

PRELIMINARY FINDINGS: ARTHROPOD INDICATORS OF ONSHORE OIL SPILL SEVERITY

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**Technical Report Series
01-007**

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CITATION

Hunt, H.E., M. Vavrek, J. McKillip, and M. McCurdy. 2001. Preliminary Findings: Arthropod Indicators of Onshore Oil Spill Severity. Louisiana Tech University. Louisiana Applied and Educational Oil Spill Research and Development Program, OSRADP Technical Report Series 01-007.

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Preliminary Findings: Arthropod Indicators of Onshore Oil Spill Severity

Abstract

Terrestrial arthropods respond to microhabitat changes caused by disturbance and pollution. Arthropod diversity has thus been used to assess the impact of oil and nutrient enrichment on aquatic systems. However, little work has focused on the use of arthropod community measures, such as changes in abundance, diversity, and richness, to assess the severity of pollution events in upland environments. We used pit-traps to capture macroarthropods and other organisms seasonally in 81, 1 m² blocks of habitat exposed to two intensities of light crude oil within a fenced enclosure. Macroarthropod abundance in oil treated plots was significantly less than in control plots one and four months after oil application. Seven to 10 months after application, macroarthropod abundance in oiled plots was significantly higher than in control plots. Oil toxicity may reduce populations of some macroarthropods in the weeks immediately after a spill. However, vegetation regrowth six to seven months post-spill may attract large numbers of herbivorous macroarthropods. Several orders, including mites (Acari), ants (Hymenoptera), springtails (Collembola), millipedes (Glomeridae) and snails (Stylomataphora), consistently differed in abundance between oil treated and control plots. Although macroarthropod diversity varied little by treatment, the number of orders (richness) appeared to be higher in control than in treated plots zero and four months post-treatment. Richness was lower in the control than in treated plots seven and 10 months post-treatment. Several values including, (a) relative changes in the mean number of organisms per trap, (b) mean number of Acari, Hymenoptera, Collembola, Glomeridae and Stylomataphora, and (c) mean number of animal orders per trap have potential as indicators of upland habitat quality after oil spill events.

1.0 Introduction

The role of arthropods as indicators of environmental quality has received considerable attention (Magurran 1988) because of arthropods' wide distribution and responsiveness to environmental change. Rosenberg (1976) and Schafer (1973) documented a reduction in arthropod community diversity resulting from pollution and nutrient enrichment in marine ecosystems. Arthropod communities were used successfully for assessment of oil pollution in marine invertebrate communities where initial mortality was high, abundance and diversity were reduced, and recovery was slow (Suchanek 1993; Jackson *et al.* 1998).

Terrestrial arthropods have great utility as bio-indicators of upland oil pollution because of their responsiveness to microhabitat changes and their direct contact with contaminated soil. Altered arthropod abundance has been associated with changes in plant species richness (Siemann *et al.* 1997), plant productivity (Siemann 1997), structural complexity of individual plants (Lawton 1983; Bach 1981), plant age (Heatwole and Lowman 1986; Lowman and Heatwole 1992), presence of specific plant species (Kaakeh and Dutcher 1992), soil moisture (Messenger 1959; Cloudsley-Thompson 1962), soil temperature (Fargo and Pepperly 1989; Reichert and Tracy 1975), and nutrient enrichment (Tomascik and Sandler 1987).

Changes in arthropod community diversity may be quantified with diversity indices (Magurran 1988). Diversity indices were effective in assessing changes in reef building corals subjected to eutrophication in the West Indies (Tomascik and Sander 1987). Wu (1982) used changing Shannon Diversity Index values to document an increase in epibenthic community diversity with increasing distance from a pollution source.

Researchers do, however, face several difficulties as they attempt to develop an easy to use arthropod index for assessing habitat change. The primary challenge involves the limited distributions of many arthropod species that may be restricted to specific habitat types. This limitation curtails the applicability of certain arthropod indices. Furthermore, collecting and identifying all organisms inhabiting a specific region to the species level is difficult, costly, and time consuming (Hammond 1994). An approach recommended by conservation biologists is to focus on single taxa that may represent all organisms within a region (Oliver and Beattie 1996; Schoenly *et al.* 1998). In order for this approach to work, the single taxa must be easy to identify, cost effective to sample, be widely distributed and continuously present in all seasons, and responsive in predictable ways to environmental change (Schoenly *et al.* 1998). Since no single species is likely to possess all of these characteristics, we focused on multiple taxa (terrestrial organisms susceptible to capture by pit trap), and broad, easily identifiable taxonomic categories (orders). Changes in abundance of macroarthropod orders or changes in community composition at the order level may provide an ecologically sound approach for evaluating the impacts of oil pollution on upland habitats.

Our objectives were to: (1) quantify the effects of oil spill intensity on macroarthropod abundance and diversity, (2) identify macroarthropod orders (or other animal orders) responsive to upland oil spill intensity, and (3) identify easy to use community measures that technicians (trained to identify animal orders) may employ to assess the effects of oil contamination on upland habitat quality.

2.0 Methods

A fenced enclosure was established in an open grassland habitat at the Louisiana Tech University Farm in north Louisiana (32° 30' north latitude, 92° 40' west longitude). The upland soils in this shortleaf pine-oak-hickory region are sandy and well drained (Brown 1972). Within the enclosure, nine 5 x 5 m blocks were established. In each block, nine (1 m²) plots were randomly chosen for treatment from systematically arranged plots 0.5 m apart. This resulted in tightly grouped plots 0.5 m apart, minimizing microhabitat differences within blocks. In each block, three plots received a heavy oil treatment (0.40 cm³ oil per cm² soil surface area), three plots received a light oil treatment (0.20 cm³ oil per cm² soil surface area), and three blocks served as controls. Locally acquired light crude oil was applied in May 2000. In order to capture arthropods, pit traps consisting of a plastic funnel and a 400 ml cup containing 2 to 3 cc of ethylene glycol were placed in the center of each oiled and control plot. Pit traps (n = 81) were buried such that the top of the cup was level with the surface of the ground. Arthropods were collected during a 10 day sampling period each season (June, September, December, and March) from June 2000 to March 2001. The three month period between collections provided adequate time

for arthropods to recolonize plots (Bultman and Uetz 1984). Collected arthropods were screened with a 0.071 micron sieve to eliminate both debris and difficult to identify microarthropods. Captured macroarthropods and other collected organisms were counted, identified to order, oven dried for 12 hours at 38° C, and weighed.

Differences in the total biomass and number of organisms captured by treatment were calculated as a percent change relative to control plots and plotted using Microsoft Excel's line-smoothing function. Hill's Family of Diversity Indices was used to quantify the diversity of captured orders (Hill 1973). Hill's Family of Diversity Indices includes N1, which is the reciprocal of the geometric mean of proportional abundances. N1 is sensitive to the presence of rare species. N2, a second index, is the reciprocal of the arithmetic mean proportional abundance and is sensitive to the abundance of common species. Richness, a count of the total number of orders, was also used to assess macroarthropod community diversity.

Differences in biomass and abundance of organisms in control, lightly, and heavily oiled plots were analyzed using a two-way analysis of variance with treatment and block effects. Tukey's HSD Test was used to identify differences between treatments within each order and season.

Separate one-way analyses of variance and Tukey's HSD Tests were conducted for each season to identify treatment effects on the mean number of organisms per trap. A one-way analysis of variance also was used to determine treatment differences in the mean number of orders.

3.0 Results

Oil was applied on May 23, 2000. In the four seasonal sampling periods that followed, we collected 32,876 organisms comprising 32 orders in seven classes. Non-arthropod orders included Amphipoda (scuds), Isopoda (pill bugs), Stylomatophora (slugs), Terricolae (earthworms), Squamata (skinks), Anura (frogs), Rodentia (rodents), and Insectivora (shrews). Non-arthropod captures were included in the analysis since they comprised only 0.02% of the total number of captures and 0.10% of the total captured weight. Orders with the largest number of captures were Collembola, Hymenoptera, Coleoptera (beetles), and Araneida (spiders). The mean number of captures per trap appeared to vary with season and treatment. The largest number of captures occurred in September and the smallest in December (Figure 1). In the June and September sampling periods, the mean number of arthropods per trap in control plots ($n = 27$) was significantly higher ($F = 33.8$, $d.f. = 2$, $P < 0.001$; $F = 9.17$, $d.f. = 2$, $P < 0.001$) than the mean number of arthropods in lightly ($n = 27$) and heavily ($n = 27$) oiled plots. However, in December, the mean number of arthropods in control plots was significantly lower ($P = 4.25$, $d.f. = 2$, $P = 0.018$) than the means in lightly and heavily oiled plots. In March, arthropod abundance appeared to be lower in the control plots than in treated plots. However, no statistically significant differences were found (Figure 1).

The total weight of captured arthropods also varied by season and treatment (Figure 2). In September, the mean biomass per trap in control sites was significantly greater ($F = 10.40$, d.f. = 2, $P < 0.0001$) than the biomass in lightly and heavily oiled sites. The December control mean biomass was significantly smaller ($F = 3.98$, d.f. = 2, $P = 0.022$) than the mean biomass in lightly and heavily oiled plots. In June and March, mean biomass was not significantly different between treatments.

Following oil application at the end of May, the relative abundance of organisms captured in control, lightly, and heavily oiled sites varied with time. In the June and September sampling periods (one and four months post-treatment), the abundance of organisms in oiled sites was 44.0% to 57.8% less than organism abundance in control plots. However, this trend reversed in December and March (seven and 10 months post-treatment), when captures in oiled sites were 69.0% to 76.2% greater than those in control sites (Figure 3). Relative changes in biomass captured by season revealed a similar trend. Biomass in oiled plots in June and September was 6.0% to 68.0% less than that in control sites. In December and March, biomass was 35.6% to 258.0% greater in oiled plots than in control plots (Figure 4).

An analysis of differences in abundance by order in June (one month post-treatment) revealed that seven orders (Acari, Araneida, Coleoptera, Hymenoptera, Collembola, Thysanura, and Stylomataphora) were significantly more abundant in control sites than in oil treated sites (Figure 5). In June, captured biomass of Acari, Collembola, and Stylomataphora was significantly greater in control plots than in oil treated plots in (Figure 6).

In September (four months post-treatment), the abundance of eight orders differed by treatment. There were a significantly greater number of Acari, Coleoptera, Hymenoptera, Dermoptera, Hemiptera, Collembola, and Psocoptera captured in control sites than in oil treated plots. However, there were significantly more Diptera captured in lightly oiled sites than in control or heavily oiled sites (Figure 7). Significantly greater biomass of Acari, Araneida, Orthoptera, Dermoptera, Hemiptera, Collembola, and Psocoptera was captured in control sites than in oil treated sites (Figure 8).

Figure 1 *Mean number of organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana.*

Figure 2 *Mean biomass per pit-trap in control, lightly, and heavily oiled plots in north Louisiana.*

Figure 3 *Percent deviation from control in mean number of organisms captured in lightly and heavily oiled plots in north Louisiana, 2000-2001.*

Figure 4 *Percent deviation from control in mean biomass captured in lightly and heavily oiled plots in north Louisiana, 2000-2001.*

Figure 5 *Mean number of individual organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, June 2000.*

Figure 6 *Mean biomass captured by pit-trap in control, lightly, and heavily. oiled plots in north Louisiana, June 2000.*

Relatively few organisms were captured in December (seven months post-treatment). There were significantly more captures of Orthoptera, Dermoptera, and Glomeridae in oiled plots than in control plots. Stylomataphora was the only order with significantly greater captures in control plots than in oil treated plots (Figure 9). Significantly less Orthoptera biomass was captured in control plots than in lightly or heavily oiled plots. Only Stylomataphora biomass was significantly greater in control plots than in oil treated plots (Figure 10).

In March (10 months post-treatment), significantly more Orthoptera, Diptera, and Glomeridae were captured in oil treated plots than in control plots. There were a greater number of Hymenoptera in lightly oiled plots than in control or heavily oiled plots. There were significantly more Orthoptera in heavily oiled plots than in control or lightly oiled plots. Only two orders-Acari and Stylomataphora-were found in significantly higher numbers in control plots than in treated plots (Figure 11). Biomass also differed by treatment in March. Control plots had significantly less biomass of Diptera and Glomeridae than oiled sites. There was significantly greater Hymenoptera biomass in lightly oiled plots than in other treatments. Stylomataphora was the only order with significantly greater biomass in control sites than in oiled sites (Figure 12).

Hill's Diversity Index value N1 was similar between treatments but appeared to vary by sampling period (Figure 13). N1 values for all treatments remained in the 5.6 to 7.2 range during the first three sampling periods (June through December). However, N1 values for all treatments declined to the 3.9 to 5.4 range in March. Hill's Diversity Index

value N2 was similar between treatments. However N2 values for all treatments increased from the 2.2 to 2.4 range in June to the 4.4 to 4.9 range in December. N2 values declined to the 2.2 to 3.2 range in March (Figure 14).

To distinguish whether the number of different orders (richness), a component of diversity, contributed to patterns of diversity over time, the mean number of orders per trap was also analyzed. The mean number of orders varied by treatment during the various seasons (Figure 15). The mean of orders captured in control plots during the first sampling period (June) was significantly greater ($F = 10.36$, $d.f. = 2$, $P = 0.0001$) than the means for lightly and heavily oiled plots. There were no significant differences in the second and third period (September and December) means. However, the fourth period (March) mean in control plots was significantly less ($F = 8.14$, $d.f. = 2$, $P = 0.0006$) than the means for lightly and heavily oiled plots.

4.0 Discussion

The application of oil to grassland habitats in north Louisiana resulted in significant changes in arthropod abundance and richness. Arthropods and other small organisms may respond directly to the application of oil via mortality or avoidance of contaminated habitats. Oil toxicity is highest immediately after a spill and tends to decline as volatile fractions evaporate (Heliovaara and Vaisanen 1993) and heavier fractions permeate sandy soils (Fingas 2000). Arthropods may be indirectly affected by oil contamination through a reduction in habitat structure as oil kills above-ground vegetation. However, as volatile oil fractions evaporate and oil degrades and permeates deeper soil layers, plant germination in oiled habitats and vegetation encroachment from surrounding habitats slowly increase vegetative structure (Fingas 2000) and promote recolonization by arthropods.

Figure 7 *Mean number of individual organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, September 2000.*

Figure 8 *Mean biomass captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, September 2000.*

Figure 9 *Mean number of individual organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, December 2000.*

Figure 10 *Mean biomass captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, December 2000.*

Figure 11 *Mean number of individual organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, March 2000.*

Figure 12 *Mean biomass captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana, March 2000.*

Figure 13 *Hill's Diversity Index value N1 for number of organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana.*

Figure 14 *Hill's Diversity Index value N2 for number of organisms captured by pit-trap in control, lightly, and heavily oiled plots in north Louisiana.*

Figure 15 *Mean number of orders per trap captured in control, lightly, and heavily oiled plots in north Louisiana, June 2000 - March 2001.*

In north Louisiana, the mean number of arthropods captured per trap varied by treatment and season. In the June and September sampling periods (one and four months after oil application, respectively), there were significantly more arthropods in control sites than in oil treated sites. In December (seven months after oil application) there were significantly fewer arthropods in control plots than in treated plots. Changes in mean arthropod biomass per trap varied according to a similar pattern. The reduced abundance and biomass of organisms in treated plots one and four months post-treatment may reflect arthropod sensitivity to toxic oil fractions. The composition of the oil, local temperature and rainfall patterns, and soil texture influence the degradation rate of oil (Fingas 2000). Our use of a light crude oil on sandy soils, combined with high winter rainfall, may have

hastened the reduction of toxic oil fractions on our study site. The increase in abundance and biomass of organisms captured seven and 10 months post-treatment may reflect the appearance of grass shoots in oil treated plots in December. Young shoots lacking well-developed structural defenses have been associated with increased arthropod abundance in other studies (Heatwole and Lowman 1986; Lowman and Heatwole 1992). Thus, the mean number of individual arthropods or the percent deviation from control sites in the number of arthropods per trap may serve as a useful integrated measure of the degree of habitat change caused by oil.

In north Louisiana during the first two sampling periods (one and four months) following oil application, three orders, Acari, Hymenoptera, and Collembola, displayed significant reductions in the number of individuals and biomass by treatment. Several studies have documented the lethal effects of oil products on water fleas and midges such as *Daphnia magna* (Crustacea) and *Chironomus tentans*, order Diptera (Nix *et al.* 1993). Heliovaara and Vaisanen (1993) in their study of jet fuel impacts on arthropods, found that the composition of an arthropod's cuticle influences its susceptibility to petrochemical contaminants. They found that earwigs (*Forficula auricularia*), Diptera, and rice weevils (*Sitophilus oryzae*), Coleoptera, were most susceptible to the toxic effects of fuel. Tenebrionid beetles (*Tenebrio molitor*), Coleoptera, and cockroaches (*Blaberus cranifer*), Blattaria, were the least susceptible to the toxic effects of fuel either because of the high hydrocarbon content of the cuticle or the presence of hardened waxy layers over the cuticle (Bombick 1987). Acari and Collembola lack the thick cuticles and waxy coverings possessed by many beetles and cockroaches and may be more susceptible to the toxic effects of oil than other arthropod orders. Thus, these orders may have been affected directly by the application of oil.

In our study, Orthoptera (grasshoppers) and Glomeridae (millipedes) displayed significant increases in the number of individuals and biomass in oil treated plots in the third and fourth sampling periods (seven and 10 months) following oil application. Arthropod abundance has been associated with changes in plant species richness (Siemann *et al.* 1997), plant productivity (Siemann 1997), structural complexity of individual plants (Lawton 1983; Bach 1981), and plant age (Heatwole and Lowman 1986; Lowman and Heatwole 1992). As it reduces habitat structure and slows the breakdown of litter and soil organic matter (Heliovaara and Vaisanen 1993), oil may make habitats more suitable for detritus feeders like Glomeridae. The appearance of grass shoots in oiled plots in December (seven months post-treatment) may have attracted herbivorous Orthoptera. Thus, changes in the abundance of these orders in treated versus control habitats may support their utility as indicators of disturbance and eventual recovery following oil pollution.

Diversity indices that incorporate species richness and evenness are commonly used to quantify community diversity (Magurran 1988). Shannon's Diversity Index was effective in assessing changes in reef building corals subjected to eutrophication in the West Indies (Tomascik and Sander 1987). Wu (1982) used changing Shannon Diversity Index values to document a decrease in epibenthic community diversity with increasing distance from a pollution source. In north Louisiana, Hill's Diversity Index values for N1

and N2 appeared to vary little between treatments. This is contrary to the findings of Bendell-Young *et al.* (2000) who found that wetlands impacted by oil sands effluent supported benthic invertebrate communities of low diversity but high abundance and dominance. Perhaps our quantification of community diversity at the level of order instead of species reduced the utility of diversity indices.

Species richness is one of the simplest measures of diversity (Magurran 1988). Homer (1976) used species richness to quantify the effects of thermal pollution on fish in Florida marshes. Our differences in the number of macroarthropod orders (equivalent to species richness) for oiled and control habitats in June and December were statistically significant. The richness values for all four of our sampling periods paralleled the changes in mean number of individuals captured per trap. In the first two sampling periods when control plots had more individuals than oiled plots, control plots also had more orders. In the last two sampling periods when control plots had fewer individuals than oiled plots, control plots also had fewer orders. Based on these results, richness may be a useful index for assessing oil spill severity.

One of the difficulties in using arthropods as indicators of environmental quality is the rapid spatio-temporal change in arthropod community composition and high arthropod diversity encountered in most habitats (McGowen and Walker 1993; Schoenly *et al.* 1998). We attempted to reduce the diversity and variability in our samples by limiting the number of macroarthropod taxa sampled to groups susceptible to capture by pit-trap, and grouping captured arthropods by order. However, terrestrial macroarthropods susceptible to capture by pit-traps may not be representative of the entire arthropod community impacted by oil spill events. Ground dwelling macroarthropods, because of their intimate contact with oil contaminated soils, may be more likely to respond to oil contamination than flying invertebrates or vertebrates with higher vagility. Grouping macroarthropods by order may limit our ability to examine changes in species diversity or foraging guild interactions, but it may make our index applicable over wide regions and usable by persons with limited arthropod identification skill.

Our preliminary findings suggest that several variables bear further examination as indicators of habitat quality changes resulting from oil pollution. These variables include: (a) mean number of arthropod orders per trap in oiled versus control sites, (b) mean number of Acari, Hymenoptera, Collembola, Glomeridae, and Stylomatophora per trap, and (c) mean number of orders per trap. Continued monitoring of these variables for an additional year will determine their validity as indicators of habitat recovery from an oil pollution event.

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