione	75.4 ± 7.0	62.4 ± 28.5	24.8 ± 9.2	89.1 ± 3.4	47.6 ± 29.7
Juncus	37.1 ± 25.3	44.3 ± 18.3	27.6 ± 22.3	0.0 ± 0.0	0.0 ± 0.0
Suaeda	7.9 ± 13.6	20.3 ± 29.1	30.5 ± 17.3	10.4 ± 11.3	39.6 ± 26.5
Aster	6.4 ± 6.1	0.0 ± 0.0	0.0 ± 0.0	18.0 ± 12.2	0.0 ± 0.0
Bare spot	0.8 ± 0.8	5.6 ± 3.7	2.8 ± 3.5	0.0 ± 0.0	8.0 ± 4.0
Creek	3.7 ± 3.0	7.3 ± 2.5	20.8 ± 12.2	3.7 ± 4.4	4.3 ± 4.7
Panne	0.0 ± 0.0	5.7 ± 4.5	0.0 ± 0.0	0.8 ± 0.8	0.7 ± 1.2
Crust	0.0 ± 0.0	1.8 ± 1.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Trench	0.4 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

1. INN, Ile Grande North; IN, Ile Grande; IS, Ile Grande South (Notenno); C, Cantel; LC, Le Conquet

For T-tests, a value of $n = 3$ was assigned to each treatment analyzed statistically, based upon three transects composing each treatment. A two-tailed rejection region was implemented and based on a T-distribution with $(n_1 + n_2 - 2)$ degrees of freedom. Critical T-values ($t_{0.025}$) were compared to the actual values calculated for each comparison of treatments. The critical T-value for all treatments was 2.776 (df = 4). Mean, m^2 occurrences of common species, and geomorphological features were compared using ANOVA. A significance level of $\alpha = 0.05$ and a tabulated F-value of 6.61 were used.

Results

Photos of sample transects are shown in Figures 4–6. Summaries of the data for 15 transects in five sites are given in Table 2. Random transects across the marshes showed some variability in both treatment and control sites. The occurrence of the annuals, *Salicornia* and *Suaeda,* was high and relatively constant except for the Cantel marsh which had the least area suitable for their growth (relative to elevation). The high measurement for annuals at INN was due in part to a particularly dense population of *Salicornia* at the water's edge in two transects. An illustration of the role of *Salicornia* as a pioneer species is shown in Figures 7 and 8.

Halimione was the dominant or co-dominant plant in practically all transects, and percentages reached 75.4 ± 7.0 at Ile Grande and 89.1 ± 3.4 at Cantel. The dense coverage frequently precluded the growth of smaller species and was an illustration of the role of the plant as a climax species.[12]

The high marsh plant, *Juncus,* was common throughout its elevation except at Cantel, where highland abruptly joins the marsh. The transects run at the wide marshes of Le Conquet were not adequate in length to reach the *Juncus* zone; however, this zone was sampled using plots.

Other geomorphic features included bare spots, pannes, and crusts. The Le Conquet control site contained the largest percentage of bare spots. Cantel showed no exposed bare spots although the dense canopy of *Halimione* could be pushed aside to reveal bare areas in some transects. These hidden spots were not quantified since the study focused on occurrence and coverage. Pannes and crusts were common at the Ile Grande site, although pannes were larger and more numerous in plots at the Le Conquet site. The pannes seen in transects were natural features, showing no unusual characteristics and no oil sheen upon disturbance of the sediment. A 90 cm section of asphaltic crust was found in one Ile Grande transect (IN).

Results of the T-tests for the transect data are summarized in Table 3. Significant differences were seen between two Ile Grande sites and between the northernmost Ile Grand site and the Cantel marsh. However, the latter difference was positive, indicating that more coverage or larger total occurrences of each species were found at Ile Grande. A 90 percent chance that the sites were significantly different existed between INN and Le Conquet, IN and IS, and IN and Cantel. In the first and last cases, the T-value was positive, indicating greater coverage in the INN and IN sites than in the Le Conquet and Cantel

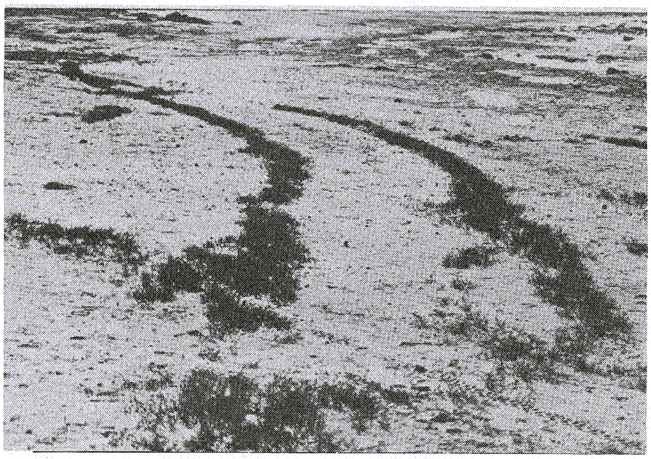

Figure 7. Population by *Salicornia* of wheel ruts at site IS in late fall 1985—The plants are undergoing late season die-off and are thus represented as dried twigs.

Figure 8. A section of the same ruts shown in Figure 7, in August 1986, illustrating the rapid spread of the *Salicornia* and its fuller appearance near the end of the growing season.

Table 3. Results of t-tests performed on the mean ± S.D. total occurrence (m^2) of the seven major plant species between treatments

Test	T-value
IN versus control	1.96
IS versus control	−0.32
INN versus control	2.19_2
Cantel versus control	−0.25
IN versus IS	2.26_2
IN versus INN	0.56
IS versus INN	2.88_3
IN versus Cantel	2.30_2
IS versus Cantel	0.15
INN versus Cantel	3.18_3

1. IN, Ile Grande; INN, Ile Grande North; IS, Ile Grande South (Notenno); Control, Le Conquet
2. Denotes a less significant difference ($\alpha = 0.10$) $0.05 > t < 0.05$
3. Denotes a significant difference ($\alpha = 0.05$)—two-tailed $0.025 > t < 0.025$

Table 4. Results of ANOVAs performed on the mean occurrence (m^2) of plant species as a comparison of sites IN and Cantel

Subject	Tabulated F-value	Calculated F-value
Salicornia	6.61	50.32_1
Triglochin	6.61	3.76
Limonium	6.61	4.80
Puccinellia	6.61	42.19_1
Halimione	6.61	2.59
Juncus	6.61	17.58_1
Suaeda	6.61	0.30

1. Significant at $\alpha = 0.05$ level

Table 5. Results of ANOVAs performed on the mean occurrence (m^2) of plant species as a comparison of sites IN and LC

Subject	Tabulated F-value	Calculated F-value
Salicornia	6.61	0.05
Triglochin	6.61	50.03_1
Limonium	6.61	4.80
Puccinellia	6.61	0.19
Halimione	6.61	0.39
Juncus	6.61	17.58_1
Suaeda	6.61	0.72

1. Significant at $\alpha = 0.05$ level

controls. It is assumed that the larger marsh width and higher elevation at IS versus IN resulted in the difference between these two Ile Grande sites.

Results of the ANOVAs for the transect data are shown in Tables 4 and 5. Comparisons are made between the IN site and the Cantel and Le Conquet marshes. Significant differences were seen in the occurrence of *Salicornia* and *Juncus* because, as mentioned previously, the proper elevations for growth of these species did not exist at Cantel. *Puccinellia* was rare at Cantel for unknown reasons (possibly due to the coverage of *Halimione*). The dominant plant, *Halimione,* did not vary in occurrence between the two sites. The occurrence of *Triglochin* and *Juncus* was the major difference between the IN and control sites. Although the two plants were located in plots taken on the upper marsh, the intermediate section where the transects were taken was predominantly *Halimione* and *Salicornia.* Otherwise, the data did not show significant differences between occurrence of vegetation at the treatment and control sites.

Analyses of the plot sampling data provide additional information on important species and geomorphological features. A summary of these data for Ile Grande, Cantel, and Le Conquet is given in Table 6. The marsh zones are roughly divided into lower, intermediate, and upper elevations. The Cantel marsh is almost entirely at an intermediate elevation. The five most common plants are compared between the sites. The annuals (*Salicornia* and *Suaeda*) occupy low-lying areas and make up substantial portions of these areas. *Halimione* was found to be most common in the control site using the plot sampling method (note that its occurrence at the belt transects was greater in the Ile Grande site). *Juncus* was dominant in the higher elevations but was not found in the transects at Le Conquet because the plant occupied a narrow fringe at the upper reaches of the wide marsh at Le Conquet. The bare spots were shown to exist primarily in the lower marsh sections as a function of coverage of either *Salicornia* and/or *Suaeda* (note that percent coverage which combines the annuals plus the bare spots totals 100).

Conclusions

The data from the late summer (1986) and fall (1985) surveys indicate that the marshes impacted by the spill have recovered or are well on their way to recovery. The results show little or no difference in species occurrence and coverage between the treatments and controls. The bare spots, which may be construed as results of perturbation, were most common in the control site which had no oiling. This conflicts with observations by Gross[6] and Levasseur[8] that bare spots are problems which result from improper cleanup. The remaining evidence of the spill was the presence of insignificant amounts of crust in transects at Ile Grande. The lack of crusts in 75 m^2 of transects at Cantel indicate their presence there is insignificant.

The long-term impacts of the spill appear to be the results of marsh cleanup and the associated removal of marsh substrate. The Cantel marsh which was oiled but had no cleanup was essentially restored by natural processes within five years of the spill. Significant revegetation was noted by various workers at the spill/cleanup impact site at Ile Grande within four years of the spill, but complete restoration has only recently taken place (7–8 years after the spill). Even with the

Table 6. Mean percent coverage values (±S.D.) for plant species and bare spots measured from plot samples taken at various elevations at sites Cantel, IN, and LC

	Mean percent coverage by elevation						
	Cantel	IN			LC		
Species	intermediate	upper	intermediate	lower	upper	intermediate	lower
Salicornia	—	4.3 ± 3.8	—	66.2 ± 7.2	—	—	8.7 ± 10.1
Puccinellia	9.2 ± 19.6	—	57.9 ± 12.1	—	—	—	—
Halimione	57.9 ± 28.7	3.8 ± 6.6	42.1 ± 12.1	—	40.2 ± 5.7	91.5 ± 11.7	—
Juncus	—	89.5 ± 1.6	—	—	59.8 ± 5.7	—	—
Suaeda	—	—	—	—	—	—	35.6 ± 22.7
Bare spots	8.2 ± 16.5	2.3 ± 2.1	—	33.8 ± 7.2	—	8.5 ± 11.7	55.7 ± 12.7

large amount of artificial plantings, the extreme cleanup procedures in particular areas apparently delayed restoration by 2–3 years.

The ecological changes which have taken place over the study sites within the past eight years appear to be well defined and are summarized as follows:

1. The spill killed annuals and the leaves of perennials which were coated in varying degrees of oil at Ile Grande. At Cantel, the initial impact was less.
2. The cleanup operations killed perennials in some areas by destruction and compaction of roots, and prevented recolonization in some areas by removal of substrate.
3. Erosion of channel banks and sediment redeposition occurred at Ile Grande in the four years following the spill.
4. Noticeable recovery began at Ile Grande approximately four years after the spill.
5. Ile Grande recovered or is in the final stages of recovery 7–8 years after the spill, and Cantel recovered less than five years after the spill.
6. Recovery at Cantel was marked by dense colonization of *Halimione* with grasses and other vegetation in uppermost areas.
7. Recovery at Ile Grande comprises dense *Halimione* on creek banks and uppermost areas, a mixture of *Puccinellia* and other species at moderate elevations, and *Salicornia* at the lowest and moderate elevations.
8. Artificial plantings were very beneficial to recovery by stabilizing open areas and providing attachment substrates for seeds and propagules.
9. The succession at moderate elevations of the Ile Grande marshes is from *Salicornia*-to-*Puccinellia* and grasses-to-*Halimione.*

These ecological results agree with the literature on long-term, oil-spill impacts on local marshes. Ranwell[11] reported the 1967 *Torrey Canyon* oiling of Ile Grande as damaging *Puccinellia* and *Salicornia.* Baker[1] reported that annuals were sensitive and recovered poorly, that *Halimione* was susceptible but recovered by shoot production, and that perennials were resistant. In one of the longest studies of oil impacts on marshes, Dicks and Iball[3] report ten years of monitoring a United Kingdom marsh. *Salicornia* spp. began colonizing the chronically oiled area immediately after effluent improvement and had colonized most of the impact site within 5–6 years.

The *Amoco Cadiz* experience and the literature on marsh recovery indicate that one can expect recovery of tidal marshes in exposed situations within 4–5 years after a large spill. Marsh cleanup activities may delay this recovery by 25–50 percent. However, the present research and others cited show that marsh recovery would not require centuries as suggested by Vandermuelen et al.[15] Recovery should be enhanced by low-level cleanup and artificial planting. Geomorphological changes such as canal and dike construction to drain or direct oil and roads to transport oil should be used only in extreme cases and these changes should be repaired following cleanup.

The following cleanup methodology is reiterated:

1. Emphasis should be on protection rather than cleanup, and dispersants may be favored over floating oil (i.e., short-term impacts on fauna as opposed to long-term impacts on their habitat).
2. The need for cleanup should be ecologically, rather than aesthetically, determined.[14]
3. Cleanup techniques should be appropriate and not harsh. Many guides and publications are available giving alternatives.
4. An ecologist should be present at large-spill cleanup of marshes to (a) conduct baseline surveys, and (b) monitor cleanup.

Lessons learned from the *Amoco Cadiz* have provided valuable insight into long-term impacts on marsh and other habitats. Using appropriate planning, cleanup, and restoration procedures should help prevent future, long-term impacts due to large spills.

Acknowledgment

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