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CUMULATIVE EFFECTS OF OIL SPILLS ON MANGROVES

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To the Editor:

In their recent paper, Proffitt and Devlin (1998) reported results from an experimental study of potted plants through which they set out to examine cumulative effects of oil spills on seedlings and saplings of red mangroves (*Rhizophora mangle* L.). While their narrowly bounded conclusion, "[F]or these life history stages, oil types, and modes of oiling, there was no evidence for cumulative or synergistic effects of two oiling events on *R. mangle*" is technically correct, the overall picture presented in their manuscript contrasts sharply with decades of field observations and unplanned "experiments" (i.e., oil spills) (reviewed by Odum and Johannes [1975], Rodriguez [1981], Getter [1982], Lewis [1983], Ellison and Farnsworth [1996]). The apparent absence of cumulative or synergistic effects in Proffit and Devlin's (1998) study most likely resulted from an experimental design that did not approximate field conditions, rather than from the true absence of such effects on *R. mangle*.

Mangrove growth and physiology are very sensitive to edaphic factors (e.g., McKee 1993, 1996), and it is very important to mimic field edaphic conditions as closely as possible in greenhouse and laboratory experiments with these plants (e.g., McKee 1993, 1995, 1996, Farnsworth et al. 1996, Ellison and Farnsworth 1997). Two key edaphic factors pertain. First, whereas shoots of seedlings growing on an oiled shore may remain oiled for months while their roots grow in oil-saturated sediments for months or even years (e.g., Levings et al. 1994), the experimental design of Proffitt and Devlin (1998) did not include continuous oiling of seedlings. Propagules (dispersed, viviparous seedlings [Tomlinson 1986]) were oiled in the field only for the two days between a spill of Number 6 fuel oil in Tampa Bay and when they were collected by Proffitt and Devlin. While it is possible that some residual oil on propagule surfaces was washed into the potting soil during regular watering, the concentration of oil in the potting soil throughout the experiment was not reported, and was likely orders of magnitude lower than that normally encountered by mangrove seedlings growing in oiled field sites. Thus, the seedling oiling experiment is not representative of conditions that these plants would encounter following an oil spill.

Second, mangrove ecophysiology is controlled strongly by soil salinity (reviewed by Ball [1996]), and these halophytic plants normally grow in field soils with pore-water salinity approaching that of sea water (35‰). In greenhouse studies of mangrove seedling growth, plants normally are watered with salt water at concentrations ranging from 10 through 35‰ (e.g., McKee 1993, 1995, 1996, Farnsworth et al. 1996, Ellison and Farnsworth 1997), not fresh water as used by Proffitt and Devlin (1998); salinity in Tampa Bay, from where Proffitt and Devlin (1998) collected their propagules, is ~35‰ (A. M. Ellison, *unpublished data*). Thus, interactive effects of oil and salinity that would occur in the field (Getter et al. 1985, Page et al. 1985) could not be accounted for by Proffitt and Devlin.

The growing techniques used by Proffitt and Devlin (1998) clearly had negative effects on seedling growth, regardless of oiling treatment. Their Table 1 reports that after 32 mo of growth, average seedling diameter was <9 mm, stem growth did not exceed 0.6 m, and plants had <3 branches. In contrast, greenhouse-grown seedlings growing in conditions more closely approximating field conditions routinely are >15 mm in diameter, have >1.0 m of stem growth, and produce 30–40 branches, all after only 24 mo (Ellison and Farnsworth 1997). Because Proffitt and Devlin's seedlings were so small after 32 mo, it is likely that maternal effects of the large propagules (20–30 cm tall, >25 g wet mass) were still buffering the seedlings from the different oiling treatments (see Lin and Sternberg [1995], Farnsworth et al. [1996], Ellison and Farnsworth [1997] for further illustrations of such maternal effects). An alternative interpretation of Table 1 is that the data reported for diameter are not measures of total stem diameter but are measures of diameter growth. Interpretation of these data then would require presentation of initial stem diameters (at time of planting), not reported in Proffitt and Devlin (1988). Since all other measures of growth indicate that these plants are very small, however, the remaining data in Table 1 are consistent with the interpretation that all seedlings were affected negatively by oil treatment.

In addition, statistical power of the seedling experiment was low. While results of this first phase of the experiment showed few responses to the initial oiling "treatment" after 32 mo (no differences in survival, stem diameter, main stem growth, total stem growth, or standing number of leaves), the probability of a Type II statistical error (incorrectly accepting a false null hypothesis), β, was ~0.35 (calculated from data reported in Proffitt and Devlin's Table 1 using PASS version 6.0 [Number Cruncher Statistical Systems, Kaysville, Utah, USA]). A larger sample size ($\geq$30 surviving plants per treatment, not the $N = 24$ used by Proffitt and Devlin [1998]) would be needed to decrease β to $\leq$0.1 for a fixed α value of 0.05 for rejection of the null hypothesis of no effect of oil on seedling performance. Similarly, use of a likelihood chi-square test instead of direct comparison of survivorship curves may have masked true significant effects of initial oiling on seedling survival to 32 mo (which Proffitt and Devlin reported as 83% of controls, 71% of low-oil seedlings, and 60% of high-oil seedlings).

To test for cumulative effects of oil on *R. mangle*, Proffitt and Devlin (1998) re-oiled the seedlings with two concentrations of crude oil from South Louisiana. Oil was applied once, and plants were maintained in fresh water and watered weekly. The continued use of fresh water in the second part of the experiment makes it difficult to generalize the results to field conditions. Further, the single crude-oiling event and subsequent leaching of crude oil into the water table used by Proffitt and Devlin (1998) placed the plants in conditions markedly different from those encountered in the field, where bioturbation and sediment structure results in chronic re-oiling of mangroves for several years to decades following an oil spill (Getter et al. 1984, Corredor et al. 1990, Burns et al. 1993, Levings et al. 1994). Sample size ($N = 16$ plants per treatment) was even smaller in this phase of the experiment than in the first phase, and statistical power was correspondingly lower. While survival and stem growth 12 mo after re-oiling were both reduced significantly by the high concentration of crude oil, plants treated with low concentrations of crude oil did not differ in survivorship or stem growth from controls. Not surprisingly, since few, small treatment differences were apparent in the first phase of the experiment, no interactive effects of the two oiling events were observed.

In summary, a careful examination of the experimental design and analysis used by Proffitt and Devlin (1988) suggests that these methods were not appropriate to test the hypothesis that oil has cumulative impacts on survivorship and growth of seedlings and saplings of *R. mangle*. Such experiments should match laboratory edaphic conditions with field edaphic conditions as closely as possible, and use existing data or pilot experiments to determine appropriate sample size (and statistical power) to reduce the probability of both Type I and Type II statistical errors.

The best available field data on effects of oil spills on mangrove ecosystems comes from before-and-after studies conducted following the 1986 spill of $\sim 1.5 \times 10^7$ L of medium-weight crude oil at Galeta, Panamá (synthesis in Keller and Jackson [1993]). The results of the Galeta study are complicated by the fact that 18 yr earlier, $\sim 4 \times 10^6$ L of diesel oil and heavy crude oil was spilled in the same area (Rützler and Sterrer 1970). Thus, the Galeta spill resulted, albeit unintentionally, in a cumulative effects study. Using data from the Galeta study, along with a synthesis of existing data, Burns et al. (1993) suggest that a *minimum* of 20 yr is required for mangrove ecosystems to recover from oil spills. Records of oil spills in the Caribbean show that the average time between spills in any given mangrove forest is ~15 yr (Rodriguez 1981, Ellison and Farnsworth 1996), and hydrocarbons of anthropogenic origin have been detected in mangrove estuaries far from refinery complexes or spill sites (e.g., Bernard et al. 1995). Such data, along with the presence of increased mutation rates in mangroves growing in sediments with elevated levels of hydrocarbons (Klekowski et al. 1994*a*, *b*) are consistent with postulated sublethal effects of oil on mangroves and long recovery times of individual mangrove trees and forests from oiling events, and demonstrate potential cumulative effects of repeated oiling events.

Cumulative impacts are strictly defined: "[t]he impact . . . which results from the incremental input of the action when added to other past, present, and reasonably foreseeable future actions. . . . Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (National Environmental Policy Act of 1969 [NEPA], Code of Federal Regulations, Title 40, Part 1508.7). Individual oiling events, such as those used by Proffitt and Devlin (1998), may fail to have statistically significant effects on plant performance, but repeated, even "insignificant" oiling may lead, over biologically meaningful time spans, to reduction in plant survivorship, impaired physiological performance, and increased mutation rates. Future work should focus on mechanisms by which oil exerts these effects, mitigation of these effects, and restoration of oiled mangrove forests. To be useful to ecologists, conservation and restoration biologists, reserve managers, and policy analysts, such research should be conducted in the field, or under greenhouse conditions that closely mimic field conditions.

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