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MONITORING OF MARSH VEGETATION RESPONSE TO A JET-FUEL SPILL AT VANCOUVER INTERNATIONAL AIRPORT

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INTRODUCTION

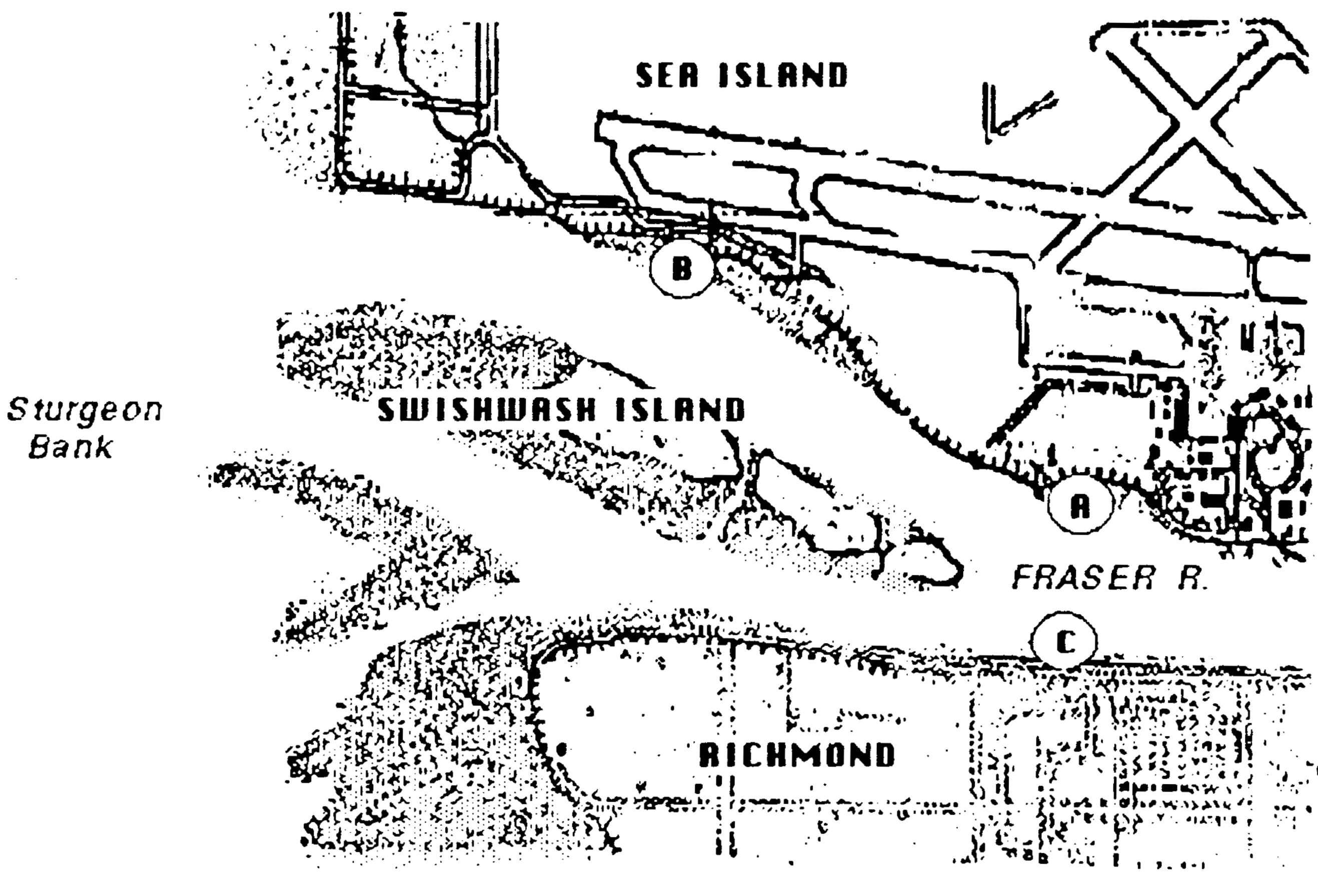
"...every oil spill is unique..." (Mitchell et al.. 1985)

Estuarine marshes have been acknowledged as highly productive habitats which contribute significantly to the estuarine food web. The Fraser River estuary contains some of the largest expanses of intertidal marshes in coastal British Columbia, ranging from fresh-water dominated marshes in the Lower Fraser River, to salt marshes in the outer reaches of the estuary. As urbanization has spread throughout the Fraser estuary these marsh areas have been threatened by dyking, agricultural expansion, industrial development and more insidiously by environmental contamination.

On March 23, 1988, an area of marsh by the Middle Arm of the Fraser River, adjacent to the Vancouver International Airport (Figure 1) was affected by a spill of Jet A fuel. AIM Ecological Consultants Ltd. (AIM) was requested by Environment Canada (Conservation & Protection) in conjunction with FEARO to monitor the vegetation in the vicinity of the spill. Due to a lack of background data, it was not possible to predict the effects of the fuel spill on marsh vegetation. This study was commissioned to identify the impacts associated with the fuel spill. It was also felt that in light of future developments in the estuary, information gleaned from this accident could be invaluable for future environmental planning.

In reviewing the available literature, it became apparent that virtually no information was available concerning the effects of jet-fuel on the environment. In the marine environment, the majority of environmental disasters have involved crude oil. Although there have been extensive descriptions and follow up studies of oil spills, there is a great deal of variability to be expected, depending on the type of oil spilled. Even crude oils from different locations have been documented as having a variety of effects on the environment. In general, the most toxic effects to aquatic life have arisen from highly refined oils containing substantial amounts of soluble, aromatic hydrocarbons.

Figure 1: Location of Jet-Fuel Sampling Stations at Vancouver International Airport



BACKGROUND

Properties of Hydrocarbon Fuels

Petroleum products are normally divided onto four groups; napthenes, normal paraffins, isoparaffins, and aromatics. These groups occur in characteristic percentages for the various refined petroleum products. Jet A, is a kerosene based fuel with a flash point ranging from 102 to 155 ^{o} F (Shelton & Dickson 1983). Depending on the individual product, the aromatic volume ranges from as low as 11.8% to a high of 24.8% (ibid). The aromatic content is important as this tends to be the most acutely toxic component of the fuels.

The volatile and somewhat soluble "lighter" oil fractions, including the low boiling point aromatics, are potentially the most toxic to aquatic life (Hutchinson et al.. 1979). Following an oil spill, the aromatic components of petroleum are lost within the initial 24 hours as some of the oil evaporates, some dissolves, and some emulsifies. Large quantities are usually accumulated in the sediments (Ganning et al. 1984).

Impacts on Vegetation

Oil spills may have acute, short-term impacts, or may result in less obvious but more long-term chronic effects. Salt marsh vegetation can often recover from a single moderate size oil spill. However, chronic or severe oil contamination may result in long-term environmental damage (Stebbins 1970, Baker 1971b, Baker 1971e, DeLaune et al. 1979, Hershner & Lake 1980 Krebs & Tanner 1981). The extreme in the range of possible environmental responses was seen in the wreck of the Tampico Maru. Spilled diesel oil resulted in both acute and chronic effects. The highly toxic oil was trapped in a cove where recontamination occurred, resulting in a decade of ecological damage (Ganning et al. 1984).

Factors which influence the effect that an oil spill will have on the vegetation include:

- -salinity
- -species
- -age of plants
- -physiography of the marsh
- -soil type
- -timing of the spill
- -type of oil
- -weather conditions
- -wave & current energies
- -viscosity of the oil

Plants with large rhizomes (underground stems) are thought to tolerate oiling better than plants without, since new growth is able to regenerate from below-ground even after the aerial parts have been destroyed (Baker 1970). However, the growth of roots and rhizomes may be reduced by incorporation of oil into substratum. The less viscous the oil the greater its penetration into sediments (Baker 1970, Hershner & Moore 1977). In general, the less viscous oils are also the more highly refined petroleum products which are the most toxic to marsh vegetation (Baker 1971a). In addition to the toxicity of the oil itself, chronic oil pollution may stimulate anaerobic conditions in the substrate which may in turn inhibit vascular plant growth (Ranwell 1968, Cowell 1969). Weathering, or the evaporation of volatile hydrocarbons results in a lower toxicity to plants (Baker 1971a). However, mortality appears to be increased by hot sunny conditions, whether tropical or temperate (Chan 1977).

Physiological response

Plant sensitivity to oil is a product of:

- an affinity between plant cuticles and hydrocarbons,
- blockage of leaf pores, restricting gas exchange
- reduction of light, therefore photosynthesis, and
- toxicity of oil to plant metabolism (Baker 1970).

The "...lipophilic nature of hydrocarbons and the lipid-protein nature of the cell's semi-permeable membranes have suggested membrane disruption (and incorporation) as a primary site of hydrocarbon action." (Hutchinson et al. 1979). Fleshy leafed plants such as *Batis maritima,* and *Salicornia* spp. are particularly sensitive to oil coating their leaves, stems or substrate (Chan 1977).

Most of the marsh/oil studies have indicated that annuals fare more poorly than do perennials in an oiled environment. Annuals have small root systems and low food reserves, thus making recovery from oil pollution more difficult than for perennials which have rhizomes able to send forth new growth. *Spartina* appears to be a fairly tolerant genus in terms of oil pollution, both chronic and acute. It has been reported that *S. anglica* contains 80% of its production underground (Baker 1971). No information has been found concerning the response of *Carex* or *Scirpus* species to oil. Seagrasses function as a natural absorbent for oil. Seagrass detritus retains the oil and accumulates in the upper intertidal zone. Decomposition of oiled seagrasses is substantially slower than for clean seagrass detritus, thereby reducing the input of detritus into the food web (Chan 1977).

OIL CHARACTERISTICS AND PLANT RESPONSE

The type of oil involved in a spill influences the speed and extent of the recovery. Light refined oils containing large proportions of aromatic hydrocarbons are much more toxic than crude oils or heavy refined products (Ganning et al. 1984). Incidents involving #2 fuel oil have had a more rapid, broader and long lasting impact than those involving #5 fuel oil (ibid). Partial coverage of plants was reported to be damaging only for #2 fuel oil when compared with 3 other heavier

oils and complete coverage of the plant resulted in virtually complete mortality. Growth in the test plots in the first year was reduced significantly as a result of both initial above and below-ground mortality. Complete recovery occurred within 2 years. Residual toxicity of the sediments did not appear to be a problem as the No. 2 fuel oil was retained least of the oils tested in the sediment. The light fuel oil, was subject to greater evaporation or dispersed by tidal activity than the heavier oils tested. Weathering had also significantly reduced the toxic compounds in the oil but there were indications that a portion of the oils remained in the sediment for long periods of time (Webb et al. 1985).
A No. 6 oil resulted in death only if the plants were completely covered by oil. If the top third of the plants was unaffected results were not serious. Regeneration was possible if oil was only lightly covering the soil. Successive tidal activity also influenced the plants' abilities to recover. Very high tides completely coated the plants with oil as the tide rose (Webb, et al. 1981).

Substrate effects

In monitoring the West Falmouth oil spill, Burns & Teal (1979) concluded that most of the oil entering the marsh ecosystem was incorporated into the anoxic marsh sediments. High molecular weight aromatics and naphthenes were the most persistent fractions. Concentrations of oil were the highest in the surface layers although Burns & Teal (1979) found the oil extended to at least 115 cm in depth. Previously unaffected areas were being influenced by oil contamination within 2 years. The oil persisted in the marsh causing deleterious effects for at least 8 years. This has implications for the present study, in terms of the oil seeping from the contaminated areas and being carried to other areas causing chronic low level contamination.

Oxygen is necessary within the sediments for the degradation of the oil. As this process occurs, depletion of the oxygen supply can cause anoxic conditions where there is poor water exchange. These anoxic conditions can in turn result in an indefinite storage of the oil. Recovery of such an area may first require a fresh deposition of sediment over top of the damaged substrates. Depending on the deposition rate, this might take decades (Ganning et al. 1984).

In the West Falmouth oil spill, all organisms showed evidence of hydrocarbon contamination of their tissues, but there was no indication of biomagnification within the organisms. Colonization of the damaged substrates by animals occurred by immigration from nearby undisturbed areas (Burns & Teal 1979).

Chronic oil contamination of marshes may cause greater problems for the stability of marshes than periodic spills. Complete elimination of some marsh communities has been attributed to such a situation (Baker 1970, Blumer et al. 1971). Oil contamination may influence the substrate microflora by either decreasing N_2 fixing microflora or may shift the bacterial population to N_2 fixing hydrocarbon-oxidizing species (Coty 1967, Kator & Herwig 1976, Walker & Colwell 1976). If all of the vascular plant cover is destroyed, the contaminated area may revert to an earlier successional stage, dominated by nitrogen-fixing cyanobacteria (Baker 1971a, 1971b).

Oiled sediments appear to inhibit the growth of new rhizomes. Plants growing in oiled substrates in Brittany, were all vertical and had no side branching (Stebbins 1968). A similar response was noted in *Spartina alterniflora* transplanted to oily substrates. The transplants survived but very few new shoots emerged (Krebs & Tanner 1981).

Grain size of substrates appears to be another important factor for the penetration and persistence of oil. Fine textured substrates are not as severely affected by oils as sands due the lack of pore spaces for the oil to percolate down. However, once the oil penetrates the fine sediments, it is likely to remain in situ longer and is likely to cause anoxic conditions in the fine sediments.

Seasonal effects

In studies using Kuwait crude oil, Baker (1971) concluded that vegetation oiled in the spring needed the entire summer to recover, while vegetation which was oiled at the end of the growing season recovered well by the same fall. Transects oiled during the winter did not appear to show detrimental effects the following spring (Baker 1971, Ranwell and Hewett 1964). A significant difference was noted between annual and perennial plants. Recovery of a plant is by new growth, the oiled parts are shed. Annual plants are limited in their ability to produce new growth, and are also inhibited in their seed production for the year following oiling. The seed production of perennials is also reduced when the oiling occurs at the time of flowering. The plants most sensitive to oiling are seedlings of perennials and annuals at all stages of growth (Baker 1971).

The lighter fuels do not show the seasonal variation which was noted for the crude oils. When sediment or partial plant coverage occurred with No. 2 fuel oil, biomass reductions occurred regardless of the timing of application. Complete coverage of the plant during active growing periods resulted in a long term reduction in biomass. Long term effects to the ecosystem may arise from a reduction in the oxygen normally transferred to the roots via the air spaces in *S. alterniflora* (Alexander & Webb 1985).

Recovery

Ganning et al. (1984) define restoration as "the return of the ecosystem to within limits of natural variability by natural and/or artificial means. It is important to realize that natural variability occurs through time and space due to ecological interactions as well as seasonal, annual, and long-term climatic and oceanographic changes." Other definitions for recovery range from; restoration of the environment to general ecological usefulness; to -- restoration to original structure and function with the original species complement. It is likely that given time all disturbed environments will regain some ecological usefulness; however, the degree of damage dictates how close one can come to the original community structure.

METHODS

An initial site visit was undertaken on April 7, 1988 , at this time three stations were chosen for subsequent monitoring: Station A, heavily affected; Station B, lightly affected; Station C, control. At the time of the site visit, those areas which had been heavily affected retained a noticeable odour of jet-fuel. The vegetation was still alive but displayed signs of cell damage, i.e. the shoots were lacking in chlorophyll, and were translucent and limp.

The first sampling session was carried out on April 18, 1988. The marsh plants which had shown signs of damage during the initial site visit, were by this time dead. The above-ground shoots were brown and shriveled but there was still a noticeable odour of jet-fuel attached to the vegetation.

Transects for the monitoring of vegetation were set up at each of the three stations (Figure 1). Surface sediments, above-ground and below-ground plant material from two species of marsh plants were collected at each station during the first sampling session. Three replicates were obtained from each component of each species at each station. The below-ground material was sampled by removing a 20 cm deep core, 10 cm in diameter. The rhizomes were separated from the sediment by washing with a high pressure spray of clean water . The samples were placed in heat-treated glass jars and transported to the West Vancouver, Environment Canada Laboratory for analyses. During a subsequent site visit, two deep cores were taken at Station A, one in a vegetated site, the other in bare mud adjacent to the vegetated zone. A 20 cm diameter core, approximately 0.75 m deep was excavated at each location. This core was cut in half and samples were collected at 10 cm intervals from the interior of the core (to avoid contamination).

Follow-up site visits were undertaken in July and September. Stem measurements of various species were utilized as an indicator of productivity. Above and below-ground biomass samples were collected for comparisons with the stem measurements. Other data recorded included densities of both reproductive and vegetative stems. Observations of plant vigour and phenology were recorded at each site.

A greenhouse trial was also conducted to simulate field conditions during the peak of vegetative growth. Greenhouse grown plants of *Carex lyngbyei* and *Scirpus maritimus* were dipped in a 1% mixture of fresh jet fuel and a standard hydroponic nutrient solution. The jet fuel was stirred into the nutrient solution to simulate conditions which might occur during wind and wave action. These plants were only dipped to the "sediment" surface. A parallel trial was conducted to evaluate the effects on the plants if the fuel was only incorporated into the sediment, and not on the above-ground growth. Control plants were grown in the standard hydroponic nutrient solution.

The resulting data were analysed using an Apple Macintosh Plus computer with a StatView 512+ statistics package.

RESULTS

Hydrocarbon analyses of sediments & vegetation

An analysis of variance was conducted to evaluate the differences between the various stations and species. Significant differences were found between the heavily oiled site, Station A and the Control site for oils & greases and for hydrocarbons for *Carex* roots and *Juncus* shoots. No significant difference was detected for *Juncus* roots (both oils & greases and hydrocarbons), or for *Carex* shoots (oils & greases) between the two stations. A highly significant difference was detected between hydrocarbons in *Carex* shoots at Station A and the Control site. However, contrary to the other results, in this case the level of hydrocarbons detected was lower at Station A than in the control.

The differences observed between the other stations were not statistically significant, with the following exceptions:

Station B versus Control

- Oils & Greases in *Carex* shoots were higher in the control than at Station B

Station B versus Station A

- Both oils & greases and hydrocarbons were more abundant in *Juncus* shoots at Station A, than Station B.
- The concentration of hydrocarbons in *Carex* shoots at Station A, was lower than at Station B.

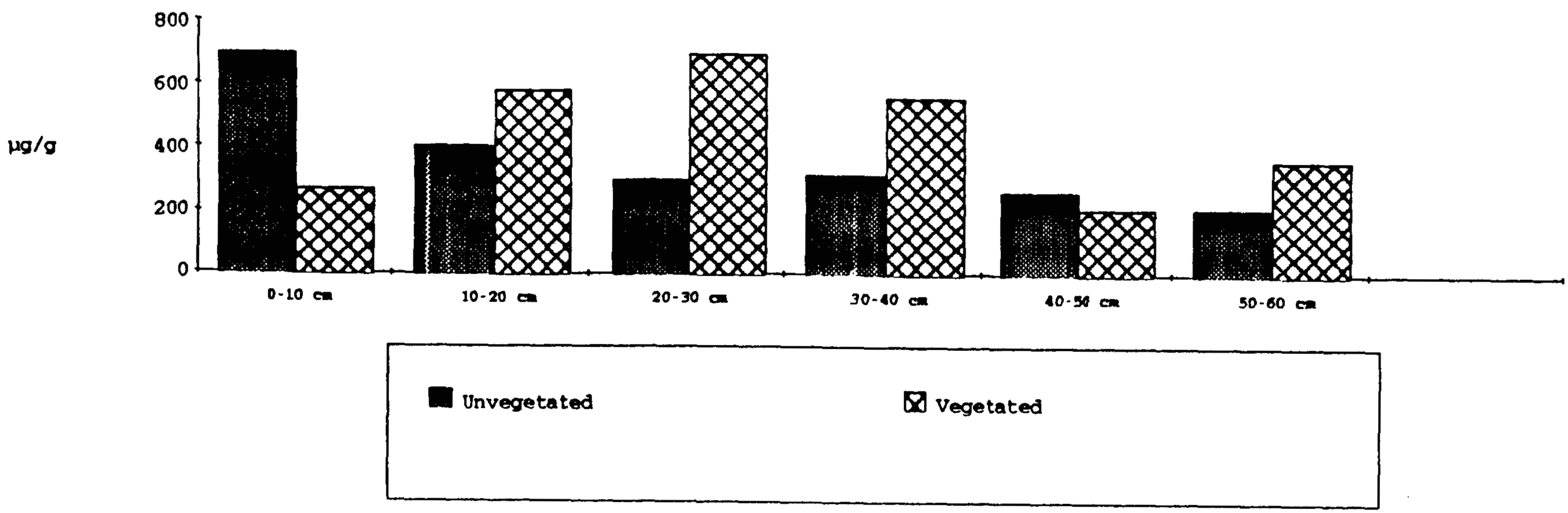
The results of the sediment cores are presented in the accompanying graphs. At the unvegetated site, the distribution of both hydrocarbons and oils & greases declined with depth. However, at the vegetated site, there was a distinct peak in the concentration of both hydrocarbons and oils & greases in the vicinity of the rooting zone (Figure 2).

Community Characteristics - stem measurements, density, biomass

Measurements taken of the plants at Station A in July and in September indicated they were all substantially shorter than those of Stations B and C (Figure 3). Further segregation of the plants at Station A into those most heavily affected by fuel, versus those less heavily affected, revealed significant differences between the two. It was obvious from the results that although the lightly fueled areas were reduced in growth, the heavily fueled areas had experienced significantly greater reductions in growth.

Statistical analyses revealed a highly significant difference ($p=0.001$) between the stem measurements from heavily oiled and lightly oiled sites versus the control for *Scirpus validus* and *Carex lyngbyei* for both July and September sampling periods. Significant differences were detected between the stem heights of *Carex lyngbyei* located at Transect A and the stem heights at Transects B and C. On the other hand, no significant differences were detected between the stem heights of *Carex lyngbyei* at Stations B and C. These trends were also confirmed by the analyses of vegetative and reproductive stem numbers, and for the above-ground biomass. Only for root biomass was there no significant difference between the three transects. The root biomass was not segregated into live and dead components, but observations during the washing process revealed that most of the below-ground biomass for Transect A was dead. This would indicate that the *Carex* community at this site was similar to those of Transects B and C prior to the fuel spill.

FIGURE 2: Comparison of Hydrocarbon Distribution with Sediment Depth in Unvegetated and Vegetated Sites at a Heavily Fuel Contaminated Intertidal Area Adjacent to the Fraser River (Station A), Vancouver International Airport, April 1988



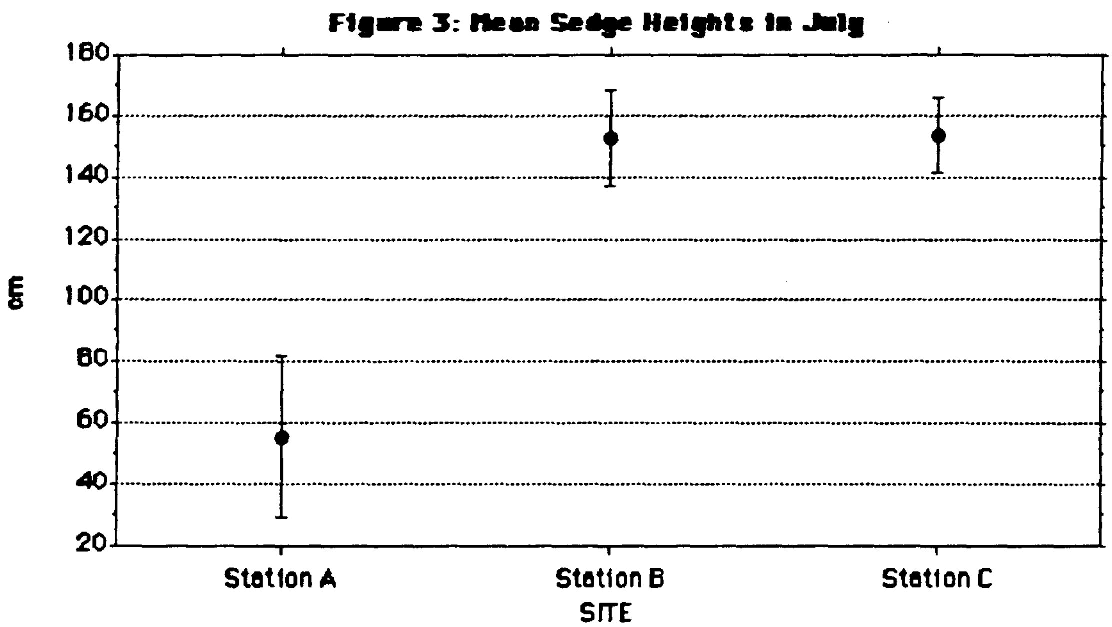


Figure 3: Mean Sedge Heights in July
180
160
140
120
100
80
60
40
20
cm
Station A
Station B
Station C
SITE

Height of Tallest Sedge (cm) at Jet-Fuel Monitoring Transects

	A-Heavily Oiled	A-Lightly Oiled	B	C
July	110	135	184	177
September	88	153	175	168

Normally the height of stems can be expected to decline toward the end of the growing season, as the older leaves break, as translocation and general aging of above-ground components take place and as lodging of plants occurs, making it more difficult to obtain accurate measurements. In the heavily oiled parts of Transect A, there was a noticeable difference in size in the surviving sedge plants between the July and September sampling periods. Perhaps these plants too had suffered some breakage and loss of upper leaves. However, we feel that the reduction in both average size as well as that of the tallest plant was a consequence of the loss of individual specimens. Statistically significant seasonal differences were found between the species (both *Carex lyngbyei* and *Scirpus validus*) found growing in the heavily oiled and lightly oiled sites of Transect A. The increase in size of the sedge in the lightly oiled site may indicate a degree of recovery at this site.

Qualitative Changes in Community Structure

By July those plant communities most severely affected by the jet-fuel in April were still unable to recover. Remnants of the dead shoots were visible, and in wet areas there were still "oil-slicks" apparent on the water. Although there was no odour of fuel on the sediment surface, the smell of fuel was very strong in the cores and in the dead root material even after it had been washed to remove adhering sediment. A few shallow rooted seedlings of annual plants had started to invade the areas denuded by the fuel spill. In some locations a few *Scirpus validus* plants were able to survive in the otherwise denuded sites. In the vicinity of the fuel spill, even those plants not killed outright by the fuel were showing after effects such as reduced height and deformities in growth. Although the translocation of hydrocarbons did not appear to have taken place in *Juncus,* no above-ground regeneration had taken place as late as September 1988.

By September, there were still many areas within the zone of high impact which had no vegetative growth, and only 10% of the sediment area was occupied by vegetation. Fuel was still seeping from the sediments in many locations leaving a distinct film on the incoming tide. *Eleocharis* had colonized in discreet patches, but did not display any seed production. In areas of light impact, approximately 75% of the *Scirpus validus* plants displayed seed heads. In the zone of high impact, only 10% of the plants had seed heads, none of which were *Carex lyngbyei.* Annuals which had colonized the high impact area by July had disappeared by September, leaving a few scattered shoots of *Carex lyngbyei, Scirpus validus, Typha* and *Eleocharis*. *Typha* which appears to have colonized the zone from seed, was approximately 1 m high in this area while in nearby areas the height exceed 2 m. In the high pond area, formerly occupied by *Juncus*, there were numerous weedy species, which appeared to be very stunted and deformed. No regeneration of the impacted *Juncus* had occurred, and the area was being colonized by *Lythrum* seedlings which were stunted and phenologically inhibited compared to nearby plants of the same species. *Scirpus validus* in the high impact areas was still showing the same deformities as earlier (i.e. twisted and bent stems).

Greenhouse Trials

The results of the greenhouse trials indicated that even at this relatively low level of concentration, the mature plants dipped into the fuel mixture experienced immediate (within 24 hours) mortality of approximately 10 % of the leaves. The portions of the plant (*Carex lyngbyei*) most susceptible to damage were the youngest leaves. Even with only a single dipping, within two weeks the test plants were showing significant yellowing (chlorosis) compared to the control. *Scirpus maritimus* grows in a different form than *Carex lyngbyei* and hence did not display the initial loss of leaves, but within two weeks showed dramatic yellowing. Baker (1971) observed that leaves under a persistent oil film stayed green for some time, but eventually turned yellow and died.

The plants subjected to the fuel by its incorporation into the soil did not show the leaf loss that the dipping caused, and the yellowing of the leaves was not as dramatic as in the dipped plants. However, the substrate-oiled plants displayed noticeable yellowing of leaves compared to the control. The most dramatic change in these plants was in the young shoots emerging from the base of the plant. These shoots showed a similar response to that observed in the field conditions in April. After 2 weeks, cell damage was evident by the loss of chlorophyll and discolouration of the shoots.

DISCUSSION

During the July sampling our observations confirmed that those plant communities most severely affected by the jet-fuel in April were unable to recover. Remnants of the dead shoots were still visible in September. In wet areas there were still "oil-slicks" apparent on the water. Although there was no odour of fuel on the sediment surface, the smell of fuel was very strong in the cores and in the dead root material even after it had been washed to remove any adhering sediment. A few annual plants had started to invade the areas denuded by the fuel spill. These plants were shallow rooted seedlings. In some locations a few *Scirpus validus* plants were able to survive in the otherwise denuded sites. In the vicinity of the fuel spill, even those plants not killed outright by the fuel were showing after-effects such as reduced productivity and deformities in growth. Although the translocation of hydrocarbons did not appear to have taken place in *Juncus*, no above-ground regeneration had taken place as late as September 1988.

In the study area, the heavily oiled areas of *Carex* showed virtually no growth as a consequence of the deposition of fuel on their shoots. In fact, those shoots affected in April remain blackened and withered to September. The fuel appears to have been translocated to the underground organs and subsequently released into the surrounding substrates. This year's growth was destroyed in these plants, and it is unlikely that any of their below-ground organs remain viable. Sub-lethal effects have manifested themselves in terms of reduced productive and reproductive capacity of the lightly fueled plants. Seedlings of some annual species have invaded the site, but even these appear to be stunted in growth compared to seedlings in unaffected areas. Vegetative colonization by nearby plants may occur in these areas provided that the fuel residues are not concentrated enough to preclude further growth. *Juncus* appears to have had a slightly different response than the sedge. Although the above-ground components of *Juncus* contained high hydrocarbon levels, there did not appear to be the same transfer to below-ground components as with *Carex*. Initially we thought that this might allow the *Juncus* to regenerate from the below-ground organs. However, by July no regeneration had occurred, and the area was being colonized by *Lythrum* seedlings which were stunted and phenologically inhibited compared to nearby plants of the same species.

Therefore regardless of species, in the most severely affected areas, the original plant species been killed. The seedlings moving into the vacated habitats are responding by altered productive and reproductive capacity. In sites less severely affected the original plants are surviving, but also with reduced productive and reproductive capacities, and with some structural deformities.

The decrease in productivity as a consequence of oil contamination has been attributed to: breakage of plant stems as a consequence of additional weight from the oil; a reduction in transpiration as a consequence of stomatal and intercellular space blockage; a reduction in the movement of oxygen to the root environment; and a reduction in photosynthesis as a consequence of blockage of light and $C0_2$ diffusion (Ferrell et al. 1984). Most of these conditions appear more suited to a crude oil spill than a light oil. In the present study it appears that in the most heavily contaminated area, the plants were killed as a consequence of the toxicity of the fuel. The reduction in productivity as indicated in the less affected spill area may have involved reductions in transpiration or photosynthesis as indicated above, or may also have been a residual effect of the toxicity of the aromatics. The contortions displayed by the surviving plants tend to point to the latter.

Most of the marsh/oil studies have indicated that annuals fare more poorly than do perennials in an oiled environment. Annuals have small root systems and low food reserves, thus making recovery from oil pollution more difficult than for perennials which have rhizomes able to send forth new growth. In our study we found that having an extensive underground root system was not an asset in the heavily oiled sites as less than 1 % of the affected plants were able to send forth new shoots. However, annuals which were able to establish by seed were not very successful in the heavily oiled environments and had largely disappeared over the course of the summer.

The greenhouse studies were designed to discern between the effects of oil on the various plant components. The dipping of the plants allowed a rapid light coating of oil to take place, as if very high marsh plants had been washed by a wave covered by a slick of oil. The initial effect was death of some of the leaves, and a generally decreased vigour of the plant. Over the long term productivity was reduced compared to that of the control plants. These findings indicate that jet-fuel (A) has its strongest effect on new growth, both shoots and leaves. New shoots are likely to be killed outright, while more mature plants may be able to survive oiling with only a reduction in productivity. If plants are oiled late in the growing season, the greatest effect may be on plants such as *Carex lyngbyei* which are at this time producing new shoots for the following year. Only about 25% of the following year's growth is produced as overwintering shoots, nevertheless, loss of these shoots may dramatically affect productivity the following year, and may also provide a mechanism for the absorption of fuel into the underground components.

To summarize, it appears that different plant species have different responses to hydrocarbons. In the study area, the heavily oiled areas of *Carex* have shown no active growth as a consequence of the deposition of fuel on their shoots. In fact, those shoots affected in April remained blackened and withered throughout the growing season. The fuel appears to have been translocated to the underground organs and subsequently released into the surrounding substrates. This year's growth has been destroyed in these plants, and it is unlikely that any of their below-ground organs remain viable. Seedling of some annual species have invaded the site, but even these appear to be stunted in growth compared to seedlings in unaffected areas. Vegetative colonization by nearby plants may occur in these areas provided that the fuel residues are not concentrated enough to preclude further growth. *Juncus* had a slightly different response than the sedge. The above-ground components of *Juncus* contained high hydrocarbon levels, which did not appear to be transfered to below-ground components as in Carex. However, no regeneration occurred, and the former *Juncus* community was colonized by *Lythrum* seedlings which were stunted and phenologically inhibited compared to nearby plants of the same species. Therefore regardless of species, in the most severely affected areas, the original plant species been killed. The seedlings moving into the vacated habitats are responding by altered productive and reproductive capacity. In sites less severely affected the original plants are surviving, but also with reduced production, and with structural deformities.

A determinant of the severity of impact due to an oil spill appears to be the type of oil involved. In general, the lighter the oil the more toxic it is to the biota and the more rapidly spread and absorbed. Light oils have a severe effect on the environment regardless of when the spill occurs, but based on the current study as well as literature sources, it appears that the active growth period is the most sensitive for the vegetation communities. *Carex lyngbyei*, (ecologically one of the most important marsh plants in the Fraser River estuary) because of its habit of forming overwintering shoots may have a broader time of sensitivity to fuel spills than other perennials. Lighter oils tend to have a shorter persistence time in the environment than the heavy oils. The time it takes for the oil to reach the habitat is an important consideration. Weathered oil will cause less damage to the ecosystem and results in a shorter recovery time (Ganning et. al 1984). Small changes in factors such as the height of the tide, climatic conditions, wind direction etc. can all influence the severity of damage as a consequence of an oil spill.

Based on the results of this study, it appears that there is recovery taking place in the heavily oiled sites. However, some of this recovery has been transitory, as seedlings were unable to remain viable in the oil saturated substrates. At present, the communities which existed at the time of the fuel spill have been replaced by a very sparse population of different marsh species. It is unknown at the present time if these species will be able to persist and thus take over the ecological role of the previous communities, or if the original communities will ever be restored.

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Appendix 1: Hydrocarbon Analysis Results of Vegetation Samples from Vancouver Airport.

vironment Canada Lab# 880352 26-May-88

RESULTS FOR VANCOUVER AIRPORT SAMPLES

Parameter Analyzed	Units	Root A CL-1 880352-001	Root A CL-2 880352-002	Root A CL-3 880352-003	Root A CL-4 880352-004	Root A J-1 880352-005
DROCARBON IDENTIFICATION		-	-	-	-	-
DROCARBONS	ug/g(w)	643	270	294	128	234
LS & GREASES	ug/g(w)	667	435	357	134	491

Parameter Analyzed	Units	Root A J-2 880352-006	Root A J-3 880352-007	Root B CL-1 880352-008	Root B CL-2 880352-009	Root B CL-3 880352-010
DROCARBON IDENTIFICATION		-	-	-	-	-
DROCARBONS	ug/g(w)	71.5	75.7	59.3	178	249
LS & GREASES	ug/g(w)	194	190	296	958	1890

Parameter Analyzed	Units	Root B J-1 880352-011	Root B J-2 880352-012	Root B J-3 880352-013	Root C CL-1 880352-014	Root C CL-2 880352-015
'DROCARBON IDENTIFICATION		-	-	-	-	-
'DROCARBONS	ug/g(w)	221	245	50.9	47.6	42.2
LS & GREASES	ug/g(w)	1430	2010	208	172	99.0

Parameter Analyzed	Units	Root C CL-3 880352-016	Root C J-1 880352-017	Root C J-2 880352-018	Root C J-3 880352-019	Shoot A CL-1 880352-020
'DROCARBON IDENTIFICATION		-	-	-	-	-
'DROCARBONS	ug/g(w)	61.3	52.6	56.7	65.2	64.3
ILS & GREASES	ug/g(w)	76.5	114	87.3	73.9	1800

Parameter Analyzed	Units	Shoot A CL-2 880352-021	Shoot A CL-3 880352-022	Shoot A J-1 880352-023	Shoot A J-2 880352-024	Shoot A J-3 880352-025
YDROCARBON IDENTIFICATION		-	-	note	note	-
YDROCARBONS	ug/g(w)	115	36.2	1890	1970	1720
ILS & GREASES	ug/g(w)	4190	3770	2110	2400	2080

Appendix 1: Hydrocarbon Analysis Results of Vegetation Samples from Vancouver Airport (continued).

ıvironment Canada Lab# 880352 26-May-88

RESULTS FOR VANCOUVER AIRPORT SAMPLES

Parameter Analyzed	Units	Shoot B CL-1 880352-026	Shoot B CL-2 880352-027	Shoot B CL-3 880352-028	Shoot B J-1 880352-029	Shoot B J-2 880352-030
DROCARBON IDENTIFICATION		-	-	-	-	-
DROCARBONS	ug/g(w)	1070	777	593	274	329
LS & GREASES	ug/g(w)	1380	1250	956	620	902

Parameter Analyzed	Units	Shoot B J-3 880352-031	Shoot C CL-1 880352-032	Shoot C CL-2 880352-033	Shoot C CL-3 880352-034	Shoot C J-1 880352-035
'DROCARBON IDENTIFICATION		-	-	-	-	-
'DROCARBONS	ug/g(w)	273	1070	644	879	230
LS & GREASES	ug/g(w)	643	3200	2620	1840	565

Parameter Analyzed	Units	Shoot C J-2 880352-036	Shoot C J-3 880352-037
/DROCARBON IDENTIFICATION		-	-
'DROCARBONS	ug/g(w)	292	355
ILS & GREASES	ug/g(w)	682	532

Appendix 2: Hydrocarbon Analysis Results of Sediment Samples from Vancouver Airport (continued).

vironment Canada Lab# 880356 26-May-88

RESULTS FOR VAN. AIRPORT SAMPLES

Parameter Analyzed	Units	880356-001	880356-002	880356-003	880356-004	880356-005
DROCARBON IDENTIFICATION		note	-	-	-	-
DROCARBONS	ug/g	701	415	303	320	264
.S & GREASES	ug/g	703	465	398	382	339
SIDUE/FIXED (SEDIMENT)	mg/Kg	888000	908000	904000	919000	871000
SIDUE/VOLATILE (SEDIMENT)	mg/Kg	112000	92000	95600	81100	129000
ZE/ -0.063 MM (-230 MESH)	%	37.6	36.4	28.7	34.6	45.7
ZE/+0.063 MM (230 MESH)	%	11.7	10.7	8.4	15.8	15.1
ZE/+0.125 MM (120 MESH)	%	7.8	7.6	6.4	8.1	7.8
ZE/+0.25 MM (60 MESH)	%	9.5	7.7	7.8	7.3	7.6
ZE/+0.50 MM (35 MESH)	%	10.5	10	9.7	7.9	8.4
ZE/+1.0 MM (18 MESH)	%	9.4	9.9	9.6	10.3	7.9
ZE/+2.0 MM (10 MESH)	%	13.5	17.7	29.4	15.9	7.4
ZE/TOTAL WEIGHT	g	64.6	62	71.6	88.2	63.6

Parameter Analyzed	Units	880356-006	880356-007	880356-008	880356-009	880356-010
DROCARBON IDENTIFICATION		-	-	-	note	-
DROCARBONS	ug/g	215	274	593	706	565
LS & GREASES	ug/g	216	312	595	744	580
SIDUE/FIXED (SEDIMENT)	mg/Kg	938000	925000	927000	918000	943000
SIDUE/VOLATILE (SEDIMENT)	mg/Kg	62200	75400	73400	82100	57200
ZE/ -0.063 MM (-230 MESH)	%	40.5	30.5	36.9	34	36.8
ZE/+0.063 MM (230 MESH)	%	15.9	17.3	9	8.4	10.7
ZE/+0.125 MM (120 MESH)	%	8.1	8.8	9.6	6.7	7
ZE/+0.25 MM (60 MESH)	%	6.6	7.2	8.9	9.7	7.7
ZE/+0.50 MM (35 MESH)	%	9.1	9.5	10.2	16.9	11.3
ZE/+1.0 MM (18 MESH)	%	9.3	10.3	8.4	11.2	12
ZE/+2.0 MM (10 MESH)	%	10.5	16.3	17	12.9	14.4
ZE/TOTAL WEIGHT	g	83.4	76.7	70.7	42.6	66.5

Parameter Analyzed	Units	880356-011	880356-012
'DROCARBON IDENTIFICATION		-	-
'DROCARBONS	ug/g	214	366
LS & GREASES	ug/g	228	425
SIDUE/FIXED (SEDIMENT)	mg/Kg	944000	952000
SIDUE/VOLATILE (SEDIMENT)	mg/Kg	55600	48100
IZE/ -0.063 MM (-230 MESH)	%	40.7	35.9
IZE/+0.063 MM (230 MESH)	%	12.6	10.1
IZE/+0.125 MM (120 MESH)	%	6.5	5.8
IZE/+0.25 MM (60 MESH)	%	8.7	7.3
IZE/+0.50 MM (35 MESH)	%	10.5	9.3
IZE/+1.0 MM (18 MESH)	%	9.3	10.6
IZE/+2.0 MM (10 MESH)	%	11.7	20.9
IZE/TOTAL WEIGHT	g	69.7	98.7

Appendix 2: Hydrocarbon Analysis Results of Sediment Samples from Vancouver Airport.

vironment Canada Lab# 880351 26-May-88

RESULTS FOR VANCOUVER AIRPORT SAMPLES

Parameter Analyzed	Units	A-1 880351-001	A-2 880351-002	A-3 880351-003	B-1 880351-004	B-2 880351-005
DROCARBON IDENTIFICATION		-	-	note	-	-
DROCARBONS	ug/g	546	586	693	148	115
LS & GREASES	ug/g	855	951	693	148	115
SIDUE/FIXED (SEDIMENT)	mg/Kg	1946000	1947000	1957000	1908000	1919000
SIDUE/VOLATILE (SEDIMENT)	mg/Kg	153500	152700	143000	192100	180700
ZE/ -0.063 MM (-230 MESH)	%	26.7	27.5	22.6	26.7	22.7
ZE/+0.063 MM (230 MESH)	%	8	7.5	6.3	6.8	5.5
ZE/+0.125 MM (120 MESH)	%	4.2	3.8	5.1	5.6	6.2
ZE/+0.25 MM (60 MESH)	%	4.8	6.7	9.5	8.7	8.4
ZE/+0.50 MM (35 MESH)	%	9.2	10.4	12	10.4	14.2
ZE/+1.0 MM (18 MESH)	%	12.9	14	12.7	13.3	17
ZE/+2.0 MM (10 MESH)	%	34.2	30.1	31.8	28.6	26
ZE/TOTAL WEIGHT	g	84.7	87.3	117	48.6	58.8

Parameter Analyzed	Units	B-3 880351-006	C-1 880351-007	C-2 880351-008	C-3 880351-009
DROCARBON IDENTIFICATION		-	-	-	-
DROCARBONS	ug/g	157	290	569	394
LS & GREASES	ug/g	321	331	575	394
SIDUE/FIXED (SEDIMENT)	mg/Kg	1913000	1944000	1934000	1937000
SIDUE/VOLATILE (SEDIMENT)	mg/Kg	186600	156500	166200	162900
ZE/ -0.063 MM (-230 MESH)	%	21.9	39.4	29.7	34.2
ZE/+0.063 MM (230 MESH)	%	5.7	6.7	6	7.3
ZE/+0.125 MM (120 MESH)	%	5.5	5.6	4.2	5.9
ZE/+0.25 MM (60 MESH)	%	10.4	7.3	6.4	8.4
ZE/+0.50 MM (35 MESH)	%	13	10.6	9.3	13.4
ZE/+1.0 MM (18 MESH)	%	14.1	11.8	13.4	15.9
ZE/+2.0 MM (10 MESH)	%	29.4	18.4	31	14.9
ZE/TOTAL WEIGHT	g	60.1	82.9	89.7	79.2

Appendix 2b: HYDROCARBON CHANGES WITH DEPTH AT TWO LOCATIONS WITHIN SITE A
'April 1988'

Unvegetated Station

	Hydrocarbons [ug/g]	Oils & Greases[ug/g]
0-10 cm	701	708
10-20 cm	415	465
20-30 cm	303	398
30-40 cm	320	382
40-50 cm	264	339
50-60 cm	215	216

Vegetated Station

	Hydrocarbons [ug/g]	Oils & Greases[ug/g]
0-10 cm	274	312
10-20 cm	593	595
20-30 cm	706	744
30-40 cm	565	580
40-50 cm	214	228
50-60 cm	366	415

Appendix 3: Stem Measurements [cm] at Jet-Fuel Sampling Stations

C.l.St'n A- heavy fuel	C.l.St'n A- light fuel	S.v. St'n A heavy fuel	S.v. St'n A light fuel	S.v. St'n B	C.l. St'n B Rep. #1	C.l. St'n B Rep. #2	C.l. St'n B Rep. #3	C.l. St'n C Rep. #1	C.l. St'n C Rep. #2	C.l. St'n C Rep. #3
84	120.5	150	148	205	149	172	181	161	160	125
89	114	151	187	218	184	166.5	154	162	176	142
100	128	148	177	189	177	142.5	127	164	173.5	134
110	128.5	122	165	200	146	149.5	173	175	157	164.5
94	111	128	178	210	153.5	150.5	139	144	139	145.5
93.5	119	143	163	220	177.5	163.5	142	155	160	138
87	115	145	182	212	152	168	126	171	158	131.5
73.5	122	156	187	198	153.5	159.5	134	166	157	166
78.5	124.5	138	173	175	138	148	128	165.5	151	162.5
77	119	137.5	185	207	177	150	136.5	155.5	158	166.5
64	111 •	•	•		169.5	161.5	141	151	156	143
67	134.5 •	•	•		173	153	155	157.5	159	142
93	120 •	•	•		161	148	137	147.5	138	158
78	121 •	•	•		166	167	128	147	144	154
59.5	122.5 •	•	•		179.5	149.5	154	166	138.5	151
94.5	117 •	•	•		160	147	125	143	155.5	142
80.3	130 •	•	•		145.5	142	142	162	149.5	159.5
73	122 •	•	•		175.5	152.5	138	153	136	152
80.5	128 •	•	•		153.3	146.5	149	162	157.5	154.5
78	112 •	•	•		125	139	151.5	174.5	176.5	155

Appendix 4: Jet-Fuel Quadrat [0.1m²] Measurements [July]

Site	# Veg. Stems	# Dead Stems	# Repr. Stems	Dry Wt.[g] Shoot	Dry Wt.[g] Root
A1	4	10	0	15	35
A2	0	7	0	0	43
A3	0	13	0	0	22
B1	45	0	4	125	30
B2	54	0	2	140	27
B3	70	0	2	210	40
C1	48	0	1	145	25
C2	54	0	3	150	22
C3	62	0	4	175	35
Mean ± 1 S.D.					
A	1.3 ± 2.3		0	5.0 ± 8.6	33.3 ± 10.6
B	56.3 ± 12.7		2.7 ± 1.2	158.3 ± 45.0	32.3 ± 6.8
C	54.7 ± 7.0		2.7 ± 1.5	156.0 ± 16.0	27.3 ± 6.8

Appendix 5: Jet-Fuel Quadrat [0.1m^2] Measurements [September]

Site	# Veg. Stems	# Repr. Stems	Dry Wt.[g] Shoot	Dry Wt.[g] Root
A1	0	0	0	30 [dead]
A2	5	0	10	22 [partially dead]
A3	1	0	2	16 [mostly dead]
B1	47	2	110	32
B2	53	3	122	27
B3	68	2	150	35
C1	65	4	144	33
C2	50	1	137	25
C3	53	3	140	30
Mean ± 1 S.D.				
A	2 ± 2.6	0	4 ± 5.3	22.7 ± 7.0
B	56 ± 10.8	2.3 ± 0.6	127.3 ± 20.5	31.3 ± 4.0
C	56 ± 7.9	2.7 ± 1.5	140.3 ± 3.5	29.3 ± 4.0

Appendix 6: ANOVA of *Carex lyngbyei* July quadrats - Site vs Biomass.

One Factor ANOVA X_1: SITE Y_3: SHOOT BIOMASS

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	46516.667	23258.333	29.174
Within groups	6	4783.333	797.222	p = .0008
Total	8	51300		

Model II estimate of between component variance = 11230.556

One Factor ANOVA X_1: SITE Y_3: SHOOT BIOMASS

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
A	3	5	8.66	5
B	3	158.333	45.369	26.194
C	3	156.667	16.073	9.28

One Factor ANOVA X_1: SITE Y_3: SHOOT BIOMASS

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
A vs. B	-153.333	56.418*	22.118*	6.651
A vs. C	-151.667	56.418*	21.64*	6.579
B vs. C	1.667	56.418	.003	.072

* Significant at 95%

Appendix 7: ANOVA of *Carex lyngbyei* July quadrats - Site vs Number of Vegetative Stems.

One Factor ANOVA X_1: SITE Y_1: *VEG. ST

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	5872.222	2936.111	40.969
Within groups	6	430	71.667	p = .0003
Total	8	6302.222		

Model II estimate of between component variance = 1432.222

One Factor ANOVA X_1: SITE Y_1: *VEG. ST

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
A	3	1.333	2.309	1.333
B	3	56.333	12.662	7.311
C	3	54.667	7.024	4.055

One Factor ANOVA X_1: SITE Y_1: *VEG. ST

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
A vs. B	-55	16.916*	31.657*	7.957
A vs. C	-53.333	16.916*	29.767*	7.716
B vs. C	1.667	16.916	.029	.241

* Significant at 95%

Appendix 8: ANOVA of *Carex lyngbyei* July quadrats - Site vs Number of Reproductive Stems.

One Factor ANOVA X_1: SITE Y_2: *REPR. ST.

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	14.222	7.111	5.818
Within groups	6	7.333	1.222	p = .0394
Total	8	21.556		

Model II estimate of between component variance = 2.944

One Factor ANOVA X_1: SITE Y_2: *REPR. ST.

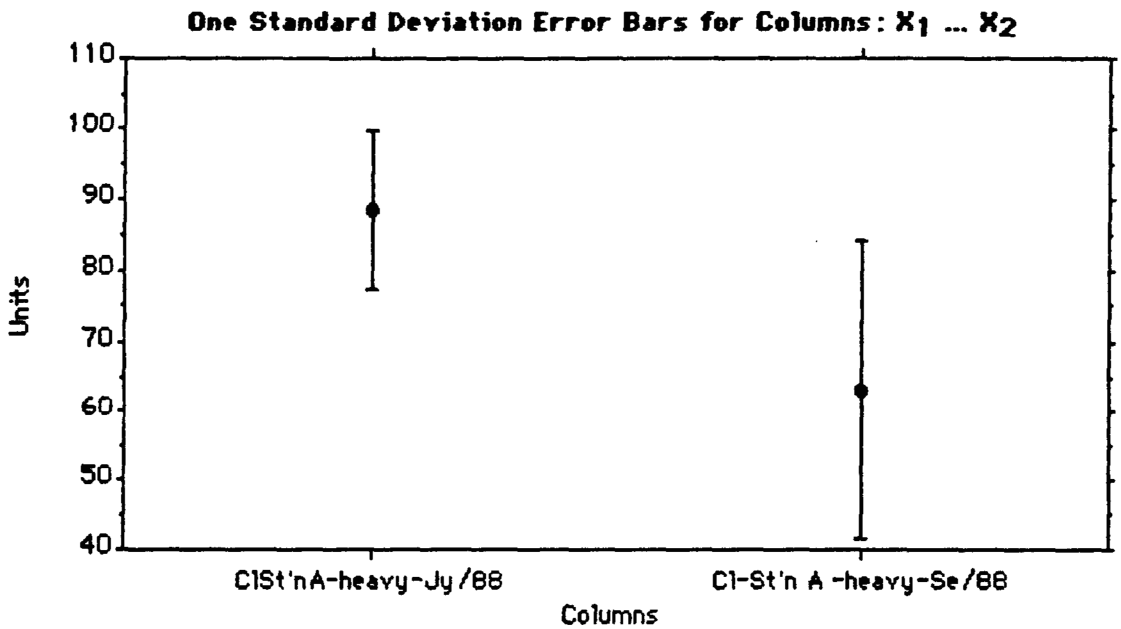
Group:	Count:	Mean:	Std. Dev.:	Std. Error:
A	3	0	0	0
B	3	2.667	1.155	.667
C	3	2.667	1.528	.882

One Factor ANOVA X_1: SITE Y_2: *REPR. ST.

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
A vs. B	-2.667	2.209*	4.364	2.954
A vs. C	-2.667	2.209*	4.364	2.954
B vs. C	0	2.209	0	0

* Significant at 95%

Appendix 9: **Comparison of *Carex lyngbyei* stem lengths in July and September at a heavily fueled site.**



Appendix10: ANOVA of *Scirpus validus* stem measurements in July at a heavily and lightly fueled site.

One Factor ANOVA X_1: Treat Y_1: July

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	5313.8	5313.8	39.21
Within groups	18	2439.4	135.522	p = .0001
Total	19	7753.2		

Model II estimate of between component variance = 5178.278

One Factor ANOVA X_1: Treat Y_1: July

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
S.v.-heavily oiled	10	141.9	10.619	3.358
S.v.-lightly oiled	10	174.5	12.581	3.978

One Factor ANOVA X_1: Treat Y_1: July

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
S.v.-heavil... vs. S.v.-lig...	-32.6	10.939*	39.21*	6.262

* Significant at 95%

Appendix11: ANOVA of *Scirpus validus* stem measurements in September at a heavily and lightly fueled site.

One Factor ANOVA X_1: Treat Y_2: September

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	17169.8	17169.8	82.937
Within groups	18	3726.4	207.022	p = .0001
Total	19	20896.2		

Model II estimate of between component variance = 16962.778

One Factor ANOVA X_1: Treat Y_2: September

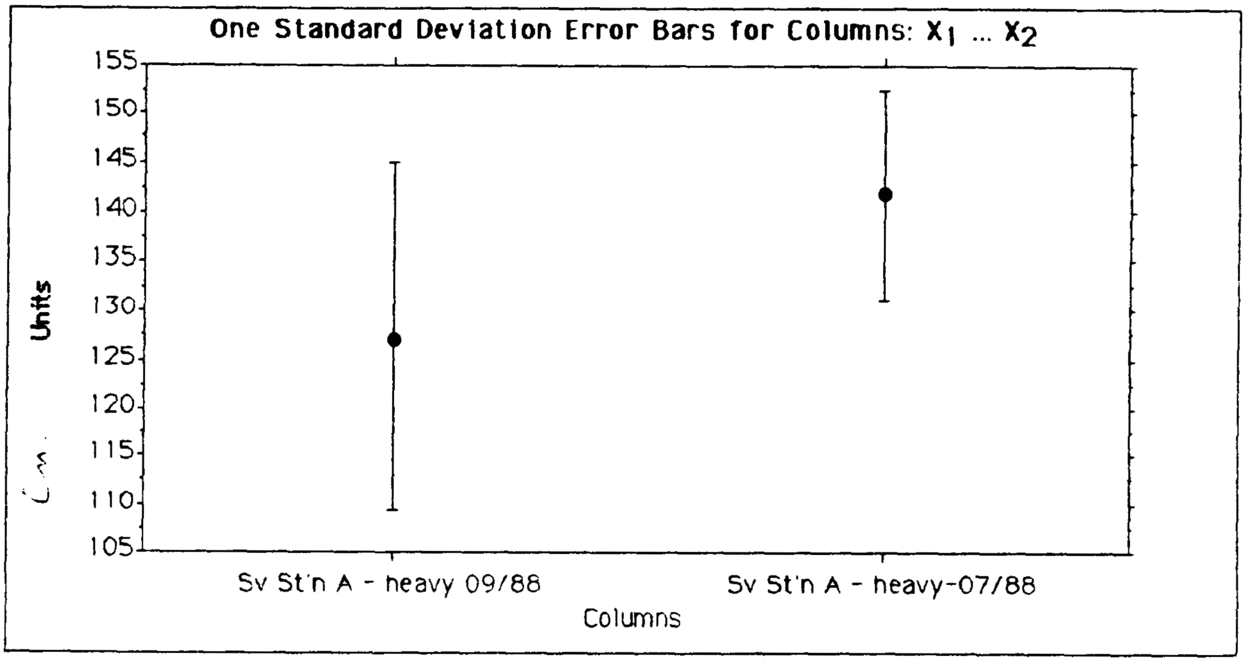
Group:	Count:	Mean:	Std. Dev.:	Std. Error:
S.v.-heavily oiled	10	125	16.647	5.264
S.v.-lightly oiled	10	183.6	11.702	3.7

One Factor ANOVA X_1: Treat Y_2: September

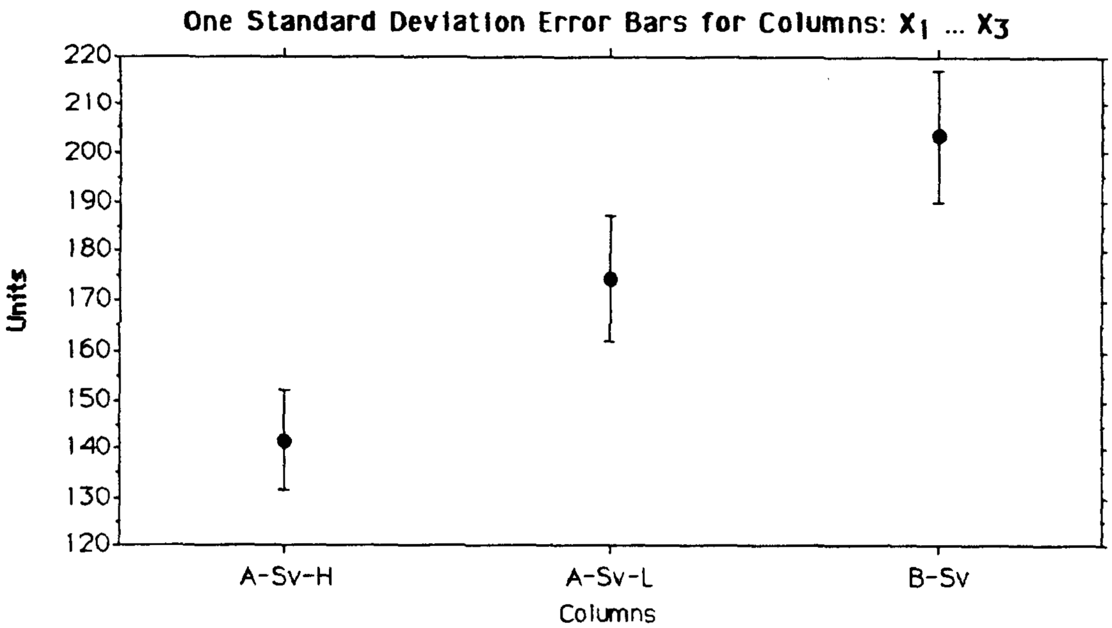
Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
S.v.-heavil... vs S.v.-lig...	-58.6	13.52*	82.937*	9.107

* Significant at 95%

Appendix 12: **Comparisons of *Scirpus validus* heights at a heavily fueled sites in July and September 1988.**



Appendix 13: **Comparisons of *Scirpus validus* heights at heavily and lightly fueled sites at Station A, and at Station B, Vancouver Airport.**



Appendix 14: Comparisons of *Carex lyngbyei* above-ground biomass to stem density [averaged over all stations], Vancouver Airport.