Vegetation Response and Sediment Polycyclic Aromatic Hydrocarbon Attenuation in a *Carex* Marsh in Howe Sound, British Columbia, Canada Following a Spill of Bunker C Fuel Oil

Greg Challenger[1], Gary Sergy[2], and Andy Graham[1].
[1]Polaris Applied Sciences, Kirkland, WA, USA,
[2]Emergencies Science and Technology, Environment Canada, Edmonton, AB, Canada.

Abstract:
A spill of Bunker C fuel oil in Howe Sound, British Columbia, Canada in August 2006 affected approximately 10.5 acres (4.2 hectares) of marsh habitat unique to the Pacific Northwest. A cleanup approach to reduce impacts from response actions was balanced with a desire to remove all residual oil. Cleanup techniques that were used include flushing, cutting, raking, passive sorbent collection, natural recovery, and manual excavation (sediment removal). Evaluation of the habitat response relative to oiling conditions and treatments was undertaken by examining vegetation indices in treatment and control areas and temporal changes in sediment concentrations of polycyclic aromatic hydrocarbons (PAHs). One year post-spill results suggest that the amount or degree of oiling on the dominant vegetation, *Carex lyngbyei* and *Eleocharis palustris,* had little or no apparent effect, or was insignificant in comparison to the impact of the treatment. Vegetation cutting alone had no positive or negative effect on vegetation recovery indices. Treatments which were aggressive in physically disturbing the sediments and root systems of the marsh (heavy trampling, heavy scraping, excavation and/or excessive trampling) retarded vegetation recovery in oiled and unoiled habitats and prolonged oil persistence in comparison to non aggressive treatment, vegetation cutting alone or natural recovery. Mechanical damage was the best predictor of PAH persistence.

Introduction

On August 5, 2006 the forest products carrier M/V WESTWOOD ANETTE had its hull punctured while at a dock in Squamish, British Columbia (Figure 1). The incident resulted in the release of an unknown quantity of IFO 380 fuel oil (Bunker C fuel oil cut with less than 5% gas oil) into Howe Sound and the adjacent Squamish Estuary. The Squamish estuary contains tidal marshes and is fringed by forested slopes and the City of Squamish. The fjord-head estuary lies at the head of Howe Sound and receives a mean daily discharge of 272 m^3/s (Hutchinson, 1988). Peak discharges occur during heavy fall rains and spring snowmelts. When combined with strong winds and high tides, peak discharges can result in severe floods and erosion of the marsh fringe is evident.

Saltmarshes are the largest component of the estuary and are dominated by sedges (Cyperaceae), grasses (Graminae) and rushes (Juncaceae). Spike-rush (*Eleocharis palustris*) favors regions near the Squamish River mouth at lower tidal elevations and Lyngbyei's sedge (*Carex lyngbyei*) dominates the marsh interior. Other common marsh plants include silverweed (*Potentilla pacifica*) and bulrush (*Scirpus* sp.). Over 20 fish species and more than 80 water birds can be found throughout the year in the estuary (Ascaphus Consulting, 2003). The marsh is fronted by large mudflats. The substrate of the vegetated marsh bench is characterized by silt clay with a hard organic layer in a vegetation root mass. Soft silt and mud sediments are uncommon and

primarily found within tidal creeks and a few shoreline depositional areas. The tidal range in the Squamish Estuary is commonly over three meters and routinely covers the entire marsh area.

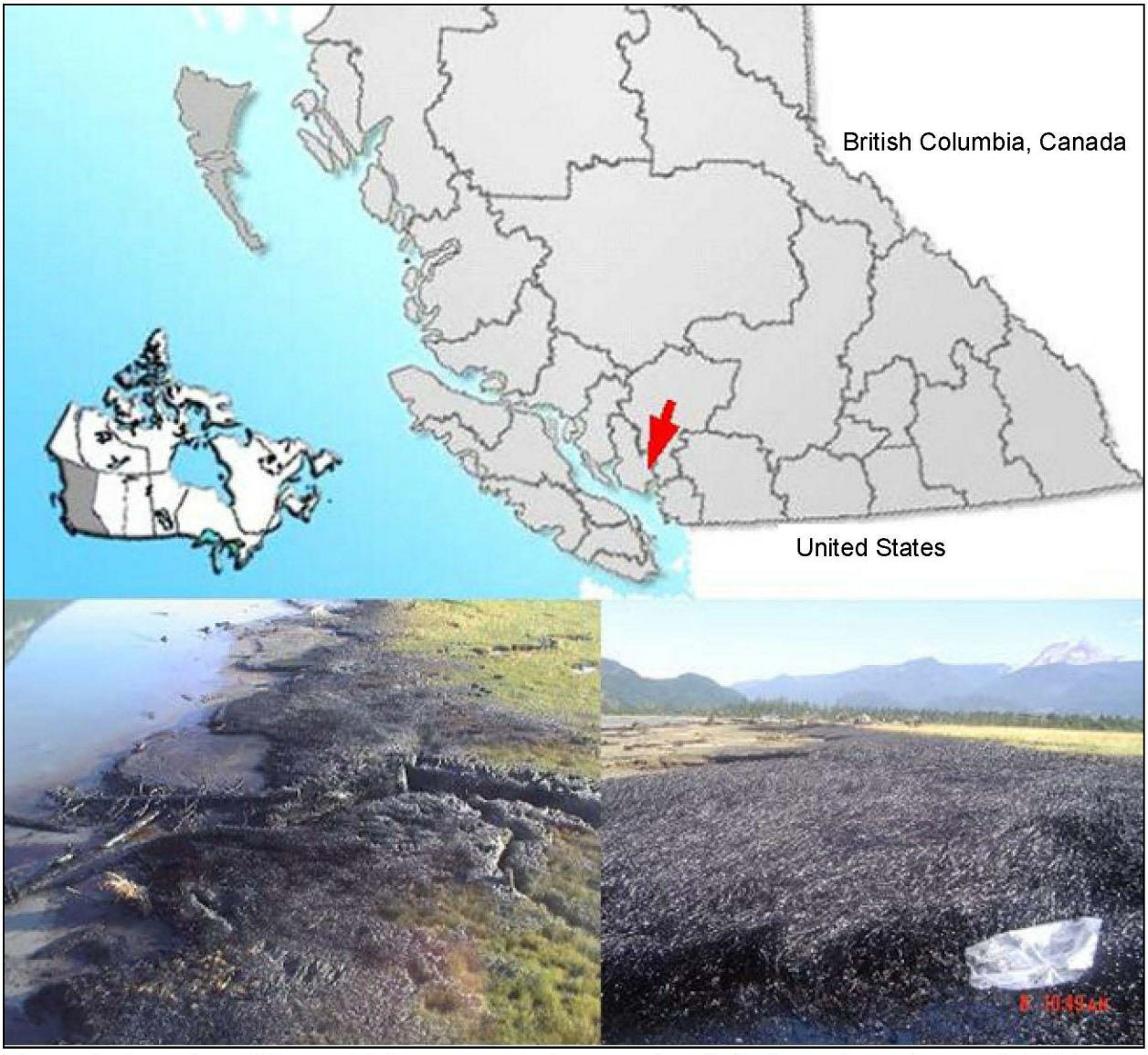

Figure 1. Location of Squamish Estuary and photographs of oiled marsh on August 6, 2006.

In general, salt marshes are recognized as sensitive habitats requiring site-specific considerations in spill response planning. International shoreline vulnerability indices include salt marshes in the "most vulnerable category of habitat". The effects of oil and treatment techniques on British Columbia *Carex* wetlands are largely unknown. No specific studies of oil spill effects or impacts on British Columbia wetland species assemblages are reported (Morris and Harper, 2006). The majority of research on effects of oil spills and cleanup techniques in marsh habitats has been performed in *Spartina* marshes. *Spartina* has different morphology and characteristics than native Pacific Northwest wetland vegetation, making it tenuous to extrapolate those studies to British Columbia situations.

In planning the response to the oiling of the Squamish marsh, an attempt was made to balance wildlife protection, a strong local desire to removal all oil in the marsh, and the need to avoid the use of cleanup techniques that would do more harm than good, i.e. that would result in a negative net environmental benefit. Recommending treatment methods was complicated in the absence of direct oil spill treatment knowledge for the plant assemblages listed. Determination of a cleanup endpoint was made by following a simplified impact assessment approach (Sergy and Owens, 2008). For the most part, the cleanup endpoints were judgment calls by technical specialists on the basis of net environmental benefit, where further oil removal may cause excessive unacceptable environmental damage.

Experience with marsh cleanup and recovery in other regions was reviewed when determining cleanup priorities and recommendations. There were no studies located on treatment efficacy for previous spills in similar estuaries. Existing studies of treatment results in marshes in other regions are also centered on vegetation indices and do not often report the potential lasting effects of polycyclic aromatic hydrocarbons (PAH) in the sediment. Since the effect of various treatments and response-related impacts on marsh vegetation and sediment in this region is unknown, a variety of techniques were applied depending on the degree of sediment oiling. These were typically considered in a hierarchical order of increasing aggressiveness. As a result, the oiled marsh was subjected to numerous types of "treatment" conditions ranging from no-action and ambient flushing to aggressive treatment including sediment removal and vegetation cutting. In some cases, an unwanted by-product of treatment included excessive trampling of sediment and vegetation which added to the treatment variables.

Cutting in the vegetated portions of the estuary was favored by local stakeholders. The decision to cut an oiled marsh is often based on a desire to reduce potential impacts to wildlife (Baker et al., 1993). Best Management Practices in the Washington State Northwest Area Contingency Plan for coastal marshes in the U.S. Pacific Northwest lists cutting as a potential method to protect wildlife and removed trapped sediment. However, the potential threat to wildlife must be balanced with the desire to maximize vegetation survival and recovery and the associated ecological services of the marsh to aquatic organisms. In some instances, oiled marshes are cut to enhance the survival or recovery of oiled vegetation. Cutting for this purpose is generally considered when thick coatings of oil entirely cover the above-ground vegetation (Getter et al., 1984). It is thought that marsh vegetation may be killed when oil coating the leaf surfaces interferes with oxygen diffusion to the root zone. Cutting may be proposed in these cases to open a passageway for gas exchange. It is expected in these cases that the vegetation will recover through new shoot growth from below-ground root and rhizome energy stores (Zengel and Michel (1996). Hoff (1995) also reports vegetation cutting is only viable when oil is very heavy on the sediment, not likely to weather, or represents an unacceptable contact risk to wildlife.

However, a number of studies report adverse effects of aggressive cleanup techniques in marshes, including vegetation cutting. Many studies of oiled vegetation indicate that aggressive response strategies may often stress vegetation beyond their ability to recover (Zengel and Michel, 1996). Often, most damage is caused during attempts to remove oil from the marshes rather than from the oil itself (ITOPF, 2006). Hoff et al. (1993) reported that foot traffic needed to cut large areas may exacerbate erosion, kill plants, and sometimes delay recovery. In a study that examined analytical chemistry of underlying sediments in an eastern Canadian marsh, vegetation cutting suppressed recovery parameters, with no reported statistical differences in soil

hydrocarbon attenuation rates (Lee et al., 2003). Toxicity testing in this instance suggested natural processes removed 87% of n-alkanes in soil in the first 20 weeks, and all treatment sites were below Environment Canada guidelines by 9 weeks (Lee at al., 2003). Plants that are cut may recover equally as fast as uncut plants (Levine et al. 1995); however, cutting increases the chances of increased human impacts.

Treatment scenarios with direct comparisons between oiled and cut vegetation versus oiled and uncut vegetation offer varying results. For example, Zengel and Michel (1996) reported that plant survival was positively affected by cutting in one case, negatively affected by cutting in five others, and equally affected by cutting or not cutting in another six instances. The meta-analysis was used to predict that vegetation cut to protect wildlife would have had negative vegetation impacts in 42% of the cases. They also used the data to predict that vegetation cutting with the objective of aiding plant recovery would have been harmful, unnecessary or ineffective in 92% of the cases. Low-pressure ambient temperature flushing of salt marsh vegetation and sediments is typically recommended as a non-aggressive technique (Zengel and Michel, 1996) prior to engaging more invasive methods.

No positive recommendations were found in the literature for sediment scraping or sediment removal in a marsh following oil spills. Sediment removal is more of a remediation technique than a response technique and is a case of destroying the marsh to save it (Hoff, 1996). Sediment removal is typically considered in only extreme situations of thick smothering deposits of oil on sediment. Sediment removal has resulted in severe hindrance of marsh recovery in several case studies (Hoff, 1995; IPIECA, 1994). Despite reported negative experiences from cutting vegetation, some external stakeholders preferred that sediment scraping and excavation tactics be applied in more heavily oiled areas.

This study examines the effect of various treatments and response-related impacts on marsh vegetation and sediment in a *Carex lyngbeyei* marsh in British Columbia, Canada. The vegetation response of dominant species, including *Carex lyngbeyei* and *Eleocharis palustris*, is also compared with sediment characteristics and analytical chemical analyses.

Methods

Oiling conditions in the estuary marsh were mapped by Shoreline Cleanup Assessment Technique (SCAT) and oiled vegetation and treatment boundaries were subsequently refined with GPS (Figure 2). For monitoring purposes, twenty plots of 1-m^2 each were established to represent the main vegetation types, treatments, oiling conditions, reference and control conditions (Table 1, Figure 2). Observations of (a) oil distribution, (b) oil character, (c) oil thickness and, (d) oil penetration in the sediment of each plot were collected over a one year period using standard Shoreline Cleanup Assessment Technique (SCAT) terminology (Owens and Sergy 2000). Oiling conditions on the vegetation within each plot were recorded as (a) % distribution (the percent of all stems that are oiled within a fixed area), (b) % stem length oiled (width of the oil band on the plant stem relative to the length of the stem) and (c) oil thickness. For purposes of cleanup decision-making during the spill, similar techniques were applied to make observations of oiling conditions throughout the marsh and were used to guide the selection of tactics and endpoints.

Observations of oiling conditions within the plots and for the overall marsh were combined to summarize the degree of oiling. The oil categories were used in both the treatment decision process and in the plot-by-plot comparisons. The oiling categories were created by using a variation of the Environment Canada SCAT approach, modified for this spill and shown in Table 1 and Table 2.

Table 1. Surface Oil Cover Category for Estuarine Marsh Vegetation
(such as *Carex sp., Eleocharis sp., Potentilla sp.*)

		Distribution of Individual Plants Oiled				
		91-100%	**51-90%**	**11-50%**	**1-10%**	**<1%**
% Length of Stem Oiled	**91-100%**	Heavy	Heavy	Moderate	Light	Very Light
	51-90%	Heavy	Heavy	Moderate	Light	Very Light
	11-50%	Moderate	Moderate	Moderate	Light	Very Light
	1-10%	Light	Light	Light	Very Light	Trace
	<1%	Very Light	Very Light	Very Light	Trace	Trace

Table 2. Surface Oil Cover Category Index for the Estuarine Marsh oiled by the *M/V Westwood Annette* Spill.

		Oil Distribution				
		91-100%	**51-90%**	**11-50%**	**1-10%**	**<1%**
Oil Thickness	**Thick Oil >1.0 cm**	Heavy	Heavy	Heavy	Moderate	**Light**
	Cover 0.1-1.0 cm	Heavy	Heavy	Moderate	Moderate	**Light**
	Coat 0.01-0.1cm	Moderate	Moderate	Moderate	Light	Very Light
	Stain <0.01	Light	Light	Light	Very Light	Very Light
	Film or Sheen	Sheen	Sheen	Sheen	Sheen	Sheen

The oiled marsh was subjected to the following types of treatment:

- Natural recovery, no treatment
- Vegetation cutting
- Vegetation cutting and low pressure ambient temperature flushing of sediment
- Vegetation cutting and sediment trampling
- Vegetation cutting; sediment flushing, trampling and heavy raking/scraping
- Shallow excavation of sediment
- Trampling of oiled vegetation and sediment
- Trampling of un-oiled vegetation and sediment

Each treatment condition was represented by one or more plots. Light sediment raking was done after cutting vegetation over heavily oiled sediments to remove oily debris and avoid compaction and consolidation of oily sediments without removing the root layer. Increasing aeration in the soil also promotes oil degradation. All treatments were associated with varying degrees of unavoidable foot traffic related to response actions. In some cases, sorbent collection and replacement continued for a month following initial treatment.

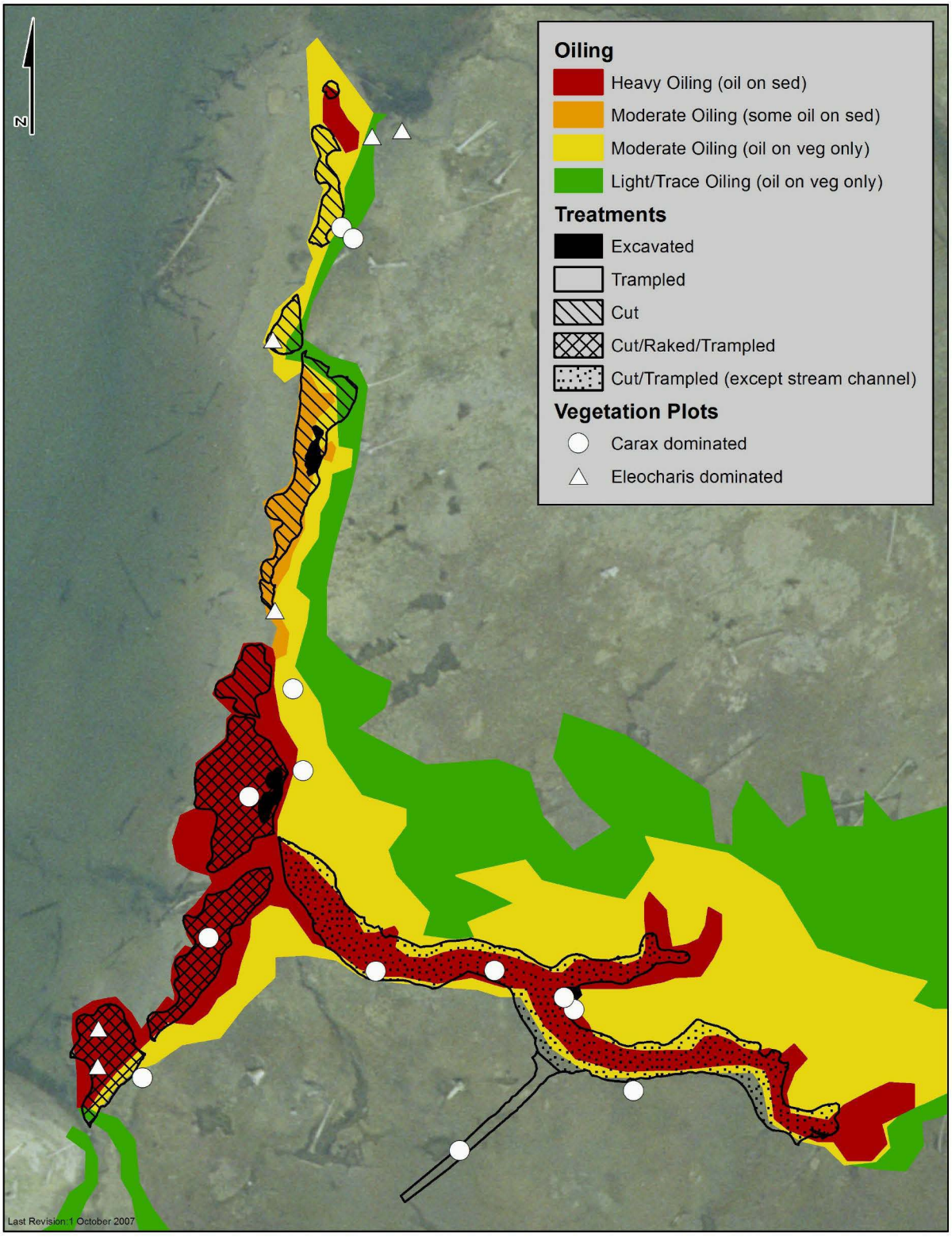

Figure 2. Boundaries of oiled vegetation and different treatments areas and location of monitoring plots within the Squamish estuary marsh.

Table 3. Individual vegetation plot initial oiling condition and treatment.

Dominant	Oiling		Treatment					
Vegetation	Sediment	Vegetation	None	Flush	Cut	Rake	Excavate	Trample
Carex	Heavy	Heavy		X	X	X		X
Carex	Heavy	Heavy			X			
Carex	Heavy	Heavy					X	
Carex	Heavy	Heavy			X			X
Carex	Heavy	Heavy			X			
Carex	Heavy	Heavy			X			X
Carex	Moderate	Heavy			X			
Carex	Moderate	Heavy	X					
Carex	Light	Heavy	X					
Carex	Very Light	Very Light	X					
Carex	None	None						X
Carex	None	None	X					
Carex	None	None			X			
Eleocharis	Heavy	Heavy		X	X			
Eleocharis	Heavy	Heavy		X	X			
Eleocharis	Moderate	Heavy			X			
Eleocharis	Very Light	Heavy	X					
Eleocharis	None	None	X					
Eleocharis	None	Heavy	X					
Eleocharis	None	Trace	X					

Observations of vegetation within the plots were conducted in August, September, and November 2006, and April and August 2007. Species composition, stem height and stem density data were collected in three random 0.25-m^2 subplots within each square meter sample plot. When minimal vegetation was present within a sample plot, the indices within the entire plot were recorded. Above-ground biomass was collected in three random quarter-meter subplots within each square meter in August 2007. Independent measures t-statistics (two-tailed, $\alpha = 0.05$) were computed to test the hypotheses that levels of oiling and treatments significantly affected vegetation indices. Oil distribution, thickness and penetration were also recorded for each plot during each sampling period.

Vegetation biomass was collected by cutting the stems to the soil horizon in three 0.25-m^2 subplots within each meter plot in August 2007. No biomass was collected in 2006 to avoid destructive sampling. When very little biomass was present, the entire plot was sampled. In some instances, insufficient biomass was present to collect samples. Vegetation was dried and weighed and compared across oiling conditions and treatments.

Figure 3. Vegetation cutting, raking, manual excavation and trampling in the Squamish Estuary.

Intertidal and subtidal sediment samples were collected from the marsh interior, marsh fringe, tidal creeks and adjacent channel for chemical analytical analyses. Sampling protocols adhered to industry standards including British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment, Biological Materials and Discrete Ambient Air Samples (BC Ministry of Environment 2007). All samples were composites of approximately 10 random subsamples within a 3 to 5 square-meter area and from the top 2 to 5 centimeters of sediment. Samples were analyzed at ALS Laboratories in Vancouver, Washington for 40 different PAHs and alkylated PAHs by gas chromatography/mass spectrometry (GC/MS).

Results

Carex lyngbyei dominates the interior of the marsh which represents the majority of the area oiled. *Eleocharis palustris* is found on the marsh fringe at lower tidal elevations. The third most common species was *Potentilla pacifica* which was often found mixed among the two dominant species at lesser percentages. For purposes of treatment effects comparisons, plots were identified as either *Carex* or *Eleocharis* dominated.

Carex-dominated Vegetation Plots

Carex lyngbyei-dominated plots were grouped by similar oiling conditions and treatments for comparison (Table 4). Average stem density measured over the sampling period within each plot grouping shows reduced stem densities in three treatment categories (Figure 4), heavy sediment scraping, trampling, flushing and cutting, excavation, and severe trampling. Plots in moderately and heavily oiled sediment and vegetation that were either not treated or treated but not trampled did not differ significantly in stem densities from unoiled untreated plots at one year (t=-1.53, df = 16, p=0.14). *Carex* stem density was lowest overall in November 2006 and not reported due to natural senescence or lack of vegetation in all plots.

Table 4. *Carex lyngbyei* dominated plots grouped into similar oiling condition and treatment.

	Oiling Condition		**Treatment**					
Group	**Sediment**	**Vegetation**	**None**	**Flush**	**Cut**	**Rake**	**Excavate**	**Trample**
1	Heavy	Heavy		X	X	X		X
2	Heavy	Heavy			X			X
3	Heavy	Heavy			X			
4	Heavy	Heavy					X	
5	Moderate	Heavy			X			
6	Moderate/Light	Heavy	X					
7	Very Light	Very Light	X					
8	None	None						X
9*	None	None	X					
10	None	None			X			

* Reference Plots

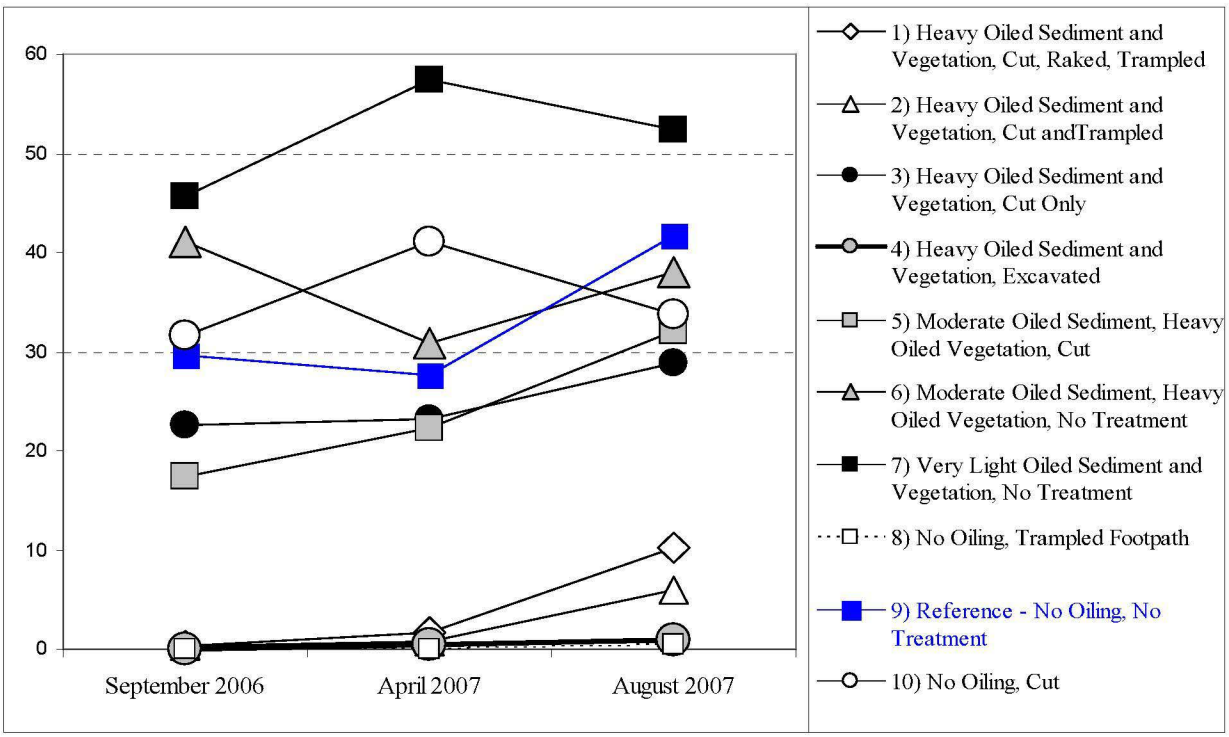

Figure 4. Average stem density (per 0.25-m^2 quadrat) of *Carex lyngbyei* in plots grouped by oiling condition on sediment and vegetation, and treatment type.

Comparison of stem densities in heavily oiled *Carex* plots indicates trampling and excavation significantly hinder recovery to reference stem densities. Oiled trampled plots were significantly different than oiled untrampled plots in August 2007 (Figure 4, Figure 5) ($t = 4.72$, $df = 15$, $p = 0.0002$). Heavily oiled untrampled plots were not significantly different than reference plots ($t = -1.53$, $df = 16$, $p = 0.14$), indicating trampling is a better predictor of recovery than oiling. Although insufficient sample sizes for statistical analyses were available for sediment removal treatments (few to no stems were present in most instances), stem densities in the excavated plot were lower than all other plots with the exception of trampled plots, which had similarly low stem densities in both oiled and unoiled plots. Adjacent excavated and trampled areas outside of the sample plots provided no reason to believe that vegetation indices were different in any other similar locations. Unoiled trampled plots were similar to heavily oiled trampled plots with extremely limited vegetation re-growth at one year (Figures 4 and 6). Cutting in oiled untrampled plots did not result in significantly lower stem densities versus unoiled uncut reference plots by August 2007 ($t = -1.14$, $df = 7$, $p = 0.29$). Similarly, unoiled cut versus unoiled uncut plots did not show significant differences in stem densities ($t = 1.62$, $df = 7$, $p = 0.15$).

Natural variation in *Carex* above-ground biomass is evidenced by the stem density differences between groups 7 and 9, where little or no oiling and no treatments occurred (Figure 7). However, when groups 7 and 9 are pooled for comparison to other groups, no significant differences between oiled untrampled treatments were found ($t = 0.66$, $df = 11$, $p = 0.26$). Oiled and unoiled trampled and excavated plots had little or no biomass to measure (Figure 7). Unoiled cut plots also did not differ from reference plots ($t = 0.73$, $df = 5$, $p = 0.25$). Maximum stem height was consistent with stem density and biomass results. Stem height after one year was lowest in trampled and excavated plots (Figure 8). Oiling condition or cutting alone did not significantly affect stem height after one year.

Qualitative observations of sediment oiling conditions within each plot indicated that oil persistence was increased by aggressive cleanup treatments (Figure 5, Figure 9, Table 5). Total Petroleum Hydrocarbon (TPF) analysis confirmed the highest occurrence of residual oil in these plots. Source oil chemical analytical analysis indicates approximately 8.1 % of the spilled oil consisted of polycyclic aromatic hydrocarbons (PAH) (80,950 mg/Kg). Sediment PAH was measured in varying oiling condition and treatment locations, although sampling was not robust for all treatment groups. Sampling focused on only those areas where sediment PAH levels exceed numeric criteria for the protection of aquatic life. However, PAH differences between trampled versus untrampled areas are apparent. Sediment PAH measurements in composite samples showed higher concentrations in oiled and trampled marsh regions compared to oiled untrampled areas, further indicating trampling enhances oil persistence in sediment (Figure 10). Sediment samples in lightly oiled areas showed no PAH signature from the spilled oil by August 2007. Sediment samples in oiled untrampled areas, when they had detectable levels of PAH, did not exceed BC Ministry of Environment PAH numeric criteria for the protection of aquatic life.

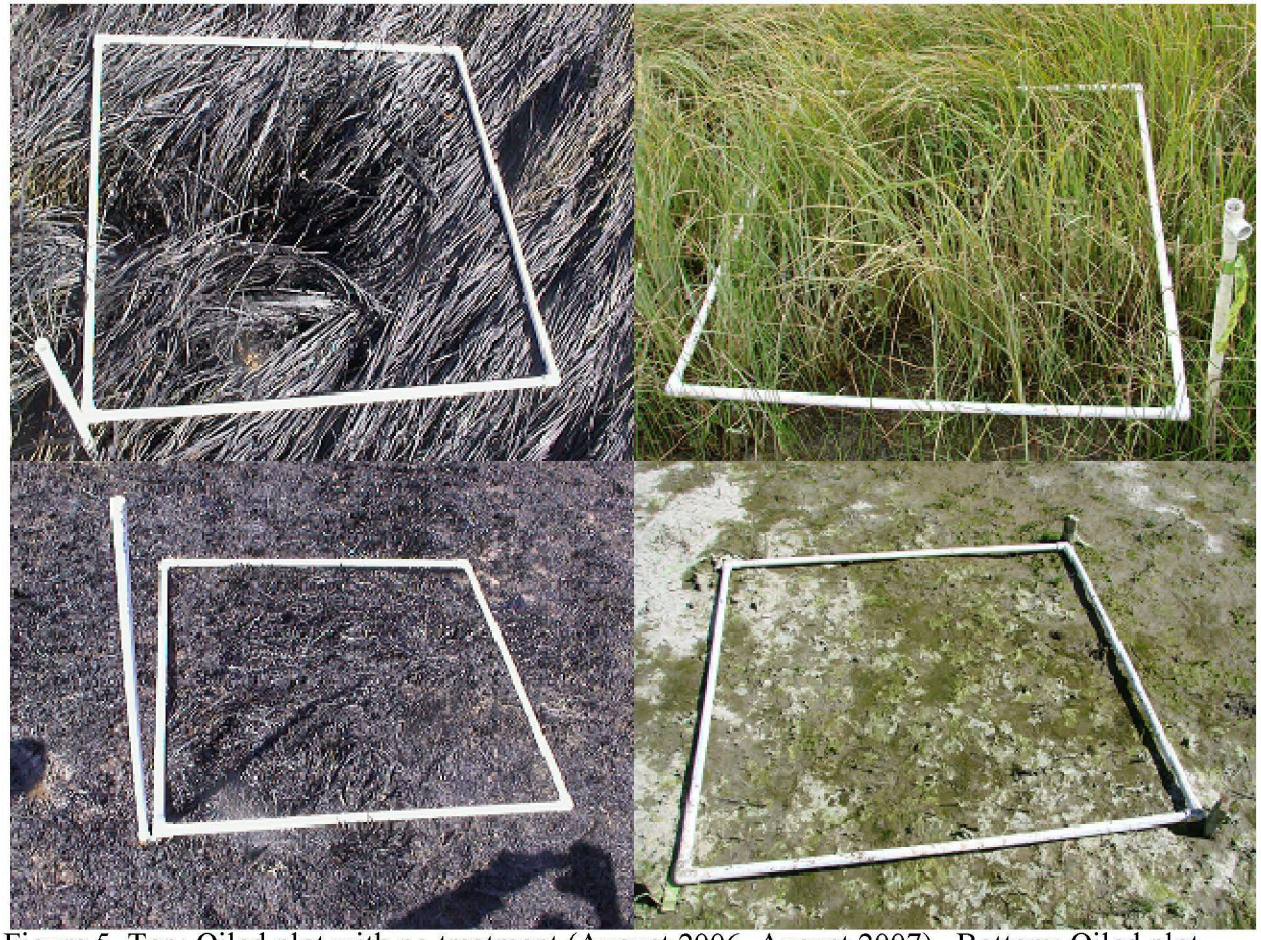

Figure 5. Top: Oiled plot with no treatment (August 2006, August 2007). Bottom: Oiled plot that was cut and raked and experienced substantial foot traffic.

Figure 6. Unoiled footpath (August 2007).

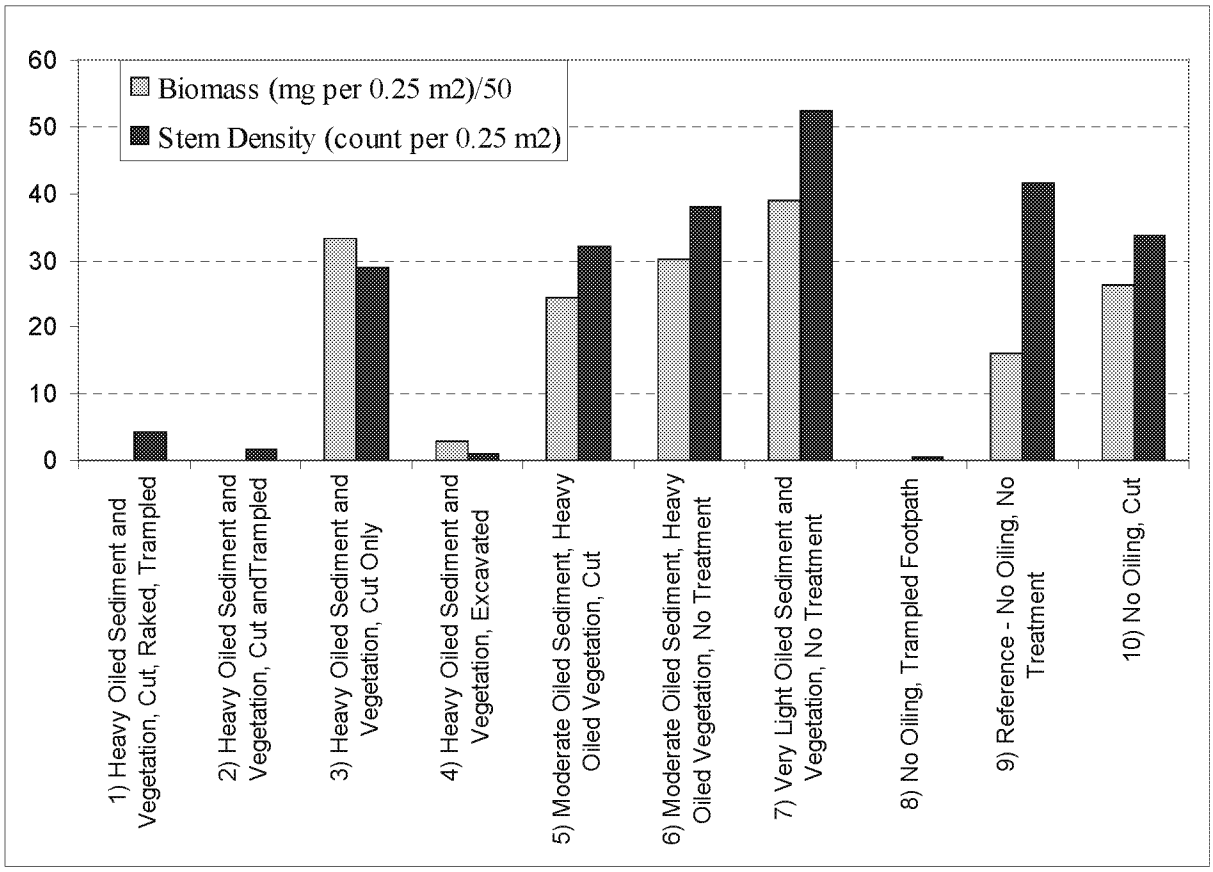

Figure 7. Above-ground biomass of *Carex* plots (per 0.25 $m^{2)}$ in August 2007.

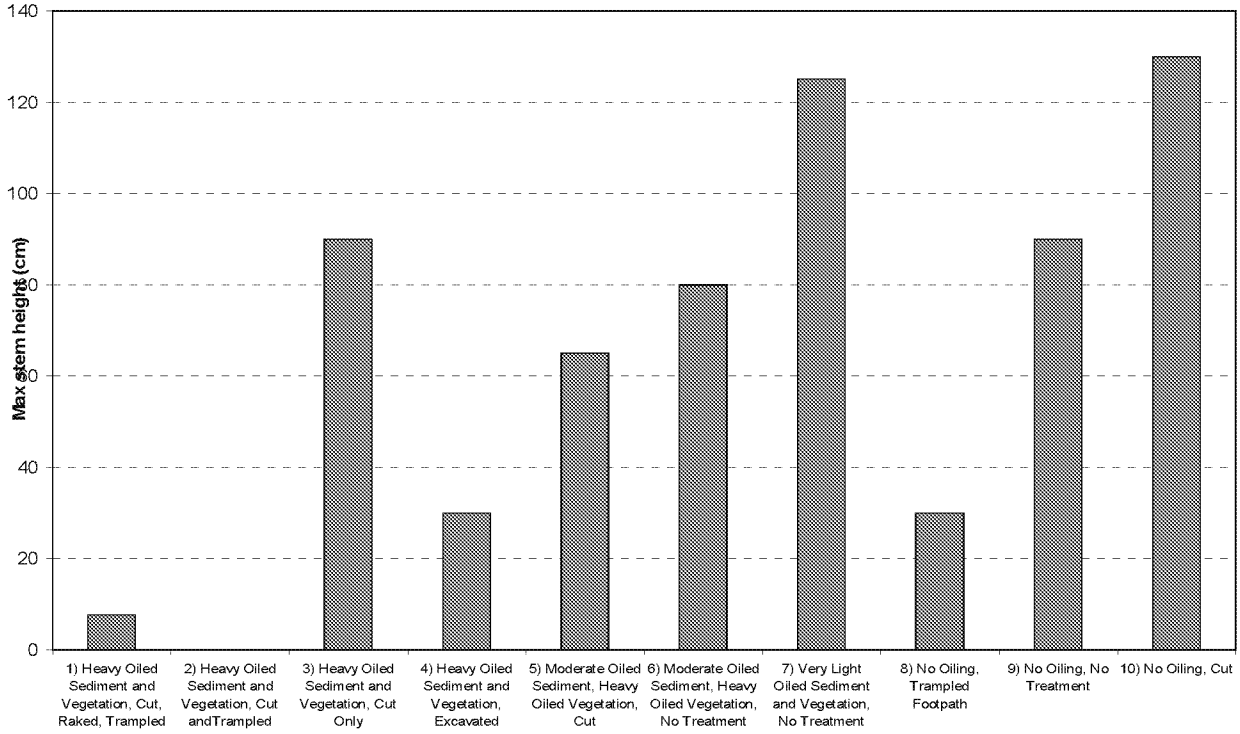

Figure 8. Average maximum stem height in *Carex* groups after one year (August 2007).

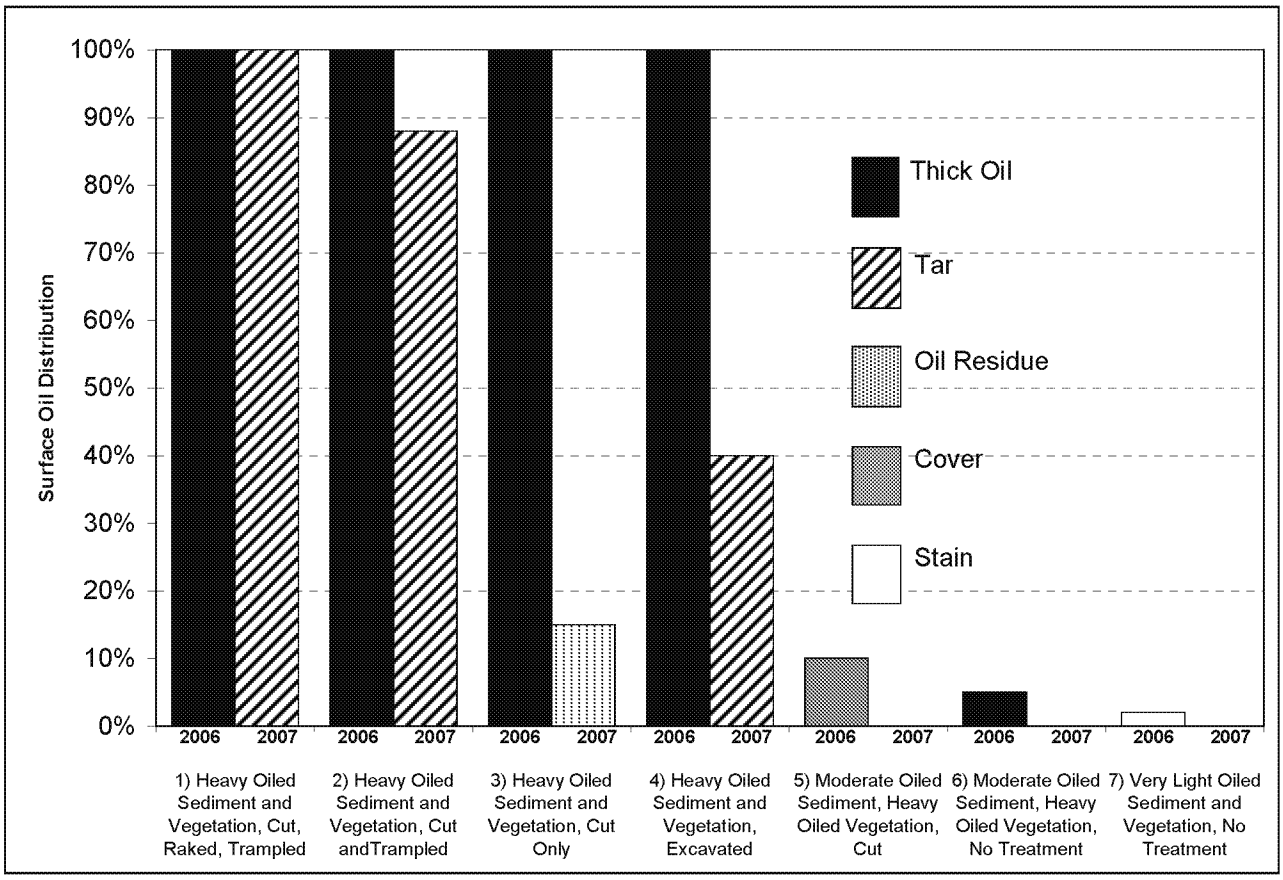

Figure 9. Change on sediment oil characteristics over time.

Table 5. Change in sediment oiling category in Carex Plots.

Group	Sediment Oiling Category		Treatment Category
	Aug-06	Aug-07	
1	Heavy	Heavy	Trampling, raking/scraping, flushing and vegetation cutting
2	Heavy	Heavy/Mod.	Heavy trampling and vegetation cutting
3	Heavy	Mod./NOO	Vegetation cutting
4	Heavy	Heavy	Shallow excavation of sediment
5	Moderate	NOO	Vegetation cutting
6	Mod./Light	NOO	Natural recovery, no treatment
7	Very Light	NOO	Natural recovery, no treatment
8	Sheen	NOO	Trampling
9	NOO	NOO	Natural recovery, no treatment
10	NOO	NOO	Vegetation cutting

NOO = No oil observed

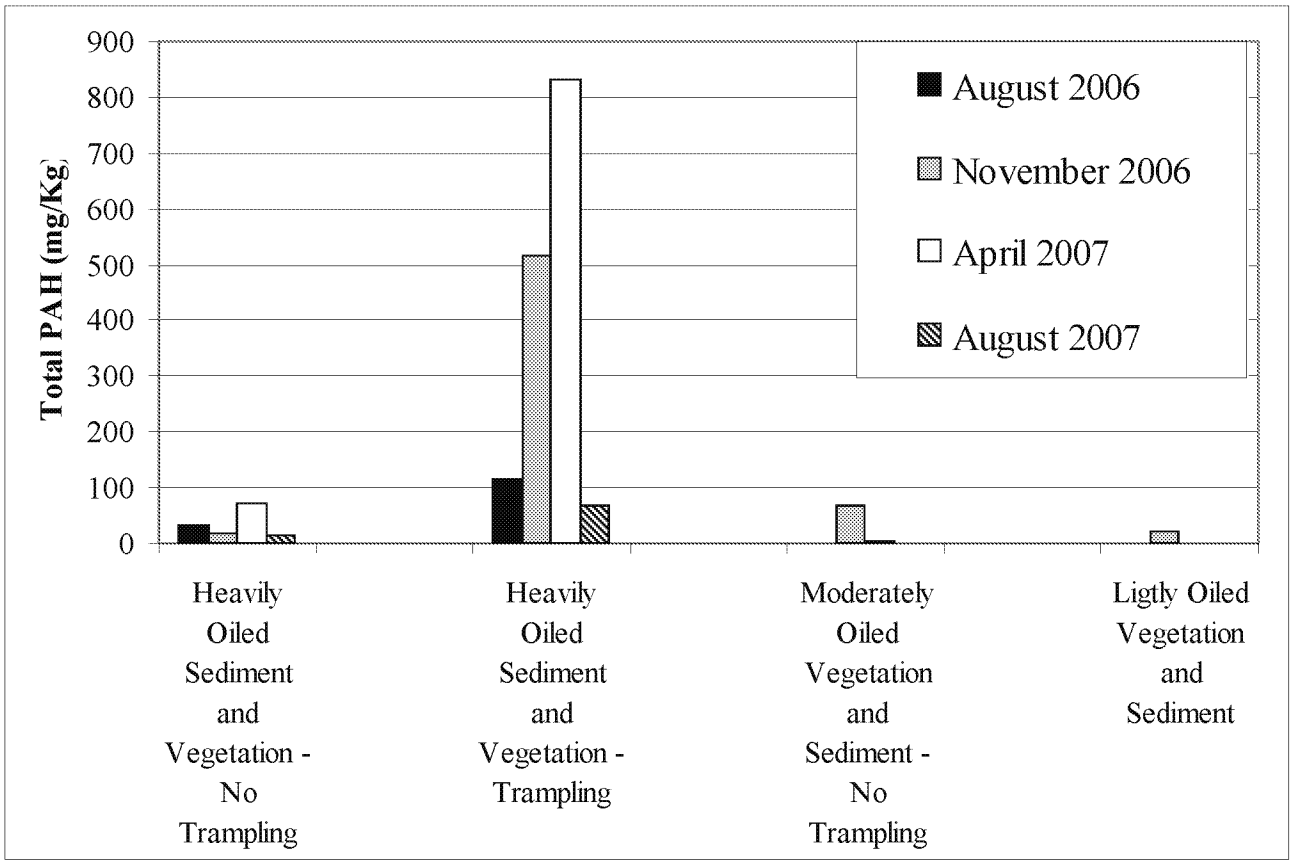

Figure 10. Average sediment total PAH concentrations in differing oiling conditions and treatments.

<u>*Eleocharis*-dominated Vegetation Plots</u>

Eleocharis palustris plots were grouped into similar oiling conditions and treatments (Table 6). No *Eleocharis* plots experienced heavy foot traffic or mechanical damage. *Eleocharis* appears to retain much of its stem density throughout the winter and does not experience as substantial die-back as *Carex lyngbyei*. Average stem density over the sampling period within each plot grouping shows reduced stem density in plots with heavily oiled sediment in November 2006 and April 2007 (Figure 11). Stem density of cut plots with heavily and moderately oiled sediment was significantly lower than reference plots in April 2007 ($t = -3.0$, $df = 13$, $p = 0.01$). Stem density of cut plots with heavily oiled vegetation but little or no oil on the sediment was also significantly lower in April 2007compared to unoiled reference plots ($t = -1.95$, $df = 10$, $p = 0.07$). By August 2007, significant differences in stem density were found between heavily oiled sediment and vegetation plots versus reference plots ($t = 1.91$, $df = 10$, $p = 0.07$); however, heavily oiled cut plots had significantly greater stem density than reference plots. It is doubtful the treatment or the oiling resulted in greater stem density in the *Eleocharis* portions of the marsh and more likely the result of a Type I error. Stem density of uncut plots with heavily oiled vegetation alone were not significantly different from unoiled plots in August 2007 ($t = 1.69$, $df = 7$, $p = 0.06$).

Table 6. Oiling and Treatment groupings for *Eleocharis palustris* dominated plots.

	Oiling Condition		**Treatment**		
Group	**Sediment**	**Vegetation**	**None**	**Flush**	**Cut**
1	Heavy	Heavy		X	X
	Heavy	Heavy		X	X
2	Moderate	Heavy			X
3	Very Light	Heavy	X		
	None	Heavy	X		
4*	None	Trace	X		
	None	None	X		

* Reference Plots

There were no significant differences in *Eleocharis* above-ground biomass in August 2007 between oiled treatments and oiled plots with no treatment ($t = -0.39$, $df = 12$, $p = 0.70$), indicating treatment did not significantly alter vegetation response. Oiled treated plots had significantly more biomass than reference plots, but sample size was low and few similar reference locations for *Eleocharis* were available ($t = -2.10$, $df = 10$, $p = 0.06$). No *Eleocharis* plots were trampled and we cannot report on the effects of trampling, although oiling in the absence of trampling did not impede recovery. Maximum stem height was lower in *Eleocharis* plots that were heavily and moderately oiled, but we were unable to determine if this was an artifact of oiling or plot elevation and location with respect to tide (Figure 13). There were no *Eleocharis* plots in heavily oiled sediment that were not cut to test the hypothesis that a lack of treatment would result in significant differences, although plots with heavily oiled stems that were not cut responded well (Figure 14).

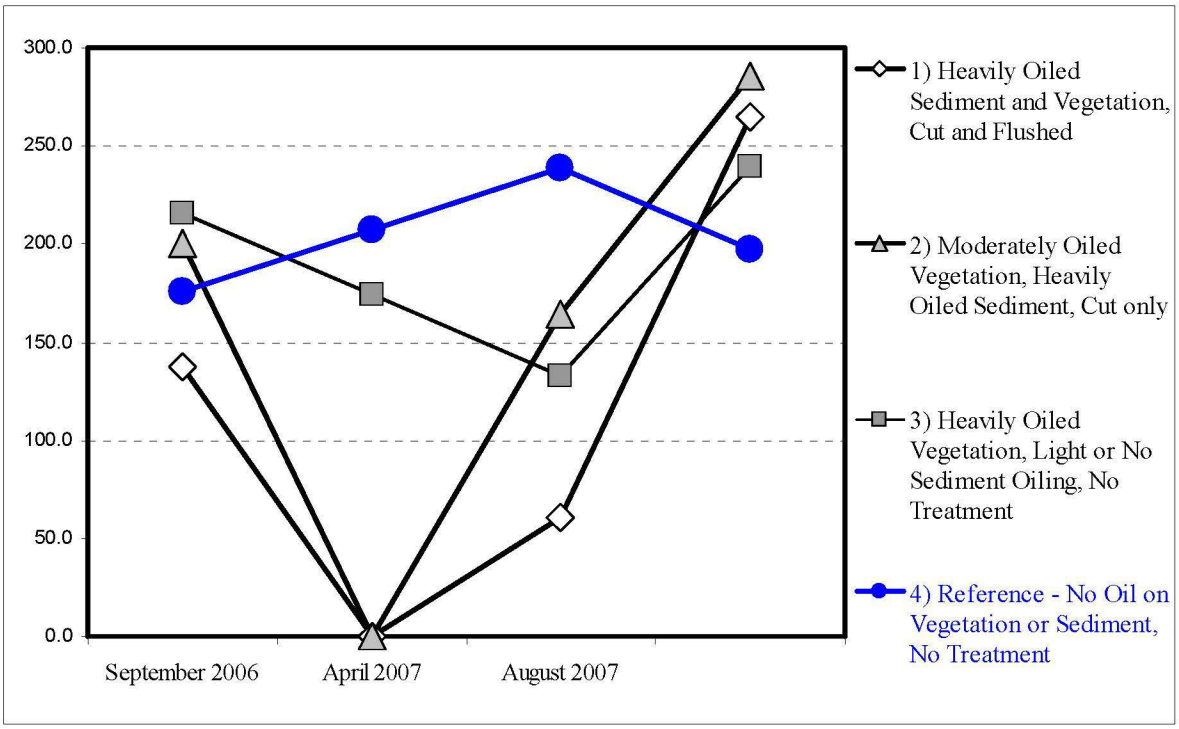

Figure 11. Average stem density (per 0.25 m^2) of *Eleocharis palustris* in grouped plots.

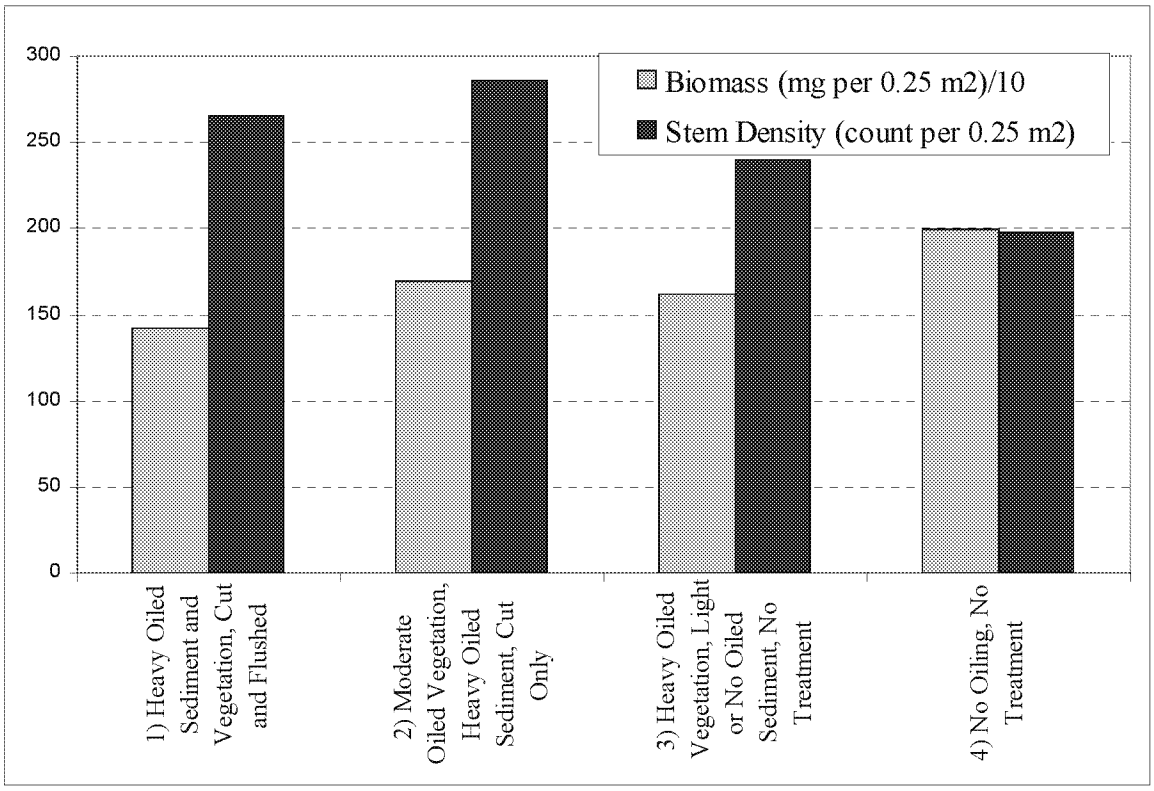

Figure 12. Above-ground biomass of *Eleocharis* plots (per 0.25 m2) in August 2007.

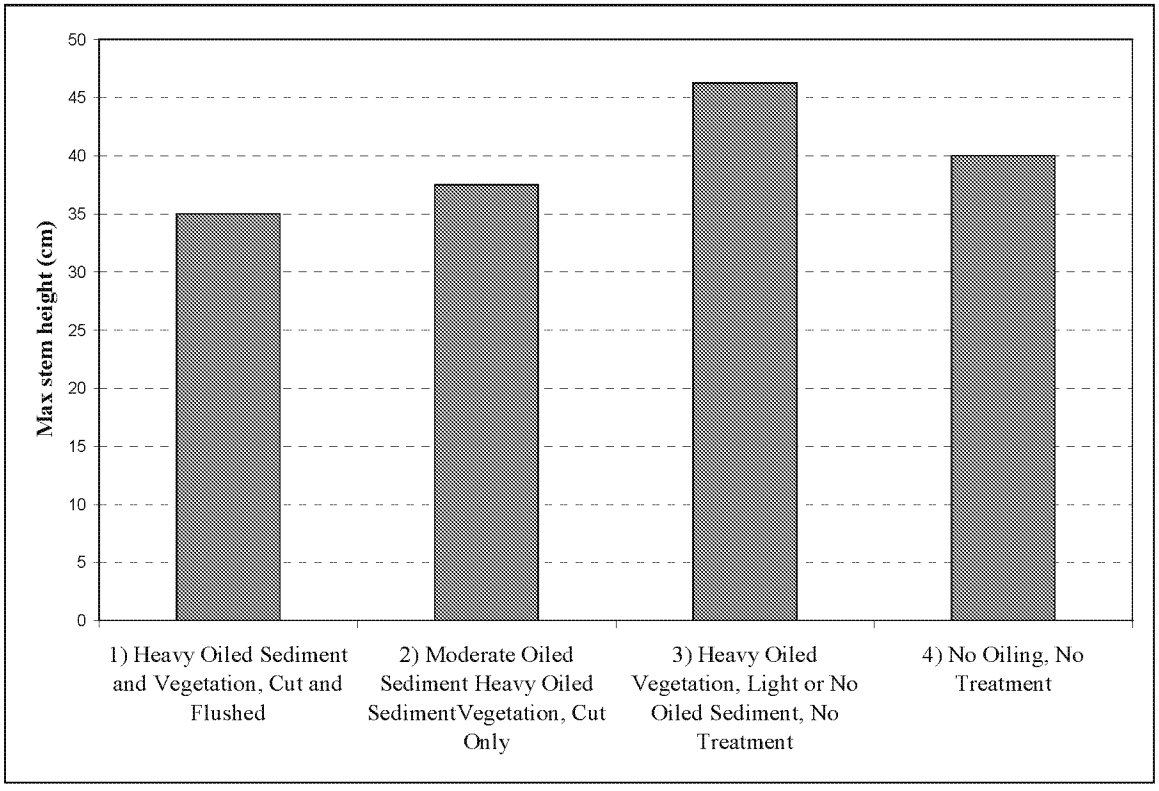

Figure 13. Maximum stem height in *Eleocharis* treatment groups after one year (August 2007).

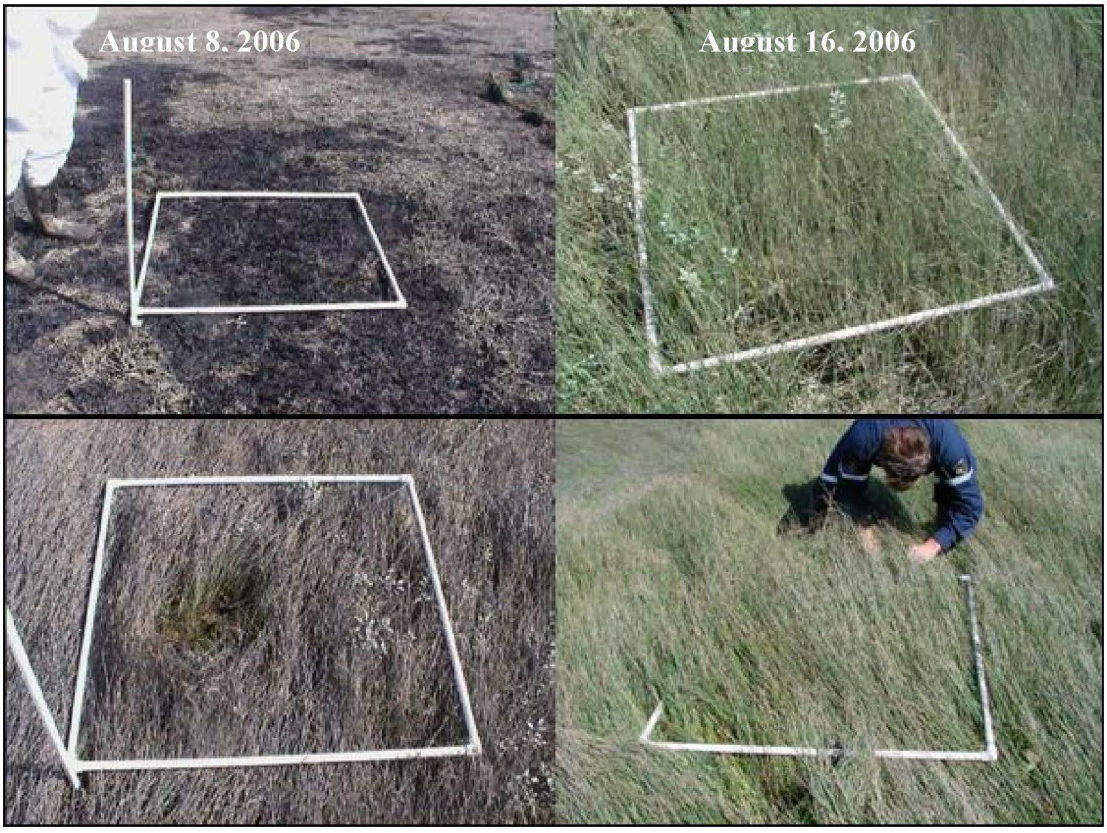

Figure 14. Heavily oiled cut plot (top). Heavily oiled vegetation untreated (bottom)

The surface oil conditions in *Eleocharis* plots were variable with some areas of heavy oiling retaining a surface tar layer and others with no evidence of oil after one year. Overall, surface oil characteristics in *Eleocharis* plots were greatly reduced (Table 7, Figure 15) since most *Eleocharis* stands did not experience trampling.

Table 7. Change in sediment oiling category in *Eleocharis* Plots.

Group	**Sediment Oiling Category**		**Treatment Category**
	Aug-06	Aug-07	
1	Heavy	Heavy/NOO	Flushing and vegetation cutting
2	Heavy	NOO	Vegetation cutting
3	Light	NOO	No treatment
4	NOO	NOO	No oiling, no treatment

NOO = No oil observed.

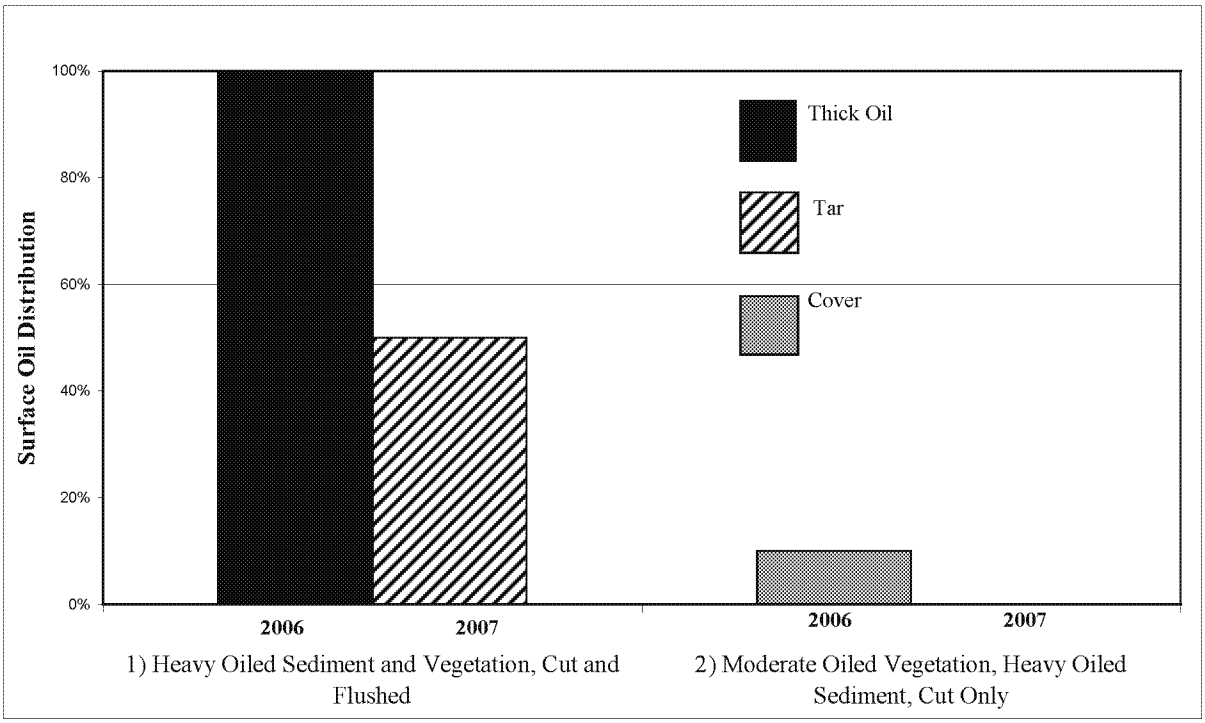

Figure 15. Surface oil characteristics in *Eleocharis* plots.

Other Species

Potentilla pacifica, the third most common species of vegetation in the oiled area, was monitored in several plots. From visual observations and stem density counts in several 'paired' (i.e. oiled/unoiled) plots, there was no defined difference in health or numbers of plants. There also appeared to previously unidentified rushes that occurred in heavily impacted plots that may serve a pioneer function of breaking the surface compacted layer and re-establishing vegetation.

Discussion

The effect of oil in marshes is known to vary with type of oil, degree of weathering, climate, and time of year (IPIECA 1994). Although areas with high tidal flushing are more likely to naturally recover without aggressive cleanup actions (Zengel and Michel 1996) and significant affects to wildlife had not been observed, a strong local desire to remove all the oil from the marsh prompted ongoing response activities and ultimately unnecessary mechanical damage in some places. However, the area of mechanical damage and residual oil represents only a few percent of the affected area and the overall recovery of the marsh is good. Cutting the heavily oiled portions of the marsh would have resulted in less mechanical damage had it been followed by removal of personnel from the marsh and allowing the remaining underlying oil to attenuate naturally. Several weeks of continued sorbent placement, spot cutting, and site maintenance in the affected areas did not remove substantial amounts of oil following the initial cutting and resulted in reduced vegetation recovery and prolonged oil persistence in some areas. A desire to remove residual oil in a marsh even when the oiled vegetation has weathered and cannot easily foul wildlife is an insufficient reason to increase foot traffic and mechanical damage and results in increased rather than decreased persistence of oil in the marsh sediments.

Oil migration into the marsh was observed following initial cutting of heavily oiled areas. Oiled vegetation may have served as a partial barrier to migration (Figure 16). It is possible that delaying cutting in the most heavily oiled areas until mobile oil was removed would have reduced the overall oil footprint, but the risk of wildlife oiling may persist and must be considered. Cutting vegetation immediately following a spill may lead to increased marsh exposure to oil (if the oil on the sediment is mobile), and possibly the need and desire to cut more vegetation.

Figure 16. Evidence of oil migration in the marsh.

The time of year of the spill in Squamish may have made vegetation less vulnerable to cutting or oil effects than if the spill occurred in spring. However, the growing season extends well into the fall in the maritime climate of Squamish as evidenced by re-growth of some oiled cut vegetation in September prior to dieback and reduced stem densities in November. There was a concern that attempts at re-growth prior to senescence would deplete valuable winter food storage in roots and compromise recovery in the spring, which was not evident in the data. In oiled and trampled plots, some signs of recovery are evident and plants have begun to break through the surface layer of residual tar and mud to facilitate natural attenuation and weathering (Figure 17).

Figure 17. Signs of vegetation re-growth in oiled and trampled locations.

Reduced vegetation cutting, less foot traffic, and a deluge flush system with containment and collection at the mouth the marsh creek shown in Figure 16 may have been more successful at promoting recovery, but was not likely to have been considered appropriate by local stakeholders at the time. Overall, more than 90% of the oiled marsh area recovered to within reference vegetation parameters within one year. Differences in species present in heavily oiled plots after one year are the likely result of natural succession rather than more permanent changes due to oiling; however, further investigation of recovery after one year would be necessary in the few remaining plots that have not returned to normal stem densities and biomass. This study suggests that less is sometimes more when responding to oil spills in marshes and is consistent with study results in other marsh ecosystems. While cutting does not harm vegetation recovery, the increased foot traffic may result in decreased recovery and increased oil persistence.

While this study does not present the analytical results of mechanical tilling and berm relocation on the sandy shorelines, both were very successful at attenuating sediment PAH in the silty clay estuarine environment with substantial wind and wave energy.

Conclusions

With respect to stem density, above-ground biomass, and stem height of *Carex lyngbyei*:

- The amount or degree of oiling on the vegetation had no apparent impact on *Carex*, or was insignificant in comparison to the impact of the treatment.
- Heavily oiled untreated *Carex* did not differ from the unoiled reference or very lightly oiled *Carex*.
- Cutting of *Carex* stems had no apparent impact, positive or negative.
- Visually and statistically significant impacts to *Carex* following one year of observations were found from three types of treatments categories
    1) Aggressive and severe sediment scraping and trampling,
    2) Sediment removal, and
    3) Trampling alone, with or without oil.

With respect to stem density, above-ground biomass, and stem height of *Eleocharis palustris*:

- The amount or degree of oiling on the vegetation had no apparent impact on *Eleocharis*.
- Heavily oiled untreated *Eleocharis* did not differ from the unoiled reference or very lightly oiled plots.
- Cutting of *Eleocharis* stems had no apparent impact, positive or negative.
- Positive recovery of *Eleocharis* stems was evident 1 year post spill in that area subjected to very heavy oiling and non-aggressive treatment (minimal trampling and mechanical disturbance of oiled sediment). This was occurring in plots with and without the presence of thick tar residues.

The sediment PAH measurements indicate the contributing factor to oil persistence in sediment were activities that pushed the oil into the sediments such as excessive trampling. Patches of thin tar or tar/vegetation mats were formed in some locations, presumably due to a combination of compaction and/or low energy. Treatments that were aggressive in physically disturbing the oiled sediments and root systems of the marsh (heavy trampling, heavy scraping, excavation

and/or excessive trampling) also retarded vegetation recovery and prolonged oil persistence in comparison to non aggressive treatment, or vegetation cutting or natural recovery.

Acknowledgements

This study was supported by the owners of the wood products carrier Westwood Anette in cooperation with the British Columbia Ministry of Environment and Environment Canada, Emergency Sciences and Technology Division, Edmonton, Alberta Canada.

References

Ascaphus Consulting. 2003. Conservation Priorities in the Squamish River Estuary. A Report to the Squamish Estuary Conservation Society, Squamish, B.C. October 25th, 2003.

Baker, J. M., Little, D. I. & Owens, E. H. (1993). A review of experimental shoreline oil spills. In *Proc.* 1993 *International Oil Spill Conference,* pp. 583-590. American Petroleum Institute, Washington, DC. USA.

BC Ministry of Environment. 2007. British Columbia environmental laboratory manual for the analysis of water, wastewater, sediment, biological materials and discrete ambient air samples. Water and air Monitoring and Reporting Section, Water, Air and Climate Change Branch, Ministry of Water Land and Air Protection. ISBN 978-0-7726-5760-2.

Getter, C. D., Cintron, G., Dicks, B., Lewis, R. R. & Seneca, E. D. 1984. The recovery and restoration of salt marshes and mangroves following an oil spill. In Restoration of Habitats Impacted by Oil Spills (J. Cairns & A. L. Buikema, eds), pp. 65-113. Butterworth Publishers, Boston, MA, USA.

Hoff, R.Z., Shigenaka, G, Henry, C. 1993. Salt marsh recovery from a crude oil spill; vegetation, oil weathering and response. Proceedings of the International Oil Spill Conference, 1993:307-311.

Hoff, R.Z. 1995. Responding to oil spills in coastal marshes; a fine line between help and hinderance. HAZMAT Report 96-1. Hazardous Materials Assessment Division, National Oceanic and Atmospheric Administration, Seattle Washington, USA.

Hutchinson, I. 1988. The biogeography of the coastal wetlands of the Puget Trough: deltaic form, environment, and marsh community structure. Journal of biogeography 15: 729-745.

IPIECA. 1994. Biological Impacts of Oil Pollution: Saltmarshes. International Petroleum Industry Environmental Conservation Association, Report Series Volume 6, London, United Kingdom. 24 p.

ITOPF. 2006. Recommendations for cleanup in oiled marshes. International Tanker Owners Pollution Federation Limited. London. United Kingdom.

Lee, K, Wohlgeschaffen G., Cobanli S., Greer C., Venosa A., Tremblay G., Suidan M., Garcia-Blanco S., Doe, Kenneth. 2003. Habitat recovery in n oil-contaminated salt marsh following biorestoration treatments. Proceedings of the International Oil Spill Conference, 2003.

Levine, E.A., Pinckney, J., and Montello, T. 1995. Follow-up study on oiled vegetation cutting along the Delaware River. Proceedings of the International Oil Spill Conference. 195.

Northwest Area Contingency Plan. Chapter 9680. Oil Spill Best Management Practices.

U.S. Department of Interior. 1998. Effects and Management of Oil Spills in Marsh Ecosystems. A review produced by a workshop convened July 1996 at McNeese State University. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region. Edited by Edward C Proffitt. 33p.

Morris, M. and J. Harper. 2006. Oil Spill Response Techniques for BC Coastal Wetlands. January 2006. Report prepared for Environment Canada. Emergency Science and Technology. Edmonton, Alberta, Canada.

Owens, E.H. and G.A. Sergy, (2000). The SCAT Manual - A Field Guide to the Documentation and Description of Oiled Shorelines, Second Edition, Environment Canada, Edmonton, AB, 108 p.

Sergy, G.A. and E.H. Owens. 2008. Selection and Use of Shoreline Treatment Endpoints for Oil Spill Response. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC, *(this edition).*

Zengel, S. and J. Michel. 1996. Vegetation Cutting as a Clean-up Method for Salt and Brackish Marshes Impacted by Oil Spills: a Review and Case History of the Effects on Plant Recovery. Marine Pollution Bulletin, Vol. 32, NO. 12, pp. 876-885.