MAJOR FIELD TEST EVALUATES A SHORELINE CLEANER TO SAVE OILED MARSH GRASS

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ABSTRACT: *Extensive greenhouse studies using intact cores of marsh vegetation including* Spartina alterniflora *demonstrated the potential of a shoreline cleaner (Corexit 9580) to remove oil from plant canopy. Because of these positive results, a permit to conduct a full-scale field test was obtained by Louisiana State from regulatory agencies in June 1995. Field tests were conducted in a Louisiana marsh at a wildlife refuge in August 1995. The test site contained replicated 8 ft × 8 ft test plots that included the following treatments: oiled with South Louisiana crude oil, oiled and chemically cleaned after 2 days using Corexit 9580, and control. Significant initial reductions in plant stomatal conductance, transpiration, and CO_2 fixation rates in response to the "oil" and "oil + Corexit 9580" treatments were noted, which were followed by substantial recovery in the "oil + Corexit 9580" treatment. Use of the cleaner improved the survival and regeneration capability of treated plots because of the low initial mortality rates and the rapid restoration of plant gas exchange activities. Plots treated with "oil + Corexit 9580" had a significantly greater number of live shoots throughout the measurement period in 1995. Biomass harvests conducted at the end of the 1995 growing season revealed that live biomass per unit area of marsh was significantly reduced under all treatments. The second harvest in 1996 indicated that live biomass had recovered to levels close to those of control plots. Our field studies demonstrated that oil can be removed using Corexit 9580 in the field without any detectable adverse effects on plants. In addition, the beneficial effects of Corexit 9580 in rapidly restoring plant transpiration pathways under field conditions was evident. However, plants under all treatments recovered, showing that* Spartina alterniflora*, given adequate time, can recover from oiling with South Louisiana crude. Additional studies using more stressful oil types such as Bunker C are needed to examine the effectiveness of Corexit 9580 in cleaning plant canopies under field conditions.*

U.S. Gulf coastal wetlands play a vital role in protecting the shoreline from wave action, providing fish and wildlife habitats, and improving water quality (Webb, 1977; Mitsch and Gosselink, 1993). Some of these ecosystems are also subject to oil industry activities such as exploration, drilling, storage, refining, and transportation of petroleum products. Thus some marshes are subject to occasional oil spills. The adverse effects of oil on marsh vegetation range from short-term disruption of plant functioning to mortality (Baker, 1970; DeLaune, Patrick, and Buresh, 1979; Alexander and Webb, 1985; Pezeshki and DeLaune, 1993). Mechanical and chemical methods are available to minimize the negative effects of oil in wetlands. Oil can be physically removed from the wetland or concentrated with absorbent materials, but wetlands are particularly vulnerable to mechanical damage during removal operations (OTA, 1990). Chemical cleaners have been considered as a means of removing oil from affected wetlands, and a number of commercial cleaners are available. However, this method requires careful consideration because some cleaners can damage various organisms (Fingas *et al.*, 1989; Daniels, 1994). Corexit 9580 shoreline cleaner, developed during the cleanup of the Valdez spill in Alaska (Fiocco *et al.*, 1991), is a low-toxicity, low-dispersion cleaner. The cleaning effectiveness and low toxicity of Corexit 9580 have been confirmed and reported by Environment Canada (see Fingas *et al.*, 1989, for details).

The cleaner Corexit 9580 has been used previously in various experimental conditions to remove oil from plants. For instance, Teas *et al.* (1993) showed that Corexit 9580 prevented the mortality of oiled red mangroves (*Rhizophora mangle*) by removing oil that otherwise would have suffocated roots. Pezeshki *et al.* (1995) studied the effectiveness of Corexit 9580 in removing oil from *S. alterniflora* foliage in a greenhouse study. The cleaner was effective in removing oil from the leaf and shoot surfaces. Detailed studies on responses of plant gas exchange in *S. alterniflora* showed that the cleaner was effective in removing different types of oil and in improving short-term plant functioning, as indicated by greater stomatal conductance (Pezeshki *et al.,* 1995). However, many of the previous studies were conducted under laboratory and/or greenhouse conditions. Thus field evaluation was needed to test the effectiveness of Corexit 9580 in removing oil and to monitor subsequent plant responses under natural conditions. The present study was therefore conducted to evaluate the effectiveness of Corexit 9580 in removing oil from *S. alterniflora* plants under field conditions in Louisiana salt marshes.

Materials and methods

Study site. The experiment was conducted in a Louisiana salt marsh composed of a monotypic stand of *S. alterniflora* located at Point aux Chiens Wildlife Management Area, Montegut, Louisiana. The experiment was conducted during the 1995 and 1996 growing seasons.

Twelve enclosures (each 8 ft × 8 ft) were constructed with sheets of plywood. The enclosures were driven down into the marsh surface at the study site so that 1.5 ft remained above the surface. In plots treated with oil or oil and cleaner, an absorbent boom was used to prevent leakage of oil or cleaner outside the enclosure.

South Louisiana crude was applied in August 1995 to the 8 ft × 8 ft plots enclosed within the plywood retainers. The oil was applied at the rate of 2 L/m^{-2} onto the plant canopy. Plants were approximately 90 cm tall at the time of treatment. Two days after the oil treatment, Corexit 9580 was sprayed onto the oiled plant canopy to remove the oil. The cleaner was sprayed at the rate of 0.33 L/m^{-2} of marsh surface area using a portable garden sprayer. Following the cleaner application, a portable pump was used to draw water from an adjacent creek and to wash down the cleaner together with the oil from the plant canopy using a standard garden hose and nozzle. The plant canopy was flushed for approximately 5 to 10 minutes. The treatments were (1) control, no oil or cleaner; (2) oiled with South Louisiana crude oil; and (3) oiled with South Louisiana crude oil and cleaned with Corexit 9580. The treatments were arranged in a randomized block design consisting of four replications.

Plant responses to the treatments were monitored at various intervals throughout the study during the 1995 and 1996 growing seasons. During the 1995 growing season, stomatal conductance and transpiration were monitored at 1, 5, 15, 45, 60, and 65 days after treatment initiation. Photosynthetic carbon fixation was evaluated at 1, 2, 4, 8, and 12 weeks after treatment initiation. During the second growing season (1996), stomatal conductance, transpiration, and carbon fixation were measured on three measurement days in June, July, and August 1996. In addition to the physiological studies, data on the number of live plants, dead plants, new shoots, and plant height were recorded in 1995 at 1, 3, 11, and 15 weeks following treatment initiation. The aboveground biomass components were cut at the end of the 1995 (first harvest) and 1996 (second harvest) growing seasons, and dry weights of live and dead materials were determined by drying the harvested biomass at 80°C to a constant weight.

Experimental procedures

Plant responses to the treatments were evaluated by monitoring changes in stomatal conductance, photosynthesis, and respiration using the following techniques.

Stomatal conductance. Measurements of leaf conductance to water vapor along with photosynthetic photon flux density (PPFD) and leaf temperature were made on replicated sample leaves (six measurements per species-treatment combination) on each sampling day. Leaf conductance was measured using a steady-state porometer (LI-1600, Li-Cor, Inc., Lincoln, Nebraska).

Photosynthesis and respiration measurements. Photosynthetic rates were estimated from the difference between the rates of CO_2 change in light and dark chambers (Smith *et al.,* 1981). Light and dark chambers were placed over the marsh surface. Chambers were 1 m tall and 25 cm in diameter. They were all constructed of clear Plexiglas and were equipped with a rubber stopper for withdrawing gas samples. The dark chambers were covered with aluminum foil to block sunlight. The internal air volume was determined from the chamber diameter, chamber height, and water depth. Before sampling, chamber air was mixed by repeatedly withdrawing and reinjecting air with a 60-ml syringe. Air samples (15 ml) were collected 15 minutes after the chambers were placed over the marsh plants. Trial runs indicated that detectable changes in the CO_2 content of the air samples were noticed in 6 minutes. The amount of time elapsed between the initial and final sample was recorded to the nearest minute. Air samples were stored in 10-ml Vacutainers (Becton Dickinson and Company, Rutherford, New Jersey) and returned to the laboratory. Subsamples (1 ml) were analyzed for CO_2 content with a gas chromatograph (Shimadzu, model GC-14A) and thermal conductivity detector. Respiration rates for vegetation and soil communities were estimated from the increase in CO_2 concentration in the dark chamber. Measurements made during darkness reflect respiration, whereas measurements made during light reflect CO_2 depletion by photosynthesis. The difference between the fluxes determined with the light and dark chambers was considered to be gross CO_2 fixation (Smith *et al.,* 1981).

Stomatal conductance, photosynthesis, and respiration data were analyzed as repeated measures. This statistical method allows for correlated observations, such as those collected from the same plot (Snedecor and Cochran, 1989). Data were analyzed using the Statistical Analysis System package (SAS, 1987). Post-ANOVA tests were performed using Duncan's Multiple Range test procedure of SAS.

Results

Time-course response of stomatal conductance and transpiration showed significant initial reductions in stomatal conductance and transpiration rates in response to oiling (Figure 1). Substantial recovery was noted in plants that were cleaned using Corexit 9580 two days after oiling (see Figure 1). By day 45, plants under the "oil + cleaner" treatment had regained their stomatal functioning and had transpiration rates comparable to those of control plants. However, leaves of plants directly subjected to oiling (and not cleaned) showed no signs of recovery. The plants showed a significant initial reduction in carbon fixation in response to the treatment. However, the rates were improved in "oil" and "oil + cleaner" plants within 60 days. At the end of the first growing season, CO_2 gross fixation rates per gram of dry weight of live biomass were comparable in all treatments, representing 115% and 98% of control in "oil" and "oil + cleaner" treatments, respectively (Figure 2). When CO_2 gross fixation values were examined for the second growing season (1996), it was evident that, despite the slightly reduced values, no significant ($p < 0.05$) adverse effects of oiling on plant gas exchange were detectable; values were 90% and 80% of control in "oil" and "oil + cleaner" treatments, respectively (see Figure 2). Despite the recovery during the first growing season and the persistence of high gas exchange rates during the second growing season as evidenced by CO_2 gross fixation rates per gram of dry weight of biomass, the CO_2 gross fixation rates per unit area of marsh remained significantly lower in "oiled" plots and "oil + cleaner" plots as compared to the "control" plots. This finding was attributed primarily to low plant density in "oil" and "oil + cleaner" plots because of the initial plant mortality. Fewer live plants (Figure 3) and less aboveground live biomass (Figure 4) per unit marsh area during the first growing season had contributed to the lower CO_2 gross fixation per unit area of marsh observed in the "oiled" plots and "oil + cleaner" plots in the present study.

Use of the cleaner improved the survival and regeneration capability of plants because of the rapid restoration of gas exchange and the lower rates of initial mortality following treatment initiation. The number of live shoots per unit area of marsh was significantly reduced in response to oiling (see Figure 3). However, plots treated with "oil + Corexit 9580" had a significantly greater number of live shoots than "oil" plots throughout the measurement period in 1995 (see Figure 3). Some adverse effects of oiling on the number of live shoots remained detectable during the second growing season under all treatments.

The first biomass harvest conducted at the end of the 1995 growing season revealed that, although the values of the dead aboveground biomass component were unchanged across treatments, the live aboveground biomass component differed significantly among the treatments. Live biomass was significantly reduced under "oil" and "oil + cleaner" treatments (see Figure 4). Plants under the "oil + cleaner" treatment had slightly, but not significantly, higher live aboveground biomass dry

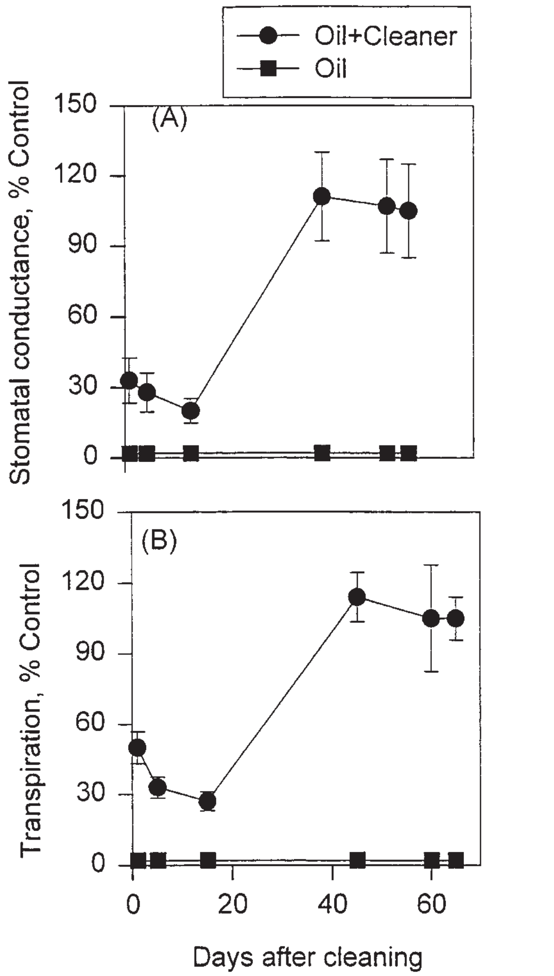

Figure 1. Responses of (*A*) stomatal conductance and (*B*) transpiration in *Spartina alterniflora* to oil (south Louisiana crude) and oil + cleaner (Corexit 9580) treatments. Values are presented as percentage of control. South Louisiana crude oil was sprayed onto plant canopies. The leaves were initially coated with oil. Stomatal data were collected on leaves that existed at the time of treatment initiation and were initially coated with oil. Values are the mean for six replications.

weights than plants under the "oil" treatment. The second harvest conducted in 1996 indicated that the live aboveground biomass component per unit area of marsh remained slightly but not significantly lower than in control plots (Figure 5). In addition, there was a remarkable recovery of live biomass in the 1996 growing season in both the "oil" and "oil + cleaner" plots when compared to the 1995 data (Figure 6). Unlike 1995 data, which showed comparable values of dead aboveground biomass across treatments (see Figure 4), in 1996 the dead aboveground biomass component was significantly different across treatments. The "oil" plots had significantly higher dead biomass than the control plots. Plots under the "oil + cleaner" treatment appeared to have lower dead biomass than the "oil" plots (see Figure 5). The accumulation of dead material in "oil" plots further indicated that oiling may have enhanced slow biomass decomposition and thus resulted in the lowest live/dead ratios during both the 1995 and 1996 growing seasons (Figure 7).

Discussion

The beneficial effects of Corexit 9580 in removing oil from leaf surfaces and restoring stomatal conductance and transpiration of oiled

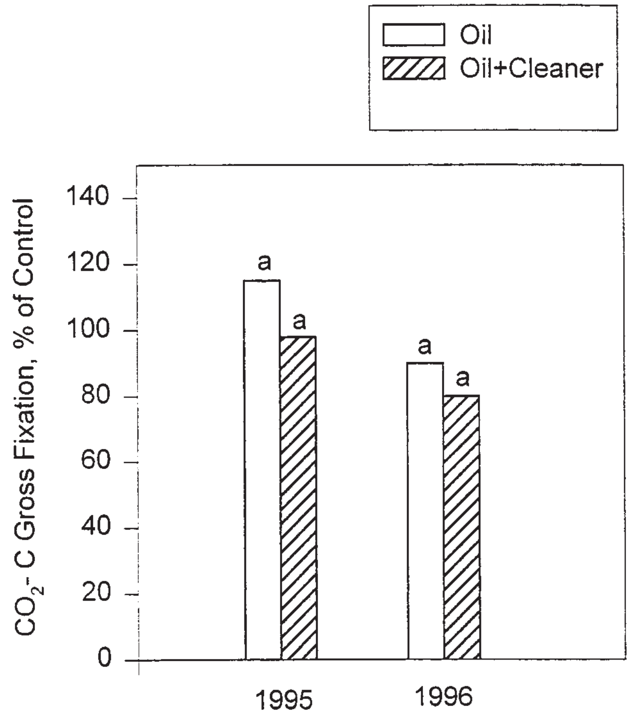

Figure 2. Photosynthetic carbon fixation ($CO_2 - C$ Gross fixation, mg CO_2 g dry weight^{-1} h^{-1}) in *Spartina alterniflora* during the eighth week following treatment initiation in 1995. Treatments were oil (South Louisiana crude), oil + cleaner (Corexit 9580), and control. The oil was initially sprayed onto the plant canopy. Values are the mean for six replications presented as percentage of control. For each year, significant ($p < 0.05$) differences among treatments are denoted by different letters.

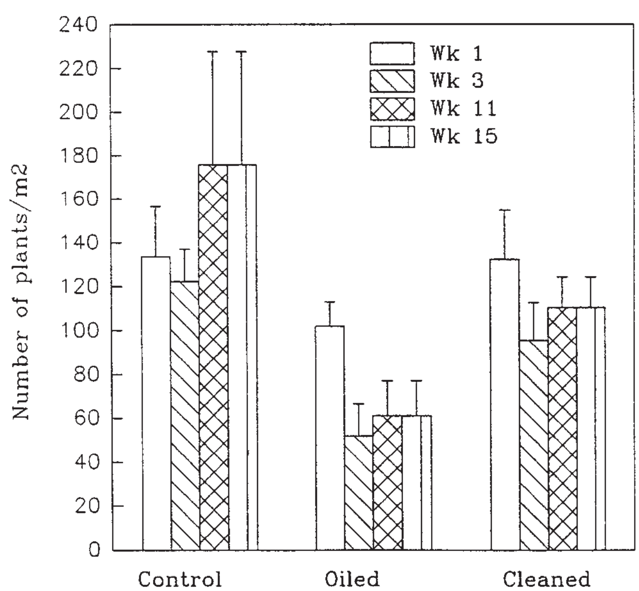

Figure 3. Number of live plants in *Spartina alterniflora* experimental plots at various intervals during the 1995 growing season. Treatments were oil (South Louisiana crude), oil + cleaner (Corexit 9580), and control. The oil was initially sprayed onto the plant canopy. Values are the mean ± SD for four replicated plots.

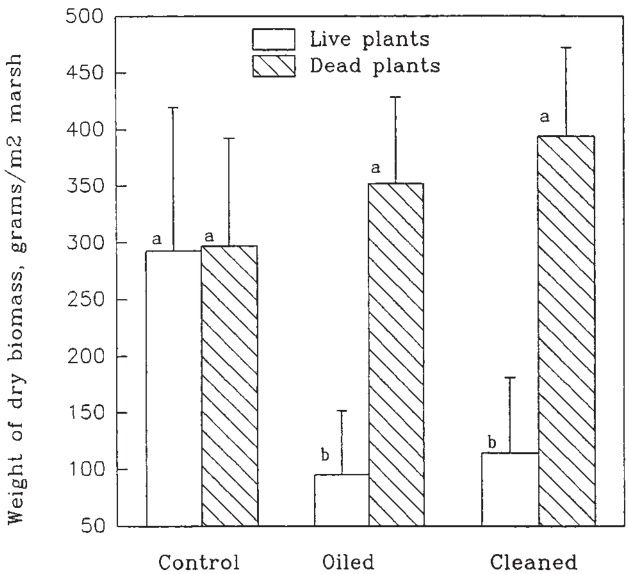

Figure 4. Accumulation of aboveground biomass components (live, dead) in *Spartina alterniflora* at the end of the 1995 growing season under various treatments of oiling (South Louisiana crude oil) and oil + cleaner (Corexit 9580). Values are the mean for four replicated plots. For each biomass component, significant ($p < 0.05$) differences among treatments are denoted by different letters.

S. alterniflora have been demonstrated in recent studies under greenhouse conditions (Pezeshki *et al.*, 1995). Plant leaves coated with South Louisiana crude oil or Bunker C oil and cleaned with Corexit 9580 solution had significant recovery of stomatal conductance, regeneration of new shoots, and leaf sheath elongation rate. In the present study, the beneficial effects of Corexit 9580 in restoring stomatal conductance and

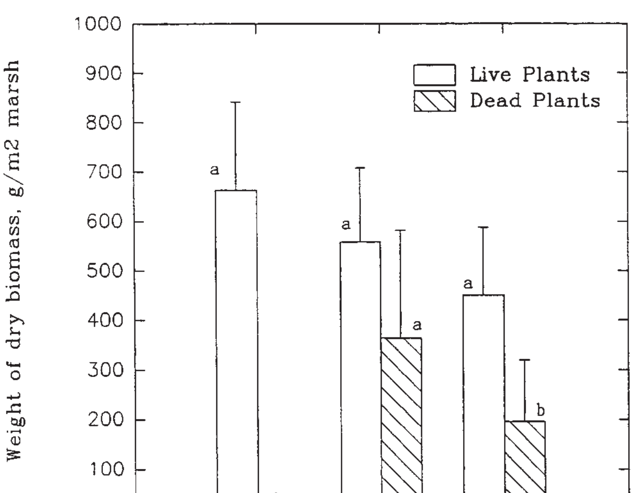

Figure 5. Accumulation of aboveground biomass components (live, dead) in *Spartina alterniflora* at the end of the 1996 growing season under various treatments of oiling (South Louisiana crude oil) and oil + cleaner (Corexit 9580). Values are the mean for four replicated plots. For each biomass component, significant ($p < 0.05$) differences among treatments are denoted by different letters.

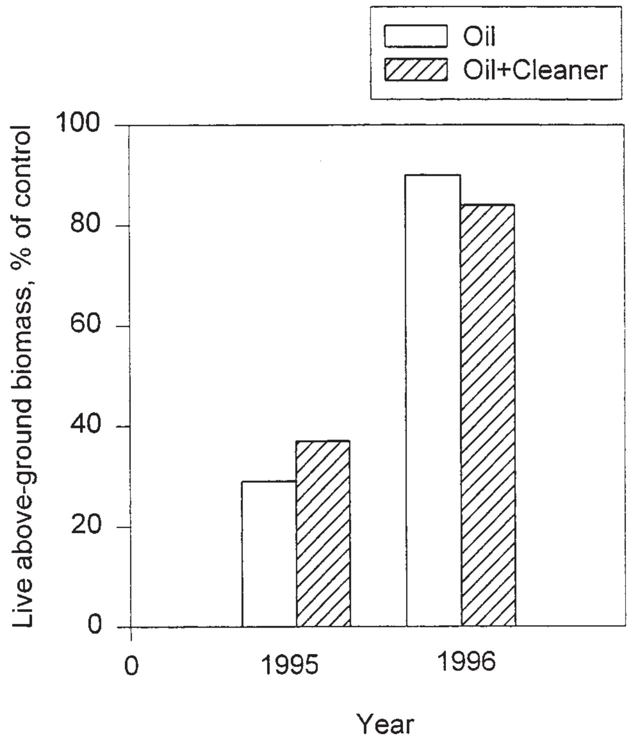

Figure 6. Aboveground biomass accumulation in *Spartina alterniflora* at the end of the 1995 and 1996 growing seasons under various treatments of oiling (South Louisiana crude oil) and oil + cleaner (Corexit 9580). Values represent percentage of control and are the mean for four replicated plots.

transpiration under field conditions was evident (see Figure 1). Leaves subjected to "oil + cleaner" treatment showed recovery of stomatal conductance, whereas leaves subjected to "oil" treatment but not cleaned did not show any recovery. Even though photosynthetic carbon fixation showed substantial recovery in both "oil" and "oil + cleaner" treatments by the end of the first growing season, the speedy stomatal recovery in the "oil + cleaner" treatment would enhance photosynthetic gas exchange functions much earlier than in plants under the "oil" treatment.

Although the initial, short-term adverse effects of oil on plants is dramatic, plants may recover in the long term. The speed and extent of such recovery may be species-specific and may depend on the type of oil, the mode of delivery, the timing, the amount of oil, and other factors. For instance, under greenhouse conditions, oiled *S. alterniflora* plants initially showed a high percentage of mortality but recovered 2 months after oil application. Natural shoot regeneration and leaf development replaced dead foliage, and no differences in biomass among the treatments were found (Pezeshki and DeLaune, 1993; Pezeshki *et al.*, 1995). In the present study, leaf death in the "oil + cleaner" plots did not appear as extensive as in the "oil" plots. Preventing death of oiled leaves with cleaner application is important because the living tissues in *S. alterniflora* resume photosynthetic activity and functioning; this was reported previously (Pezeshki *et al.*, 1995) and was evident from stomatal conductance and transpiration data in the present study. This continued plant gas exchange functioning probably contributed to the observed enhanced production of new shoots and greater live biomass in the "oil + cleaner" plots as compared to the "oil" plots (see Figures 3 and 4). Our results agree with the previous reports for *S. alterniflora* under greenhouse conditions (Pezeshki *et al.*, 1995). These new shoots produced during the postoil period possessed normal stomatal functioning and photosynthetic capacity. For example, Pezeshki *et al.* (1995) reported that, during the second month following oil application to *S. alterniflora* canopy, gas exchange rates for the leaves that emerged after the treatment initiation were similar to those of control plants. The pre-

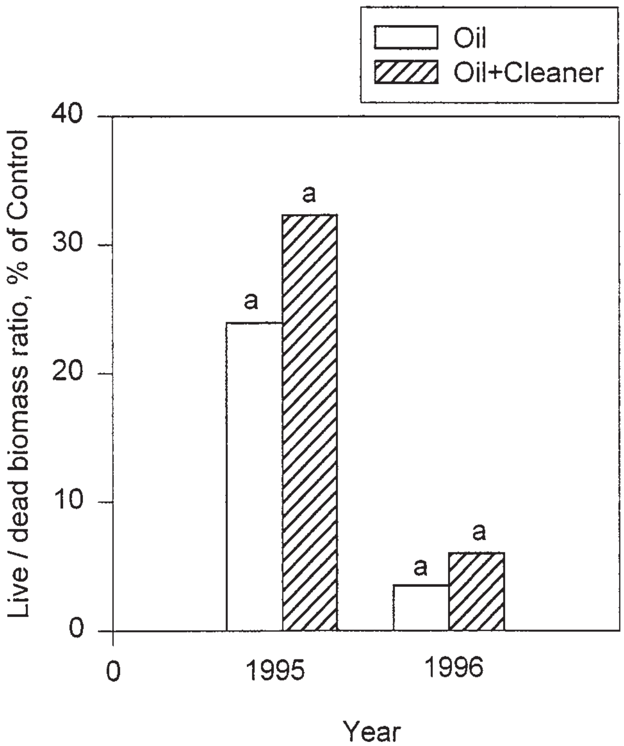

Figure 7. Live/dead ratio for aboveground biomass in *Spartina alterniflora* at the end of the 1995 and 1996 growing seasons under various treatments of oiling (South Louisiana crude oil) and oil + cleaner (Corexit 9580). Values represent percentage of control and are the mean for four replicated plots. For each year, significant ($p < 0.05$) differences among treatments are denoted by different letters.

vious findings and the present data indicate that the adverse effects of oiling on stomatal functioning and photosynthesis of *S. alterniflora* are short-term. DeLaune, Patrick, and Buresh (1979), Smith *et al.* (1984), and Pezeshki and DeLaune (1993) also found that under greenhouse conditions *S. alterniflora* and *Juncus roemerianus* plants recovered from oiling with South Louisiana crude.

Our field studies demonstrated that oil can be removed using Corexit 9580 in the field without any detectable adverse effects on plants. In addition, the beneficial effects of Corexit 9580 in rapidly restoring plant transpiration pathways under field conditions were evident. However, plants under all treatments recovered from oiling with South Louisiana crude oil. Plant responses to other oil types, such as Bunker C oil, are more dramatic (Pezeshki *et al.*, 1995); therefore, the use of cleaner may become critical in such cases. Thus additional studies using more stressful oil types such as Bunker C are needed to examine the effectiveness of Corexit 9580 in cleaning plant canopies under field conditions.

One important shortcoming of research conducted on plant responses to oiling so far is that in most cases the spill simulation is a one-time episode representing only a portion of the potential responses. Plants such as *S. alterniflora* and many other U.S. Gulf Coast marsh species that have a substantial underground system of food reserves (rhizomes) are well positioned to withstand such episodes and to reproduce vigorous new shoots. In fact, much of the literature supports this statement (DeLaune, Patrick, and Buresh, 1979; DeLaune *et al.,* 1984, Pezeshki and DeLaune, 1993; Webb, 1994; Pezeshki *et al.*, 1995). However, under chronic repeated oil spills, *S. alterniflora* plants may respond differently because frequent spills may result in weak plants that are less capable of vigorous recovery. This hypothesis must be tested with additional studies under field conditions on this and other wetland species.

Response implications

In formulating response strategies to oil spills in U.S. Gulf Coast marshes, agencies should consider a number of important factors, including the amount and the type of oil involved, the vegetation types, the timing (season), the habitat sensitivity to the physical impacts of cleaning operations, the proportion of plant canopy that is covered by the oil, and the previous history of oil spills in the area. Proper consideration must be given to these variables. For instance, the timing of the oil spill is critical. The adverse effects on *S. alterniflora* were more severe during the spring than during the dormant season (Webb, 1994) because plants grow actively during the spring season, whereas in the fall most plants become dormant. Similar differences in seasonal effects are expected for other marsh species. The oil type is also important. For instance, *S. alterniflora* marshes oiled with South Louisiana crude should recover without cleaning (Pezeshki *et al.,* 1995). On the other hand, the same species oiled with Bunker C may require cleaning to survive. In general, light oils appear to kill plant tissue on contact whereas crude oils effectively prevent plant gas exchange, thus suffocating leaves and leading to mortality (Pezeshki and DeLaune, 1993; Webb, 1994). The previous history of oil spills in the area is also important. Repeated oil spills in an area are likely to dramatically affect the most sensitive plant species within the plant community. This trauma may also result in weak individual plants that are more sensitive and vulnerable to future oil spills. In such cases, the use of cleaner may be highly justifiable because of the rapid restoration of plant functions. If the use of cleaner is feasible, then it should be applied as soon as possible following an oil spill to minimize oil penetration into the sediment, to prevent massive plant tissue death, and to speed up the recovery of normal gas exchange functioning. It is critical to give proper consideration to these variables when trying to develop the most efficient strategies for dealing with individual oil spill cases.

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Biography

S. R. Pezeshki received his Ph.D. from the University of Washington—Seattle in 1982. He is presently serving as Associate Professor, Department of Biology, University of Memphis, and as Adjunct Associate Professor, Wetland Biogeochemistry Institute, Louisiana State University. His research interests include plant physiology, plant-environment interactions, and wetland ecology.

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