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Effect of Oil on Recruitment from the Seed Bank of Two Tidal Freshwater Wetlands

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Abstract

The effect of oil spills on the recruitment of freshwater tidal wetland species was determined using soil seed bank samples collected in early March from two New Jersey Delaware River marshes. Samples were exposed to simulated tidal cycles 0 (2 days), 2 and 4 wk after soil was collected; 0 wk samples were treated before germination began. Oil treatment significantly reduced survival to 1 May (end of study) of *Acnida cannabina* and *Bidens laevis,* the dominant species, as well as number of species per sample and height of *B. laevis.* Total perennial seedlings, present in low numbers, also showed significant reduction with treatment. However, during the course of the study, *Peltandra virginica* recruitment and survival were not reduced by oil treatment and recruitment of *Sagittaria latifolia* appeared enhanced. There was no consistent pattern regarding which treatment time produced the greatest effect. Interactions (site, treatment, time) were generally not significant. Because these tidal freshwater wetlands and seed banks are dominated by annuals, reduction in seedling numbers and growth could substantially alter vegetation patterns. Timing of oil spills would be important, but impact would depend on species composition of the seed bank and colonizing vegetation, dispersal of seeds into the site, and germination requirements.

Introduction

According to Howarth (1989), the estimated amount of oil entering coastal areas worldwide, mostly from anthropogenic sources, is between 1.7-8.8 million metric tons yr^{-1}. On the east coast of North America, oil spills in the lower Delaware River (*e.g.*, Grand Eagle, 27 September 1985; Intermar Alliance, 19 March 1986; Presidente Rivera, 24 June 1989) have resulted in significant deposition of crude oil on emergent tidal wetland vegetation along 30 km of the New Jersey shoreline.

Effects of oil spills on vegetation have been studied in salt marshes (*e.g.*, Cowell and Baker 1969; Baker 1971, 1973; Dicks 1975; Hampson and Moul 1978; and de la Cruz *et al.* 1981) and some freshwater wetlands (Burk 1977 and references cited therein). Following a spill, annual species often appear not to survive as well as perennials, presumably because they lack underground vegetative structures which can produce new growth (Daiber 1986). Thus, wetlands in which annuals are important could undergo dramatic shifts in species abundance and distribution in response to oil spills. Tidal freshwater wetlands are the only coastal wetlands that are often dominated by annuals (Simpson *et al.* 1983). These wetlands are extensive in the upper estuaries of most Atlantic and Gulf Coast river systems (Simpson *et al.* 1983; Odum *et al.* 1984). Their proximity to oil storage and refinery operations makes them especially susceptible to oil spills.

This study was designed to determine the effect of oil exposure on recruitment of tidal freshwater wetland species. Observations were made using soil samples from Woodbury Creek Marsh and Hamilton Marsh. These wetlands, located along the upper Delaware River estuary, have been the sites of several previous vegetation studies (*e.g.*, Good and Good 1974-75; Whigham and Simpson 1975; Simpson *et al.* 1983; Leck *et al.* 1988). The dynamics of the seed bank, seedling populations, and vegetation composition of the Hamilton Marshes are well-known (Leck and Graveline 1979; Parker and Leck 1985; Leck and Simpson 1987; Leck *et al.* 1988, 1989).

Methods

Sites

The Hamilton Marsh is located along a small tributary of Crosswicks Creek in Mercer County, NJ. Woodbury Creek Marsh is 60 km southwest in Gloucester County, NJ. The sites, each flooded for 3 hr during a tidal cycle, are briefly described below. More information can be obtained from Simpson *et al.* (1983) and Good and Good (1974-75). Nomenclature follows Fernald (1970) except *Zizania aquatica* var. *aquatica* which follows Gleason (1952) and *Phragmites australis* which follows Godfrey and Wooton (1979).

Hamilton Marsh. The site is located near the mixed annuals site of Leck and Graveline (1979). Common annual species include *Ambrosia trifida, Bidens laevis, Impatiens capensis, Polygonum arifolium* and *Z. aquatica* var. *aquatica.* Perennials include *Peltandra virginica* and small numbers of *Acorus calamus, Leersia oryzoides, Phalaris arundinacea* and *Sagittaria latifolia.*

Woodbury Creek Marsh. The site is located in the Princeton-Jefferson section of the marsh described by Dubinski *et al.* (1986) and is dominated by mixed aquatics (Good and Good 1974-75). Common annuals include *Acnida cannabina, A. trifida, B. laevis, Z. aquatica* var. *aquatica,* in addition to the perennial *S. latifolia.*

Soil Samples

Fifty-six surface soil samples were collected on 7 March (Hamilton Marsh) and 8 March 1987 (Woodbury Creek Marsh), prior to field germination. At each site samples were collected from an area which appeared homogeneous in the amount and composition of litter. Samples (19.5 cm x 19.5 cm x 6.5 cm deep) were cut from the wetland surface and placed into plastic trays of the same size with minimal disturbance. For each site, collection of samples, transport to, and placement in the greenhouse was accomplished within six hours. Except when samples received tidal treatment, they were maintained on a greenhouse bench. Greenhouse conditions during the study included ambient photoperiod, ~30% solar irradiance, and a temperature range of 7 to 25°C. Samples were kept saturated with distilled water.

Samples from each site were randomly distributed into seven treatment groups with eight samples per group. Three groups were subjected to five consecutive tidal cycles (procedures described below) in tanks containing crude oil on the water surface, and three other groups were subjected to the same tidal regime, but without oil. Tidal treatments were begun two days (0 wk), 2 wk and 4 wk after sample collection. A control group received no tidal manipulation and no oil.

Tidal treatments were carried out in plexiglas tanks (60 cm x 82 cm x 21 cm deep) sized to permit simultaneous treatment of a set of eight replicates. The plastic trays containing soil samples were placed on 2 cm thick bars positioned on the bottom of tanks to ensure drainage. Then tap water, aged 12 hours, was added at the rate of 1 cm per minute to a depth of 8.5 cm above the surface of the soil; the total water depth in each tank was 17 cm. For the 0 and 2 wk treatments, water level was above most seedlings. Inundation lasted 3 hr, after which water was drained from the tanks.

In oil treatment tanks, a 1 cm layer of oil was poured onto the surface of 2.5 cm of water and allowed to stand overnight. Trays were placed on the bars and water was added as above. When the water was drained, some oil remained on the surface of the soil and plants in the trays, but most collected in the bottom of the tank.

Each treatment involved five consecutive tidal cycles which, for convenience, were 12 hr apart (natural cycles are 11.5 hr apart). When temperatures were $<10°$C during treatment, the oil assumed a tar-like consistency and did not completely cover the sample surface upon drawdown. Continuous cool weather during treatment of 0 wk Woodbury Creek Marsh samples resulted in $38 \pm 6\%$ of the soil surface being free of oil.

Seedling evaluation

Seedling numbers were determined at the time of treatment (except the 0 wk groups which were treated prior to germination), a week after treatment, and/or at 2 wk intervals until 1 May. Few seedlings remained unidentified ($<0.2\%$; n=14 for Hamilton Marsh samples and n=8 for Woodbury Creek Marsh). Because seedlings were not removed from samples soon after germination, it was occasionally difficult to determine whether grass shoots were from seeds or vegetative growth. Grasses were not distinguished to species, but tentative identification was based on species present at or near each site.

Bidens laevis, the only abundant species common to both sites, was used to determine the effects of oil treatment on growth. Ten seedlings per replicate were marked following 0 and 2 wk treatments or at 3 wks for controls. No measurements were made for 4 wk treated samples because oil had caused plants to collapse, making it too difficult to select plants to measure. Height measurements made on 1 May are reported.

Statistical analyses

Multivariate analysis of variance (MANOVA), coupled with Duncan's multiple range test (SAS Institute Incorporated 1985), was used to compare site (Hamilton Marsh, Woodbury Creek Marsh); treatment (control, tidal-oil, tidal-no oil); and time (control, 0, 2 and 4 wk) interactions for maximum number of seedlings (*i.e.*, the largest number recorded on any given date), for number of seedlings surviving on 1 May, and for percent of maximum surviving on 1 May (for *A. cannabina, B. laevis, I. capensis*, perennials, number of species per sample and total seedlings). The same statistical procedures were used for *B. laevis* height data. Arcsine transformation was used to normalize percentage data prior to analysis. Percent similarity was calculated using Pielou (1984). The Likelihood Ratio Chi-Square (SAS Institute Incorporated 1985) was used to compare treatment effects on survival of perennials and *B. laevis* height measurements.

Results

Seventeen species were recorded from Hamilton Marsh soil samples and 19 from Woodbury Creek Marsh samples. The mean number of species per sample ranged from 3.3 ± 0.3 to 9.3 ± 0.4 (Table 1). Hamilton Marsh soil samples had significantly more species per sample (Table 2). Of the 25 species, 11 were common to both sites, giving 61% similarity. There were no site differences for total number of seedlings (maxima and numbers surviving to 1 May) or number of species per sample surviving to 1 May (Table 2).

Oil treatment significantly decreased the numbers and percent of total seedling survival (until 1 May) in samples from both sites (Tables 1 and 2; $P \leq .001$). Oil treatment also significantly reduced the numbers and percent survival to 1 May of *A. cannabina, B. laevis, I. capensis*, perennials and number of species per sample (Table 2). For most parameters, time of treatment caused significant ($P \leq .001$) but variable effects; percent survival of total seedlings was highest in control samples and lowest when samples were treated at 2 or 4 wk (Table 2). Two- and three-way interactions were generally not significant except for *B. laevis*, perennial survival and maximum number of perennials (Table 2).

Percent survival of *A. cannabina, B. laevis* and *I. capensis* according to site and treatment are shown in Fig. 1. Few *A. cannabina* germinated in Hamilton Marsh samples and *I. capensis* germination was low

Table 1. Effect of tidal treatment, with and without oil, on wetland recruitment. Values are $\bar{x} \pm$ SE for maximum seedling density, percent of maximum surviving to 1 May, maximum perennial seedling density, percent of maximum perennials surviving to 1 May, maximum species per sample, and species per sample surviving to 1 May. Also presented is the proportion of the most common species ($\bar{x}$% ± SE). (0 wk treatment occurred before germination had begun; except for 0 wk, maximum numbers include pretreatment values).

	Maximum Seedling Density (m⁻²)[1]	% Surviving	% Most Common Species[2]	Maximum Perennial Density (m⁻²)	% Perennials Surviving	Total Species[3]	Species Surviving	% Species Surviving
HAMILTON MARSH								
oil 0 wk	3143±333	52±3	97	43± 8	63±18	3.9±0.5	3.3±0.5	85±6
oil 2 wk	4119±399	13±3	92	99±17	42±15	5.9±0.4	1.8±0.2	32±5
oil 4 wk	4347±277	14±2	84	283±46	48±10	7.5±0.4	3.4±0.4	47±6
no oil 0 wk	4855±317	77±2	89	158±23	86± 1	8.8±0.6	6.5±0.3	76±4
no oil 2 wk	4645±329	87±5	88	256±53	91± 4	9.1±0.4	6.9±0.4	76±3
no oil 4 wk	5631±436	73±4	84	266±37	96± 2	9.3±0.4	6.6±0.5	72±5
control	3912±218	83±7	82	362±24	94± 3	8.8±0.4	6.4±0.3	80±3
WOODBURY CREEK MARSH								
oil 0 wk	2825±308	77±3	98	53±16	69±16	3.3±0.3	3.1±0.2	97±3
oil 2 wk	3843±886	16±4	93	135±26	40± 9	6.4±0.5	3.5±0.3	55±4
oil 4 wk	5056±525	36±5	93	56±24	0	5.6±0.4	4.1±0.4	77±9
no oil 0 wk	4747±759	92±5	92	164±34	76±14	5.9±0.6	5.4±0.5	92±3
no oil 2 wk	4241±600	80±9	94	53±15	50±16	6.3±0.8	5.9±0.7	93±4
no oil 4 wk	5191±429	74±8	91	89±37	53±17	6.4±0.5	5.8±0.4	92±5
control	3508±284	90±4	89	66±15	76±10	6.8±0.3	6.4±0.3	92±5

[1] Maximum = largest number recorded for any given date.
[2] *Bidens laevis* for Hamilton Marsh samples and *B. laevis* and *Acnida cannabina* for Woodbury Creek Marsh samples.
[3] Seedling species (* = perennials) common to both sites were: *Acnida cannabina, Bidens laevis, Callitriche heterophyla, Cicuta maculata**, *Cuscuta gronovii, Gratiola neglecta, Impatiens capensis, Pilea pumila, Polygonum arifolium, Polygonum punctatum*, and *Sagittaria latifolia**. Species found only in Hamilton Marsh samples were: *Ambrosia trifida, Erechtites hieracifolia, Peltandra virginica**, *Typha latifolia**, Gramineae (*Phalaris arundinacea** and possibly *Leersia oryzoides**), and one unknown. Species only in Woodbury Creek Marsh samples were: *Cornus amomum**, *Polygonum sagittatum, Polygonum* sp., *Typha angustifolia**, *Zizania aquatica* var. *aquatica*, Gramineae (*Pragmites australis**), and two unknown species.

in both marsh samples. Except for *A. cannabina* from Hamilton Marsh, seedling survival in all samples not treated with oil exceeded 50% (see also Table 1). As indicated by MANOVA (Table 2) efficacy of time of treatment varied with species: *B. laevis* showed increasing impact of oil treatment with time (4 wk > 2 wk > 0 wk); *A. cannabina* from Woodbury Creek Marsh showed lowest percent survival when treated with oil at 2 wk; and *I. capensis* appeared to survive best when treated at 4 wk. However, it should be noted that even though seedlings of these and other species, survived oil treatment for the duration of the experiment, they often appeared stunted and chlorotic.

Height of *B. laevis* seedlings was significantly reduced by oil treatment (Table 2 and Fig. 2). Those from Woodbury Creek Marsh samples were significantly taller than those from Hamilton Marsh (Fig. 2 and Table 2). Survival of these marked seedlings was significantly reduced ($P \leq .001$) by oil treatment.

The impact of oil was also variable among perennials (Table 3). *Peltandra virginica* and, to a lesser extent, *S. latifolia* appeared to tolerate oil treatment, whereas *Typha latifolia* and grasses had reduced seedling recruitment and survival. Interestingly, *S. latifolia* germination appeared enhanced by oil treatment but numbers were too small for Likelihood Chi-Square analysis.

With the exception of 0 wk oil treatment groups, all tidal treatments had more seedlings than the controls (Table 1). For many parameters (Table 2), the no oil treatment values were greater than control values, although often statistically similar. This and the statistically significant greater total seedling sur-

Table 2. MANOVA and Duncan's multiple range test results for effects of tidal treatment, with and without oil, on seed bank recruitment and *Bidens laevis* height data [1]

	SITE	TREAT	TIME	SxTr	SxTi	TrxTi	SxTrxTi
Acnida (max)[2]	WH	n.s	4 2 C 0**	n.s.	**	n.s	n.s.
Acnida (1 May)	WH	N C O	n.s.	***	n s.	n.s	n.s.
Acnida (% surviving)	WH	N C O	n.s.	n.s.	n.s.	n.s.	n s.
Bidens (max)	HW	N O C**	n.s.	n.s.	***	n s.	n.s.
Bidens (1 May)	HW	N C O	0 C 2 4	***	*	*	n.s.
Bidens (% surviving)	WH*	C N O	C 0 2 4	n.s.	n.s	**	n.s.
Impatiens (max)	WH	N C O*	4 C 2 0	n.s.	n.s.	n.s.	n.s.
Impatiens (1 May)	WH**	N C O	4 C 0 2	n.s.	n.s.	n.s.	n.s.
Impatiens (% surviving)	n.s	N C O	C 4 2 0	n.s.	n.s.	*	n.s.
Perennials (max)	HW	C N O	C 4 2 0**	***	***	*	**
Perennials (1 May)	HW	C N O	n.s.	***	***	n s.	n.s.
Perennials (% surviving)	HW**	C N O	C 0 2 4*	n.s.	*	n.s.	n.s
No. species/sample (max)	HW	N C O	C 4 2 0	***	n.s.	***	n.s
No. species/sample (1 May)	n.s.	C N O	n.s.	**	n.s.	n.s.	n.s.
No. species/sample (% surviving)	WH	C N O	0 C 4 2	n.s.	n.s	***	n.s.
Total seedlings (max)	n.s	N O C	4 2 0 C**	n.s.	n.s.	n.s.	n.s.
Total seedlings (1 May)	n.s.	N C O	C 0 4 2*	n.s.	n.s	n.s.	n.s.
Total seedlings (% surviving)	WH	C N O	C 0 2 4	n.s.	*	***	n.s.
Bidens height	WH	C N O	C 0 2	n.s.	n.s	n.s.	n.s.

[1] All site, treatment, and time differences were significant at P≤.001 (***) unless otherwise indicated as follows: *= 05>P>01; **= 01>P>.001; n.s. = not significant. Groups are ranked from largest to smallest; those underlined are not significantly different (P≤.05). Sites H = Hamilton Marsh and W = Woodbury Creek Marsh; Treatments O = tidal oil, N = tidal no oil, and C = non-tidal control; Time 0, 2, 4 = 2 days, 2 wks, and 4 wks following collection and C = non-tidal control.

[2] Max = greatest number recorded on any given date, 1 May = number of seedlings alive on 1 May; % surviving = 1 May/max x 100.

vival to 1 May in no oil compared with control samples, suggest that tidal inundation was beneficial.

Discussion

The Hamilton and Woodbury Creek Marshes are dominated by annual species. Yearly biomass production of annuals may be high (2346 g m^{-2} yr^{-1} to > 6000 g m^{-2} yr^{-1}; Whigham *et al.* 1978; Sickels and Simpson 1985) with cover ranging from 75 to 90% (Leck and Simpson, unpublished data). In such wetlands, oil spills would have considerable impact on vegetation dynamics. Spills occurring after germination would be especially damaging (Table 1; Table 2, % survival data). We found significant reduction in seedling number, number of species (Tables 1 and 2), and growth (*e.g., B. laevis,* Fig. 2), but impact varied with species (Fig. 1).

Field observations have shown that oil spills in winter can cause reduced spring germination (Baker 1971). Time of treatment significantly affected most parameters in our study (Table 2) yet there was no one time which had the greatest effect. Higher percent seedling survival of the 0 wk treatment (just prior to germination) compared with later oil exposure (Table 1) can, at least in part, be attributed to poor coverage of the soil surface by congealed oil at low temperatures. Thus, there were unaffected patches where recruitment could occur. It is possible that in the field, tidal activity could cause redistribution of oil (see Daiber 1986) further reducing germination and/or survival. In addition, tides can cause continuous uncovering of oil from sediments and lead to long-term contamination (Stickney 1984).

The timing of an oil spill may determine vegetation recovery in a variety of ways. If the seed bank of a species is already depleted by spring germination (*e.g., I. capensis;* Leck and Simpson 1987), there can be no subsequent recruitment, even if oiled surfaces crack, exposing uncontaminated soil (*e.g.,* Stebbings 1970). Other species with persistent seed banks (*e.g.,*

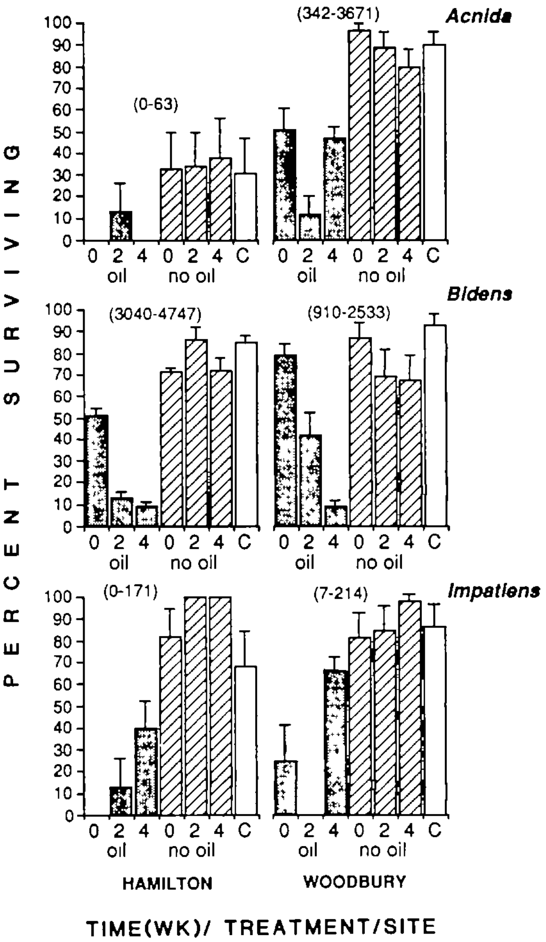

Figure 1. Percent survival ($\bar{x} \pm$ SE) of *Acnida cannabina*, *Bidens laevis*, and *Impatiens capensis* seedlings to 1 May in samples from Hamilton Marsh and Woodbury Creek Marsh. Numbers indicate density (m^{-2}) range for each site. C is the control.

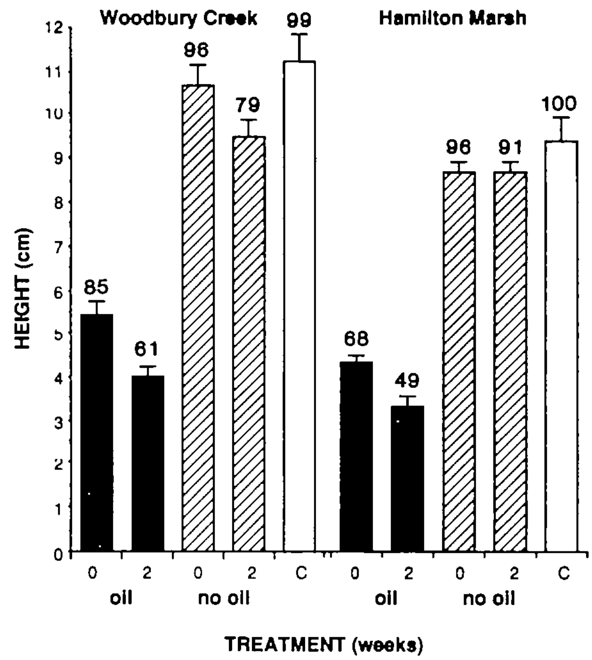

Figure 2. Height of *Bidens laevis* ($\bar{x} \pm$ SE) from both marshes measured on 1 May. Numbers above each bar indicate percent survival. C is the control.

B. laevis or *A. cannabina;* Leck and Simpson 1987) or those with continual dispersal (*Typha* spp.) could take advantage of reduced competition. Gaps in the oil (*e.g.*, cracks and other surface disturbances) may provide specific germination requirements such as improved light (*e.g.*, *Typha;* Sifton 1959) and light and aeration (*e.g.*, *B. laevis;* Leck, unpublished data). Other species may respond to seasonally higher temperatures (*e.g.*, Malvaceae; Baskin and Baskin 1989).

The impact of oil on wetland seed germination may be attributed to oil on seeds acting as a physical barrier to water and oxygen, or, if it penetrates the seed, toxicity to embryos (Amakiri and Onofeghara 1984); Daiber 1986). Moreover, effect on recruitment from the seed bank would depend on the extent to which oil penetrates and/or covers the wetland surface, distribution of seeds in the soil profile and subsequent exposure to favorable germination conditions, and seed characteristics of the component species.

As noted elsewhere (*e.g.*, Dicks 1975; Baker 1979; Daiber 1986), species differed in their tolerance to oil (Fig. 2 and Table 3). *Bidens laevis* percent survival decreased from 0 to 2 to 4 wk (Fig. 1), but a similar pattern was not observed for *A. cannabina* (Fig. 1) or *I. capensis.* Oiled *I. capensis* seedlings had improved survival at 4 wk. However, oiled seedlings were not as vigorous as no oil or control plants. The unhealthy appearance of all oil treated plants still surviving on 1 May suggested that plants would be capable of little, if any, reproductive output.

The responses of perennial species to oil treatment varied (Table 3) and likely were related to seed and seedling characteristics. *Peltandra virginica* survival was unaffected by oil treatment. Of the perennials present, it has the largest seeds (1 cm) and seedlings.

Table 3. Frequency, % survival (x̄±SE), and Least Likelihood Chi-Square (LLX²) analysis for perennials.

	Oil		No Oil		Control		
	Frequency[1] (%)	% Surviving	Frequency (%)	% Surviving	Frequency (%)	% Surviving	LLX[2]
HAMILTON MARSH							
Peltandra virginica	75	93± 6	71	94± 6	50	100	n.s.
Sagittaria latifolia	17	50±29	0	0	0	0	2
Typha latifolia	21	20±20	79	59±10	75	64±17	n.s.
grasses	63	0	96	93± 3	100	100	<.001
other	0	0	13	100	0	0	
WOODBURY CREEK MARSH							
Sagittaria latifolia	46	86± 8	4	100	0	0	-
Typha augustifolia	4	0	4	0	0	0	
grasses	63	18± 9	75	75± 9	88	74±11	<.001
other	0	0	8	100	0	0	

[1] Frequency based on samples from all treatment dates
[2] Numbers were too small for analysis

Within the single-seeded fruits, its seeds are covered with mucilage (West and Whigham 1975-1976). These features no doubt contributed to its high survival rate. Greater germination of *S. latifolia* in oil treated samples may have been caused by lowered soil oxygen. In an earlier Hamilton Marsh study (Leck and Simpson 1987), *S. latifolia* germination was significantly greater in flooded than nonflooded samples. In contrast, the susceptibility of grasses and *Typha* to oil exposure may be related to small seed and/or seedling size, and oxygen and light requirements for germination.

These Delaware River tidal freshwater marshes have considerable yearly turnover in the seed bank (Leck and Simpson 1987) because the annual-dominated vegetation is recruited from the seed bank (Parker and Leck 1985; Leck *et al.* 1989). In addition, the composition of the vegetation reflects that of the seed bank (Parker and Leck 1985; Leck and Simpson 1987). Thus, even a single oil spill could destroy or substantially alter vegetation patterns. The effect would be especially dramatic if the transient seed bank is not replenished by seed production or by dispersal, a likely result if seedling mortality is high following an oil spill. Colonization following an oil spill could shift seed bank composition, favoring species with persistent seed banks or the best dispersal. However, *in situ* deposition could alter recruitment from the seed bank or impact of dispersal by affecting seed and/or oil burial rates. (Rate of sedimentation has been estimated to be 1 cm yr^{-1} at Woodbury Creek Marsh; Orson *et al.* 1990).

If disturbance caused by oil is widespread or long-term, the extent and development of vegetation could be limited (see Dicks 1975). Following the Amoco Cadiz spill on the northwest coast of France, natural revegetation did not occur because germination was inhibited (Levasseur and Jory 1982; cited in Daiber 1986). Similarly, in a Massachusetts salt marsh, *Spartina alterniflora* did not re-establish by reseeding in the lower intertidal zone within 3 yr after an oil spill (Hampson and Moul 1978). Along the Connecticut River in a nontidal freshwater marsh, effects of oil varied with zone. High marsh and mid-marsh zones recovered after 3-4 yr, but there was a reduction in species diversity in the low marsh (Burk 1977). In addition, extensive loss of vegetation could lead to subsequent erosion of the wetland surface (Orson, Simpson and Good, pers. comm.). Lack of litter also precludes seed entrappment and subsequent establishment (Daiber 1986).

If a spill were to eliminate recruitment and reproduction of annual species, we feel that species with persistent seed banks and ability to germinate throughout the growing season, such as *A. cannabina* and *B. laevis,* or perennials with widespread and summer dispersal, such as *Typha* spp. or *P. arundinacea,* could colonize gaps as they occur. Others, such as *P. virginica* and *S. latifolia* with more tolerant seed/seedling characteristics may reinvade more quickly than annuals.

Future studies suggested by our work include the impact of oil treatment on reproductive output of annual species, effect of vegetation and litter loss on seed entrappment and establishment, and the importance of substrate characteristics in determining oil effect on recruitment. In addition, the suggestion (Tables 1 and 2) that recruitment was enhanced by tidal treatment merits further examination; a study of *Distichlis spicata* germination showed rhythms in germinability (Hadden 1970).

The overall impact of an oil spill would depend on the timing and magnitude of the spill; composition and transient/persistent nature of the seed bank; germination requirements; effect of oil on the seed bank, seedlings, adult plants, and sexual reproduction; dispersibility of species; and wetland soil characteristics. Although the impact on vegetation can be minimal (DeLaune, *et al.* 1984), our results showed that oil spills can have significant short-term effects on seedling establishment and growth that may translate into long-term effects on composition. We support Stickney's (1984) contention that "a single significant oil spill in a given estuary will have long-term effects that cannot be ignored".

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