

# **OIL SPILL RESPONSE TECHNIQUES FOR BC COASTAL WETLANDS**

**January 2006**



*Cover Photo:*  
*Portion of Chemainus River Estuary, east coast Vancouver Island, 2004*

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## SUMMARY

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The risk of accidental oil spills in British Columbia coastal waters will increase in the future as a result of (a) proposed oil exports from British Columbia, (b) increased marine shipping and large vessel traffic and (c) proposed offshore oil exploration and production. Coastal and estuarine wetlands are special features that are particularly sensitive to oil spill impact and cleanup. These features are relatively uncommon on the coast, comprising less than 10% of the total coastline length, are known to retain significant amounts of oil when inundated by a spill, are difficult to cleanup and are important wildlife habitat.

The BC ShoreZone system maps the occurrence and linear extent of coastal wetlands but does not generally subcategorize or classify wetland types or document aerial extent of the wetlands. The classification system of MacKenzie and Moran (2004) identifies typical vegetation assemblages (*site associations*) of BC wetlands but has not been used as a mapping framework. Actually there is no uniform mapping and classification system that has been applied to BC coastal wetlands and most remain unclassified.

No specific studies of oil spill effects or impacts on BC wetland species assemblages were found. Much of the research of effects of wetland oil spill and cleanup techniques has been done in *Spartina*-dominated areas. *Spartina* has very different morphology and characteristics than any native Pacific Northwest wetland vegetation, making it difficult to extrapolate those studies to BC situations. Studies of BC examples of wetlands oil spill and clean up effects are recommended, to evaluate the response of local species to these disturbances. The results of those studies could potentially be extrapolated to other areas in southeast Alaska or northern Washington where similar wetland species assemblages occur.

For the purposes of spill response planning, three broad categories of BC coastal wetlands were identified based on general characteristics: (a) *riverine, spatially complex wetlands* (e.g., Fraser River Delta, Cowichan River delta) where estuarine wetlands have developed complex patterns in the meandering channels of the deltas, (b) *alluvial delta wetlands*, where fringing wetlands occur along the upper intertidal area of the numerous alluvial fans on the otherwise steep coastline (e.g., west coast Vancouver Island, and Haida Gwaii) and (c) *marine lagoon/tidal flat wetlands* that are typically associated with spit and lagoon complexes. These general wetlands types provide a useful framework for generic spill response planning.

In terms of spill countermeasure planning, general guidelines typically recognize the uniqueness of each wetland setting and that wetlands are very sensitive to cleanup operations (Hoff 1995b). It can be expected in BC that each wetland will be considered distinct, and a site-specific cleanup plan will be developed on a site-by-site basis. In general, the *riverine, spatially complex wetlands* have the finest substrate that is sensitive to trampling during a cleanup; trampling can permanently damage plants, root structure and may push surface oil into the subsurface. Alluvial delta wetlands and lagoon/tidal flat

wetlands may have more coarse sediment and support more traffic. Trampling can be reduced by using boards placed on top of the wetland or by using flat-bottom boats to access the site on a rising tide. Manual and hydraulic cleanup techniques are likely to be the most widely used countermeasures; with vacuuming of pooled oil, raking of oiled debris and low-pressure flushing to remove loose oil being the most commonly used techniques. Cutting of oiled vegetation requires knowledge of the species sensitivity. Burning has been used on some wetland spills but most burning has been conducted on *Spartina alterniflora*, a species not represented in BC. Decisions about burning will have to be based on specific site conditions and in consultation with wetland ecologists. Non-*Spartina* burn treatments have shown wetlands to be re-established within 3-15 years after burning. Bioremediation is another cleanup technique that could be applied in BC wetlands, however specific species information about BC plant communities that would respond to this cleanup, or details of species to use as 'bio-remediators' is lacking.

Should small areas of wetland have to be removed, there are some examples of small areas of BC wetland restoration. Habitat compensation programs suggest that approximately 5 years or more are required to establish a climax-type wetland vegetation complex.

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Coastal and estuarine marshes are known to be a critical coastal habitat for wildlife and some marine fish. In BC, estuarine wetlands are relatively rare – estimated at about 2% of the shoreline in the Strait of Georgia (Harper *et al* 1991, 1992), 11% on the West Coast of Vancouver Island (Harper and Howes, 1997), 6% on Haida Gwaii (Queen Charlotte Islands; Harper *et al* 2005) and only 3% in the southern Gulf Islands (Coastal & Ocean Resources and Archipelago Marine Research, 2005). The rarity of estuarine marshes on the BC coast and significance as a critical habitat makes coastal marshes an especially important habitat in terms of resource management.

The risk to coastal marshes from oil spills in British Columbia is increasing, primarily due to the increase in vessel traffic along the coast. The Alaskan cruise ship industry has been steadily increasing with hundreds of cruise ship transits through the inland waterways. These ships have very large bunker capacities, travel close to shore – all contributing to increased risk of spills. In addition, there are currently proposals for development of a superport to ship oil to China, for offshore drilling, major expansion of the Roberts Bank container port, and for development of a large container port in Prince Rupert. All of the initiatives will increase the risk of oil spills to sensitive coastal environments.

Coastal marshes are known to be highly sensitive to oil spill impacts (Baker *et al* 1993; Fischel *et al* 1989; Hoff 1995a & b; Mendelson *et al* 1990; Vandermeulen 1981; 1986) as well as to impacts associated with the cleanup of oil spills (Hoff 1995a & b; Zengel and Michel 1995). However, there remains a question of how BC coastal wetlands differ significantly from wetlands in other regions where oil spill impacts have occurred and if there are differences, whether they might lead to different treatment options. As such it is speculative to apply impact results and treatment recommendations until the sensitivity of BC marsh types can be defined in terms of potential oil spill impact. Observations of the small estuarine marshes in BC indicate that there is rarely an organic soil horizon, which is very common in many of the marshes that have been studied for spill impact; this may make the BC model more of an oil-sediment problem than an oil-vegetation or oil-peat problem as is common in other wetland areas where oil spill risk and contamination work has been done (e.g., Louisiana).

In fact, conditions in BC wetlands are likely quite comparable to other areas of the Pacific northwest, including northern state of Washington (i.e., north Puget Sound and Juan de Fuca Strait) as well as wetlands in southeast Alaska. Vegetation assemblages and the general morphologic characteristics will be more similar to BC than those on the Gulf Coast or eastern US, where coastal wetlands tend to be dominated by *Spartina*, a species which does not dominate wetlands in BC.

## 1.1 Objectives

The overall goal of this project is to improve our ability to respond to oil spills in BC wetlands. Specific objectives are:

- develop a summary of BC wetlands that is relevant to oil spill response; this will include a review of existing classification approaches to identify attributes and variables considered to be significant for spill assessment and response.
- review existing publications on oil spill impacts to coastal wetlands and assess applicability to the BC situation. The reviews of regional spills in Puget Sound (Hoff 1995a & b; Robilliard, pers.comm. 2004) are considered particularly appropriate.
- review restoration approaches that have been used for re-establishing salt and brackish marshes as part of non-oil spill examples of restoration programs or habitat compensation sites, assessing usefulness to apply to spill countermeasures.

## 2.0 BACKGROUND INFORMATION

### 2.1 Classification of Estuaries

There are no known inventories of BC estuaries that categorize estuary type in terms of some systematic classification system, including a description of wetlands. The 1:50,000 BC wetlands classification appears to show few estuarine or marine wetlands (see: <http://www.shim.bc.ca/atlas/wetland/main.htm>). The BC ShoreZone classification (Howes *et al* 1994<sup>1</sup>) provides a detailed picture of the distribution as coastal estuaries, as indicated by the presence of wetland vegetation; however, there are no different classes of estuary provided by this classification.

There are a number of inventories where vegetation maps have been produced of wetlands areas within estuaries and these inventory programs are described below. Environment Canada is presently compiling coastal wetland maps as part of the Pacific Estuary Conservation Program (PECP; Ryder *et al* 2004) but this system does not include any classes of wetlands but rather is a GIS, polygon-based inventory procedure of estuarine wetlands.

### 2.2 Classification of Wetland Types

#### MacKenzie and Moran

The classification of estuarine wetlands in BC has recently been addressed in the recently published in *Wetlands of British Columbia, Guide to Identification* (MacKenzie and Moran 2004). MacKenzie and Moran (2004) provide an overall classification framework for both freshwater and saline wetlands. The *Estuarine Realm* classification is based on salinity and elevation classes (Fig. 1). Mackenzie and Moran (2004) identify six *site associations* that fall within this classification framework, where each of the site associations is described in terms of dominant and associated species, species diversity, soil development, elevation, and salinity regimes. A typical site association is illustrated in Figure 2 and a summary of typical species association is provided in Figure 3.

|            |        | Salinity          |                   |       |       |     |        |
|------------|--------|-------------------|-------------------|-------|-------|-----|--------|
|            |        | Fresh             | Oligo-            | Meso- | Poly- | Eu- | Hyper- |
| Tidal Zone | Upper  | Wetland – Marshes | Estuarine Meadows |       |       |     |        |
|            | Middle |                   | Estuarine Marshes |       |       |     |        |
|            | Lower  |                   | Tidal Flats       |       |       |     |        |

Figure 1. Classification rationale for the Estuarine Realm wetlands (Mackenzie and Moran 2004).

<sup>1</sup> mapping data at: [http://maps.gov.bc.ca/imf406/imf.jsp?site=dss\\_coastal](http://maps.gov.bc.ca/imf406/imf.jsp?site=dss_coastal)



### General Description

Glasswort – Sea-milkwort stands are found in the Georgia Depression and outer coastal areas on sandy or pebbly deposits at the lowest edge of intertidal vegetation. These sites experience daily and prolonged flooding by strongly brackish water.

Species diversity is low; typically only *Salicornia virginica* and *Glaux maritima* are found in abundance. Small patches of *Distichlis spicata* or *Ruppia maritima* may occur. Plant cover can be continuous or open.

Soils are often fine textured but with a pebbly or gravelly layer that provides better drainage.



### Characteristic Vegetation

**Tree layer** (0 - 0 - 0)

**Shrub layer** (0 - 0 - 0)

**Herb layer** (15 - 50 - 80)

*Distichlis spicata*, *Glaux maritima*,  
*Salicornia virginica*

**Moss layer** (0 - 0 - 0)

### Comments

The **Em02** is tolerant of eusaline conditions and may be found outside of estuary influence in protected embayments with low wave power. It is often found adjacent to the **Em03**, which occurs on more poorly drained materials, or the **Em01**, which tolerates more prolonged flooding and continuous soil saturation.

### Estuarine Grid

|            | Salinity |        |       |       |     |        |
|------------|----------|--------|-------|-------|-----|--------|
|            | Fresh    | Oligo- | Meso- | Poly- | Eu- | Hyper- |
| Tidal Zone | Upper    |        |       |       |     |        |
|            | Middle   |        |       |       |     |        |
|            | Lower    |        |       |       |     |        |

Figure 2. Example of the description for the **Glasswort Site Association** (from Mackenzie and Moran 2004).

| Species |                                               | Em01 | Em02 | Em03 | Em04 | Em05 |
|---------|-----------------------------------------------|------|------|------|------|------|
| terbs   | <i>Ruppia maritima</i>                        |      |      |      |      |      |
|         | <i>Eleocharis palustris</i>                   |      |      |      |      |      |
|         | <i>Lilaeopsis occidentalis</i>                |      |      |      |      |      |
|         | <i>Glaux maritima</i>                         |      |      |      |      |      |
|         | <i>Salicornia virginica</i>                   |      |      |      |      |      |
|         | <i>Distichlis spicata</i> var. <i>spicata</i> |      |      |      |      |      |
|         | <i>Spergularia canadensis</i>                 |      |      |      |      |      |
|         | <i>Atriplex patula</i>                        |      |      |      |      |      |
|         | <i>Plantago maritima</i>                      |      |      |      |      |      |
|         | <i>Puccinellia pumila</i>                     |      |      |      |      |      |
|         | <i>Agrostis stolonifera</i>                   |      |      |      |      |      |
|         | <i>Carex lyngbyei</i>                         |      |      |      |      |      |
|         | <i>Potentilla ogedii</i>                      |      |      |      |      |      |
|         | <i>Deschampsia cespitosa</i>                  |      |      |      |      |      |
|         | <i>Triglochin maritima</i>                    |      |      |      |      |      |
|         | <i>Juncus arcticus</i>                        |      |      |      |      |      |
|         | <i>Plantago macrocarpa</i>                    |      |      |      |      |      |
|         | <i>Hordeum brachyantherum</i>                 |      |      |      |      |      |
|         | <i>Angelica lucida</i>                        |      |      |      |      |      |
|         | <i>Agrostis exarata</i>                       |      |      |      |      |      |
|         | <i>Cicuta douglasii</i>                       |      |      |      |      |      |
|         | <i>Aster subspicatus</i>                      |      |      |      |      |      |
|         | <i>Conioselinum gmelinii</i>                  |      |      |      |      |      |
|         | <i>Festuca rubra</i>                          |      |      |      |      |      |
|         | <i>Lathyrus palustris</i>                     |      |      |      |      |      |
|         | <i>Ranunculus orthorhynchus</i>               |      |      |      |      |      |
|         | <i>Sium suave</i>                             |      |      |      |      |      |
|         | <i>Lupinus nootkatensis</i>                   |      |      |      |      |      |
|         | <i>Achillea millefolium</i>                   |      |      |      |      |      |
|         | <i>Trifolium wormskioldii</i>                 |      |      |      |      |      |
|         | <i>Poa trivialis</i>                          |      |      |      |      |      |

| Em06 | Ed01 | Ed02 | Ed03 | Common Name               |
|------|------|------|------|---------------------------|
|      |      |      |      | widgeon-grass             |
|      |      |      |      | common spike-rush         |
|      |      |      |      | western lilaeopsis        |
|      |      |      |      | sea-milkwort              |
|      |      |      |      | American glasswort        |
|      |      |      |      | seashore saltgrass        |
|      |      |      |      | Canadian sandspurry       |
|      |      |      |      | common orache             |
|      |      |      |      | sea plantain              |
|      |      |      |      | dwarf alkaligrass         |
|      |      |      |      | creeping bentgrass        |
|      |      |      |      | Lyngbye's sedge           |
|      |      |      |      | coast silverweed          |
|      |      |      |      | tufted hairgrass          |
|      |      |      |      | seaside arrow-grass       |
|      |      |      |      | arctic rush               |
|      |      |      |      | Alaska plantain           |
|      |      |      |      | meadow barley             |
|      |      |      |      | seacoast angelica         |
|      |      |      |      | spike bentgrass           |
|      |      |      |      | Douglas' water-hemlock    |
|      |      |      |      | Douglas' aster            |
|      |      |      |      | Pacific hemlock-parsley   |
|      |      |      |      | red fescue                |
|      |      |      |      | marsh peavine             |
|      |      |      |      | straight-beaked buttercup |
|      |      |      |      | hemlock water-parsnip     |
|      |      |      |      | Nootka lupine             |
|      |      |      |      | yarrow                    |
|      |      |      |      | springbank clover         |
|      |      |      |      | rough bluegrass           |

Figure 3. Site Associations (e.g., Em01, Em02, etc.) and relative abundance of typical species associations (from Mackenzie and Moran 2004).

The MacKenzie and Moran (2004) wetland classification is the most structured, detailed and well documented for the province and should provide the primary framework for development of oil spill response options for BC. The classification system is not, however, designed as a mapping system and there has been no attempt to use it as a mapping system to date. The species association table (Figure 3) provides an important summary of species associated with each *site association*; in that spill treatment is very species sensitive for wetlands (Hoff 1995b), this chart provides a useful guide as to potential treatment strategies.

### FREMP

The Fraser River Estuary Management Program (FREMP<sup>2</sup>) has developed a wetland classification for the Fraser River delta in southern BC. The basic system is summarized in Table 1. Unfortunately, there is no *site association* or plot description of the various vegetation communities, although they have been mapped in detail (1:2,500 scale). The lack of a related species association table to the classification and map types (Table 1) limits the potential use of this classification for spill response. *It is recommended that Environment Canada evaluate the potential of developing a site association description, using the framework of MacKenzie and Moran (2004) for the FREMP classification and mapping categories.* Such a site association description would be extremely useful in the development of spill response treatment options.

**Table 1 FREMP Classification Structure**

| <i>1st Order</i> | <i>2nd Order</i>         | <i>Community</i>                                                                                                       |
|------------------|--------------------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Regime</b>    | <b>Map Feature</b>       | <b>Vegetation</b>                                                                                                      |
| Tidal            | Subtidal                 | eelgrass                                                                                                               |
|                  | Mudflat                  | unvegetated<br>eelgrass                                                                                                |
|                  | SandFlat                 | unvegetated<br>eelgrass                                                                                                |
|                  | Marsh                    | reed-canary grass<br>mixed reed-canary & other grasses<br>other grasses<br>sedges<br>rushes<br>other forbs<br>cattails |
| Riparian         | Marsh                    | other grasses<br>wet grasses & herbs                                                                                   |
|                  | Grasses & Shrubs & herbs | dry grass/herbs<br>wet grass/herbs<br>low shrubs<br>high shrubs<br>cryptogram                                          |
|                  | Trees                    | coniferous trees<br>deciduous trees<br>mixed conifers and deciduous                                                    |

<sup>2</sup> [http://www.bieapfrempp.org/main\\_frempp.html](http://www.bieapfrempp.org/main_frempp.html)

## 2.3 Mapping of Wetlands

### ShoreZone

Probably the most comprehensive inventory of coastal wetlands, outside of the Fraser Delta, is from the ShoreZone project. This inventory, based on low-tide, video imaging surveys, identifies wetlands (including those less than 100m in shoreline length) and has been applied throughout the province (Howes *et al* 1994<sup>3</sup>). There is no polygon mapping and map features are indicated only as line segments (Figure 4). There is dimensional information on each wetland (length and width) and classification into lower and upper marshes as per the across-shore classification (Howes *et al* 1994). Biological attributes are also mapped, including the presence of specific wetland species assemblages (as *biobands*) and the classification of the 'estuary' habitat category.

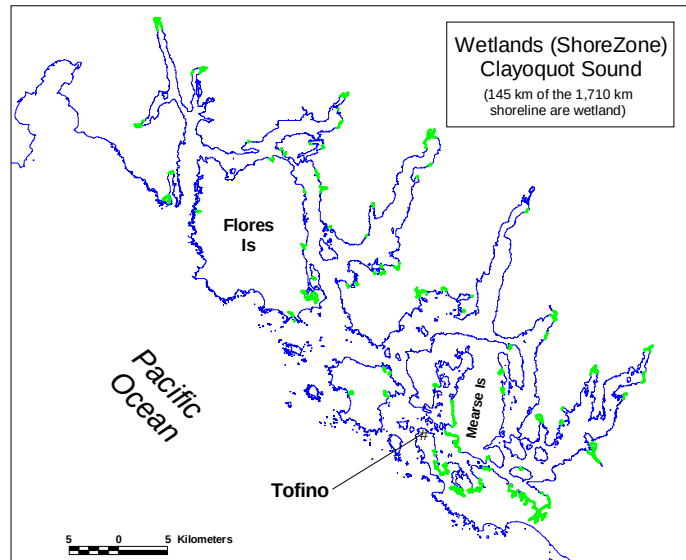


Figure 4. Location of wetlands in Clayoquot Sound on the West Coast of Vancouver Island based on ShoreZone mapping (BC Class 31). Specific mapping data on length, width and occurrence of low marsh and high marsh is available for each wetland segment.

The dataset is web accessible and useful for providing a general spatial picture of wetland occurrence and some information on wetland type.

### Hunter *et al* (1983)

The provincial government developed an estuary habitat mapping system in the early 1980s and the system has been applied to a number of BC estuaries. The system maps three marsh categories (Figure 5) but provides only the most rudimentary site associations of the map types (Table 2). There are digital GIS files of the mapping for the Campbell River, Comox, Cowichan, Nanaimo and Squamish estuaries and there may be paper copies of additional estuaries.

### FREMP

The Fraser River Estuary Management Program (FREMP) has conducted extensive, detailed (1:2,500) scale mapping of the Fraser River estuary. A sample map is provided in Figure 6. Vegetation assemblages associated with the map types are only very generally described and there is no species or site association description beyond a most general description (Table 1.)

<sup>3</sup> mapping data at: [http://maps.gov.bc.ca/imf406/imf.jsp?site=dss\\_coastal](http://maps.gov.bc.ca/imf406/imf.jsp?site=dss_coastal)

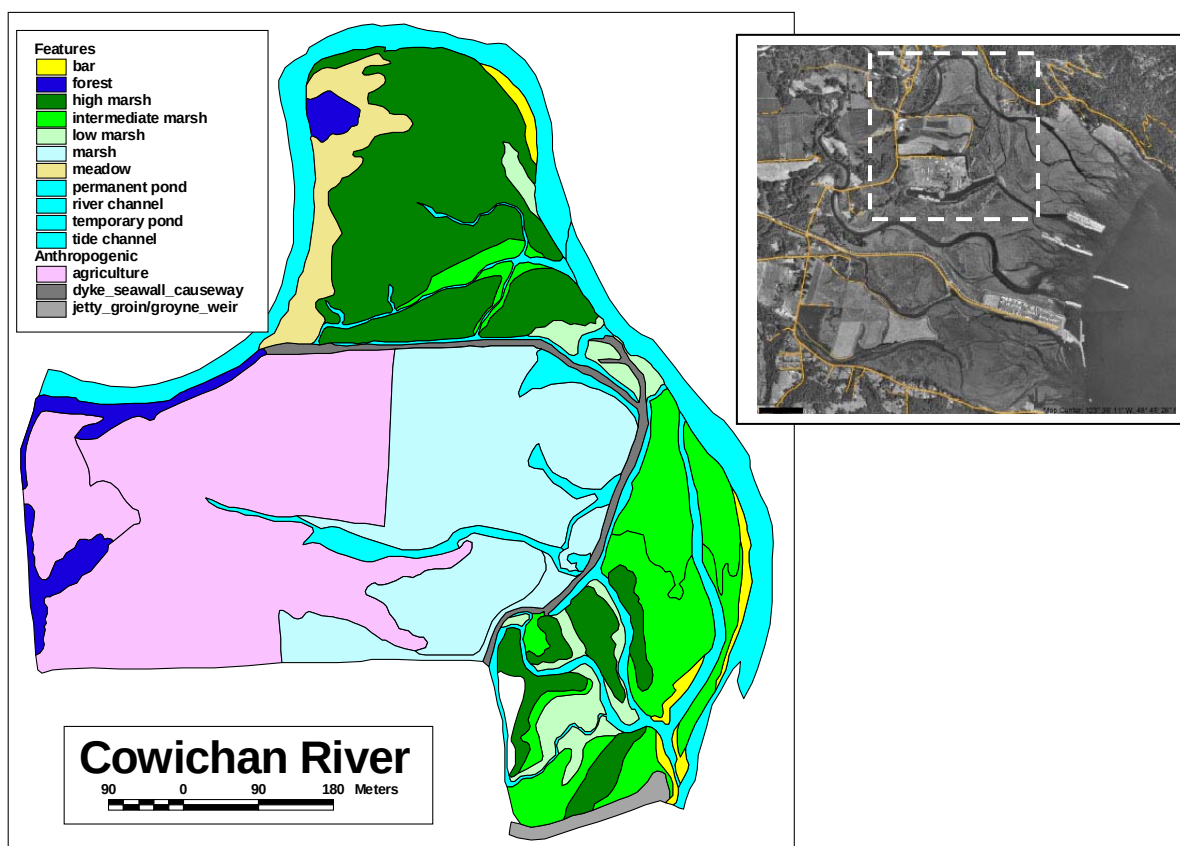


Figure 5 Vegetation mapping of the northern portion of the Cowichan delta following the classification of Hunter *et al* 1983 (electronic mapping part of the DFO estuaries inventory program; Levings, pers. com., 1995)

**Table 2 Marsh Types of Hunter *et al* (1983)**

| Marsh Type<br>(data code)      | Description                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Marsh (ma)</i>              | a generally low gradient area which supports significant (>15%) non-woody vascular vegetation for at least part of the year and is characterized by a surface accumulation of organic material deposited in water. Three types of marsh commonly exist within the intertidal zone.                                                                                                                           |
| <i>High Marsh (mh)</i>         | An intertidal marsh covered by most high tides. Some soil development and organic buildup is obvious. Such areas often exhibit a high diversity of plant species dominated by grasses and forbes, e.g., Pacific small reed grass; creeping bent grass; marsh pea vine; and parsley family members. The upper portion of the high marsh may be bounded by berm/beach face, storm ridge, shrub carr or forest. |
| <i>Intermediate Marsh (mi)</i> | An intertidal marsh covered by all high tides and some moderate tides. Such areas are transitional in nature with regard to plant species diversity and soil development. They are usually dominated by grasses, sedges and rushes.                                                                                                                                                                          |
| <i>Low Marsh (ml)</i>          | An intertidal marsh exposed at low tides and covered at most moderate and all high tides. Such areas are characterized by: little or no soil development; low species diversity; hydrophyllic and halophytic pioneer species; and often discontinuous cover. Commonly dominated by sedges, glasswort, sea-milkwort and/or sea plantain.                                                                      |



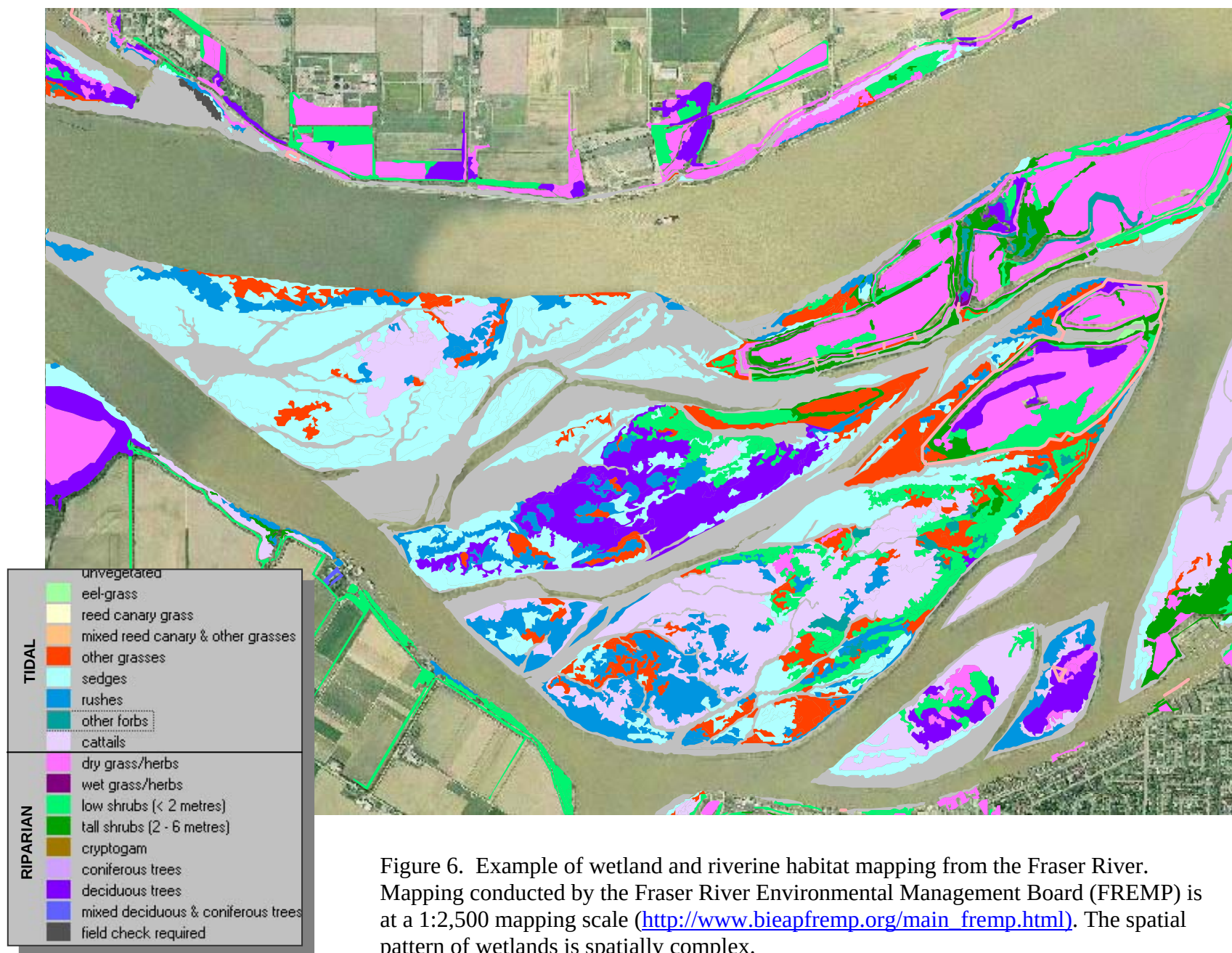


Figure 6. Example of wetland and riverine habitat mapping from the Fraser River. Mapping conducted by the Fraser River Environmental Management Board (FREMP) is at a 1:2,500 mapping scale ([http://www.bieapfremf.org/main\\_fremf.html](http://www.bieapfremf.org/main_fremf.html)). The spatial pattern of wetlands is spatially complex.

## Others

There have been a variety of other estuary mapping projects in BC, some of which have included site or plot associations of vegetation types. Dawes and White's (1982) maps of the Little Qualicum River is an example of a project that included detailed descriptions of mapping data (Table 3) which would provide the detail required to evaluate treatment options; these assemblages can be related to the BC-wide classification of MacKenzie and Moran (2004). The Little Qualicum mapping data also includes associated texture and elevation data.

**Table 3 Vegetation Assemblages Mapped in the Little Qualicum River (after Dawes and White 1982)**

| Community                                        | Sediment Texture    | Elevation (m) | Description                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------------------------------------|---------------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Glaux</i> – pioneer                           | gravel-sand         | 3.20 ± 0.07   | <i>Glaux maritima</i> occurred in pure stands. Occasionally single plants of <i>Salicornia virginica</i> and <i>Puccinellia sp</i> were noted.                                                                                                                                                                                                                                                            |
| <i>Ruppia</i> – aquatic                          | silt                | 3.54 ± 0.02   | <i>Ruppia maritima</i> defined the community, which occurs in channels and pools of standing water.                                                                                                                                                                                                                                                                                                       |
| <i>Carex</i> – channel edge                      | peat to organic mud | 3.96 ± 0.02   | This community followed the edge of tidal channels. <i>Carex lyngbyei</i> dominates, often in pure stands. Associates include: <i>Eleocharis palustris</i> , <i>Agrostis sp</i> , and <i>Potentilla pacifica</i> . Occasional associates are <i>Scirpus cernuus</i> phase and <i>Typha latifolia</i> phase.                                                                                               |
| <i>Ranunculus</i> – low pasture                  | clay-loam           | 4.06 ± 0.02   | Dominates include: <i>Agrostis sp</i> , <i>Carex lyngbyei</i> and <i>Distichlis spicata</i> with associates of <i>Ranunculus cymbalaria</i> , <i>Lilaeopsis occidentalis</i> and <i>Triglochin maritima</i> .                                                                                                                                                                                             |
| <i>Carex-Agrostis</i> slope                      | peat                | 4.19 ± 0.02   | Topographic high or levee between channel edge and flats. <i>Carex lyngbyei</i> and <i>Agrostis sp</i> dominate followed by <i>Potentilla pacifica</i> , <i>Eleocharis palustris</i> , <i>Triglochin maritima</i> and <i>Glaux maritima</i> .                                                                                                                                                             |
| <i>Ranunculus</i> – <i>Juncus</i> – high pasture | clay-loam           | 4.39 ± 0.02   | Adjoin <i>Ranunculus</i> – low pasture. Vegetation assemblage is similar to low pasture plus the <i>Juncus</i> group. <i>Juncus balticus</i> and <i>Agrostis sp</i> and <i>Carex lyngbyei</i> dominate.                                                                                                                                                                                                   |
| <i>Deschampsia</i> – flats                       | peat                | 4.44 ± 0.01   | This community covered the largest portion of the wetlands mapped. The dominants are: <i>Potentilla pacifica</i> , <i>Juncus balticus</i> and <i>Carex lyngbyei</i> . Associates include: <i>Juncus balticus</i> , <i>Deschampsia cespitosa</i> and <i>Trifolium wormskjoldii</i> with lesser occurrences of <i>Triglochin maritima</i> and <i>Glaux maritima</i> .                                       |
| <i>Juncus</i> – high marsh                       | loam to clay-loam   | 4.78 ± 0.02   | This community bounds the upper limit of estuarine marsh. Dominants are <i>Juncus balticus</i> and <i>Potentilla pacifica</i> followed by <i>Agrostis sp</i> and <i>Poa pratensis</i> . Species virtually completely absent in the lower marsh appear: <i>Plantago lanceolata</i> , <i>Festuca arundinacea</i> , <i>Achillea millefolium</i> , <i>Aster subspicatus</i> and <i>Taraxacum officinale</i> . |
| <i>Rosa</i> – gravel bar                         | loam                | 5.12 ± 0.05   | developed on fluvial gravel deposits. Dominated by: <i>Rosa nutkana</i> and <i>Plantago lanceolata</i> . Some dry site species such as <i>Bromus mollis</i> , <i>Fritillaria camschatcensis</i> and <i>Hypochaeris radicata</i> occur.                                                                                                                                                                    |

The Sensitive Habitat Inventory Mapping (SHIM<sup>4</sup>) was reviewed for wetland inventories. The west coast version of the Pacific Estuary Conservation Program (Ryder *et al* 2004) is available on the web; however, for Clayoquot Sound where ShoreZone mapped the occurrence of approximately 185 wetlands (Figure 4), the PECP maps only 24 estuaries with wetlands. Of the 52 atlases summarized on the SHIM site, only a few include wetlands mapping (e.g. Ucluelet Harbour) of very limited extent.

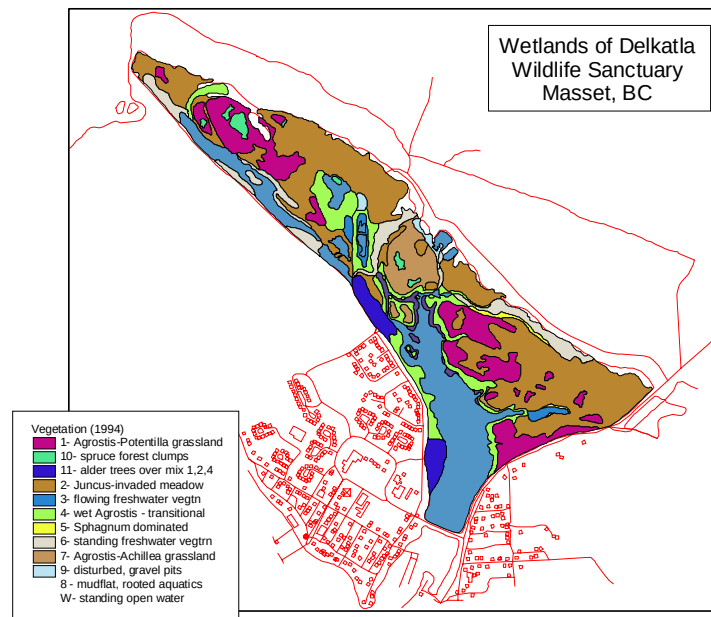
<sup>4</sup> <http://www.shim.bc.ca/atlas/atlas.html#westcoast>

A wetland survey where vegetation assemblages were mapped according to relative elevations above chart datum was completed in the Delkatla Wildlife Sanctuary, in Masset BC (Table 4). The project was measuring the affect of restoring tidal flow to an area which had been converted to a freshwater wetland due to the obstruction of saltwater by a causeway road bridge.

**Table 4. Vegetation Types Determined from Plot Data Surveys in Delkatla, 1996, post-saltwater restoration (from Morris, 1997)**

| Community                                | Elevation (m)    | Species assemblage                                                            |                                                                                                                                                                  |
|------------------------------------------|------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          |                  | Dominant                                                                      | Associated                                                                                                                                                       |
| <i>Agrostis</i> – <i>Achillea</i> – moss | > 4m, (>HHW)     | <i>Rhytidiadelphus</i> moss<br><i>Agrostis stolonifera</i>                    | <i>Achillea millefolium</i><br><i>Poa praetensis</i>                                                                                                             |
| <i>Juncus</i> -invaded grassland         | > 4m, (>HHW)     | <i>Agrostis</i> spp<br><i>Carex obnupta</i>                                   | <i>Holcus lanatus</i><br><i>Ranunculus repens</i><br><i>Juncus effusus</i><br><i>Rhytidiadelphus</i> moss<br><i>Potentilla pacifica</i><br><i>Carex lyngbyei</i> |
| <i>Juncus</i> -dominated grassland       | > 4m, (>HHW)     | <i>Juncus effusus</i><br><i>Agrostis stolonifera</i><br><i>Carex lyngbyei</i> | <i>Poa</i> spp<br><i>Potentilla pacifica</i><br><i>Deschampsia cespitosa</i>                                                                                     |
| <i>Carex lyngbyei</i> -dominated         | 3.0 – 4.0 m      | <i>Carex lyngbyei</i>                                                         | <i>Potentilla pacifica</i><br><i>Triglochin maritima</i><br><i>Deschampsia cespitosa</i><br><i>Puccinellia pumila</i>                                            |
| <i>Potentilla</i>                        | 3.0 – 4.0 m      | <i>Potentilla pacifica</i>                                                    |                                                                                                                                                                  |
| drainage channels                        | < 3.0 and > 0.5m | blue-green algal sponge                                                       | <i>Carex lyngbyei</i>                                                                                                                                            |
| <i>Lilaeopsis</i> drainage channels      | < 3.0 and > 0.5m | <i>Carex lyngbyei</i><br>blue-green algal sponge                              | <i>Lilaeopsis occidentalis</i>                                                                                                                                   |
| lower channels, intertidal flats         | < 3.0 and > 0.5m | diatom mat                                                                    | blue-green algal sponge                                                                                                                                          |
| mid-intertidal flats                     | < 3.0 and > 0.5m | diatom mat                                                                    | <i>Carex lyngbyei</i><br><i>Sagina maxima</i><br><i>Salicornia virginica</i><br><i>Atriplex patula</i>                                                           |

Figure 7. Map of wetland type in Delkatla wetland (Morris 1995).



## 2.4 Review of Treatment Options

### Overview

There is considerable literature on the oiling of wetlands and potential treatment alternatives. It is not the purpose of this study to re-hash these reviews but rather highlight information that is particularly relevant to BC wetlands. Summary reviews of oil in wetlands include: Hayes *et al* (1992), Baker *et al* (1993), Hoff (1995b) and NOAA (2000). The literature review is summarized in three tables (Tables 5, 6 & 7).

Some of the general findings are:

- cleanup operations may cause more damage to the marshes than the oil itself. In particular, bearing capacity of the marsh will dictate how the cleanup is approached. Mud and organic-rich soils run the risk of trampling and mixing the oil into the substrate whereas coarser mineral soils may support some types of foot or vehicle traffic.
- annual plants are more sensitive to oiling and cleanup than perennial plants. For perennials, lower plant stalks and root systems are more likely to survive oiling and cleanup, and this permits more rapid recovery and re-colonization of the vegetation.
- oil spill and cleanup typically have lower impacts during vegetation's dormant season.
- degree of contamination is critical where partial coverage of vegetation may have little impact but complete smothering has long-term impact
- refined hydrocarbon products are typically more toxic than unrefined products.

A summary of potential treatment techniques is presented in Table 7. This is a very generic summary for a wide range of wetland types and the key question is “*how applicable are these treatments to British Columbia wetland types?*” **No specific studies of oil impacts on BC wetlands were found, so there is no specific information about impacts on BC species assemblages.** The remainder of this report deals with probable assessment of spill impacts on treatments.

**Table 5. Factors Affecting Oil Spills in Wetlands (Hayes *et al* 1992)**

| <b>Factors</b>                                                            | <b>Description</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Oil type                                                                  | It has been shown that light refined products have the greatest acute toxicity to marsh vegetation, when compared to other types of oil. In contrast, observations of spills of crude oils and heavy refined products show mostly short-term impacts, and recovery within 1-3 years                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Extent of contamination of the vegetation                                 | Many plants can survive partial oiling; few survive when all or most of the stem is coated.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Degree of contamination of the sediments                                  | The degree of contamination of sediments is another very important factor, which can prolong impacts to marsh ecosystems for many years, compared with the initial loss of oiled vegetation. Slower re-colonization rates are frequently related to hydrocarbon levels in the sediments, though it should be noted that the composition of the oil is as important as the total petroleum content. That is, fresher oil and refined products have higher percentages of the more toxic fractions in oil, whereas heavy oils have lower initial and long-term toxicities.                                                                                                                                                                                                                                                                                                                      |
| Exposure to currents and waves which effects the speed of natural removal | Exposure can work to speed recovery, but, in some cases, it can also work to increase erosion after plant roots die and before new growth can occur. Oil deposited along the outer fringe is removed as the vegetation dies back and is exported. There are many examples of oiled vegetation along tidal rivers where, after one season, there is no visual evidence of oiled vegetation or sediments. Boat wakes, river currents, and tidal flushing are important natural removal processes, and they are usually much more effective than any man-made cleanup. In contrast, oil spilled in interior settings, such as from pipelines crossing wide marsh or swamp areas, have no physical removal mechanisms, and the oil can only weather in place or be removed by cleanup efforts.                                                                                                    |
| Time of year of the spill                                                 | In general, oiling during the dormant winter season has the lowest impact, whereas oiling of vegetation during the summer growing season had longer effects. The mechanisms responsible for the slower recoveries from a spill during the growing season have not been adequately studied, but probably are related to plant stress at a time when the plant's resources are being fully expended. For example, oiled plants rarely flower and oiled flowers do not produce seed (Baker, 1979), resulting in loss of the year's seed production. Alexander and Webb (1985) found that, in experimental plots, the time of year the oil was applied did not influence the response of <i>Spartina</i> to oil when it was applied to sediments and the lower portions of the plants; however, when the entire plant surface was oiled, impacts were greater for a May versus a November oiling. |
| Species sensitivity                                                       | There are some known species-specific sensitivity, however, most species' sensitivity is not well know. In general: <ul style="list-style-type: none"> <li>• Annuals are less resistant than perennials, which more likely to re-grow after damage to aerial portions (Getter et al, 1984); for example, the annual <i>Salicornia</i> is less resistant than other species, such as <i>Spartina</i>, to oil spills (Baker, 1971)</li> <li>• <i>Juncus</i> is more resistant than <i>Spartina</i> to chronic spills (Lytle and Lytle, 1987)</li> <li>• succulents, a common component of species assemblages in estuarine wetlands, are particularly susceptible to oiling (Moody, 1990)</li> </ul>                                                                                                                                                                                            |
| Damages associated with cleanup activities                                | The greatest damages derive from: <ul style="list-style-type: none"> <li>• destruction of the root system by trampling</li> <li>• mixing oil deeper into the sediments, slowing weathering and removal</li> <li>• removal of surface sediments suitable for supporting new growth</li> <li>• smothering of vegetation by mobilized sediments</li> <li>• exposure of the interior of the plant to toxic substances in the oil</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

**Table 6 Factors Affecting Persistence (from Hoff 1995b)**

| <b>Lengthy Recovery</b>                                                                                                                                                                                                                                                  | <b>Short Recovery</b>                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>north or south temperate (cold) environments</li> <li>sheltered location</li> <li>heavy oiling</li> <li>spills of fuel oils (bunker C or no. 2 fuel)</li> <li>in some cases intensive cleanup methods delayed recovery</li> </ul> | <ul style="list-style-type: none"> <li>warm climate</li> <li>light to moderate oiling</li> <li>usually spills of light-to medium crude oil</li> <li>variety of cleanup methods used</li> <li>often no cleanup resulted in fastest recovery time</li> </ul> |

**Table 7. Wetland Treatment Options (from Hoff 1995b)**

| <b>Treatment</b>                         | <b>Advantages</b>                                                                                                              | <b>Disadvantages</b>                                                                                                                                                                                                                   |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| No Response                              | <ul style="list-style-type: none"> <li>minimal impact (if oil degrades quickly)</li> <li>no physical impact</li> </ul>         | <ul style="list-style-type: none"> <li>potential oiling of birds or wildlife</li> <li>oil may impact adjacent areas</li> <li>heavy oils may degrade slowly or form asphalt</li> </ul>                                                  |
| Vacuum/pumping                           | <ul style="list-style-type: none"> <li>can remove large quantities of oil</li> </ul>                                           | <ul style="list-style-type: none"> <li>access /deployment of equipment</li> <li>physical impacts</li> </ul>                                                                                                                            |
| Low Pressure Flushing or Flooding/Deluge | <ul style="list-style-type: none"> <li>assists in removal by herding oil</li> <li>lifts oil off sediment surface</li> </ul>    | <ul style="list-style-type: none"> <li>requires careful monitoring</li> <li>pressure must be controlled</li> <li>physical impacts</li> </ul>                                                                                           |
| Burning                                  | <ul style="list-style-type: none"> <li>potential to remove oil quickly</li> <li>can minimize impacts from trampling</li> </ul> | <ul style="list-style-type: none"> <li>potential damage to plant roots and rhizomes</li> <li>little known about impacts due to season, inundation of marsh, species composition</li> <li>air pollution, regulatory concerns</li> </ul> |
| Sediment Removal                         | <ul style="list-style-type: none"> <li>may be only remediation possible for heavily oiled sediments</li> </ul>                 | <ul style="list-style-type: none"> <li>"destroy marsh to save it"</li> <li>increased erosion potential</li> <li>elevation changes may impede re-growth of plants</li> <li>replanting necessary</li> </ul>                              |
| Cutting Vegetation                       | <ul style="list-style-type: none"> <li>leaves most of plant intact</li> <li>prevents oiling of birds</li> </ul>                | <ul style="list-style-type: none"> <li>may kill plant</li> <li>potential for increased erosion</li> <li>must be carefully monitored</li> </ul>                                                                                         |
| Bioremediation                           | <ul style="list-style-type: none"> <li>great theoretical potential</li> <li>low impact</li> </ul>                              | <ul style="list-style-type: none"> <li>few case studies available</li> <li>potential for nutrient enrichment</li> <li>oxygen may be limiting</li> </ul>                                                                                |

### *In Situ* Burning

*In situ* burning is regarded as a potential cleanup technique for oil stranded in wetlands although there are a considerable number of qualifications with regard to the application of this technique. Table 8 summarizes some of the advantages and disadvantages of *in situ* burning in wetlands. Two statements from the NOAA Regional Response Team Guidelines (NOAA 2005) are particularly relevant:

*“Every wetland is different in terms of the wetland type, plant species composition, environmental parameters, and the known or estimated tolerances of that type of system to physical and chemical disturbances.”*

*“Little data is found on the burning of oiled wetlands.”*

**Table 8. Summary of Pros and Cons of Burning Wetlands (from NOAA 2005)**

|             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Pros</b> | <ul style="list-style-type: none"> <li>• minimizes physical damage: Where access is limited or mechanical/manual removal has the potential to cause unacceptable levels of impact by equipment mobilization and trampling, burning can rapidly remove oil from sensitive areas.</li> <li>• provides an option when other options fail: It provides a response option when no other options are acceptable or feasible, or where oil residues will be unacceptably high with other options, including natural recovery.</li> <li>• removes oil quickly: It rapidly removes oil from the habitat when there is a time-critical element, such as a short-term change in the physical conditions which will likely cause loss of containment and further spreading (e.g., rain or flooding), or a seasonal increase in wildlife use, such as arrival of large numbers of migratory waterfowl.</li> </ul> |
| <b>Cons</b> | <ul style="list-style-type: none"> <li>• Plant damage: Burning can cause substantial initial plant damage because the above-ground/water vegetation is removed.</li> <li>• Long term impact: Burning can cause long-term impacts to vegetation, when the fire is so hot or water level is too low, that the below-ground plant parts are killed.</li> <li>• Oil penetration: There is a potential for burning to increase oil penetration into the substrate, when there is no standing water.</li> <li>• Damage to biota: Any animals present and unable to escape (such as gastropods on clean vegetation above the oiled area) will be killed.</li> <li>• Residues: Heavy fuel oils, when burned, may produce residues that are difficult to remove.</li> </ul>                                                                                                                                   |

While we found two spill case studies on *in situ* burning that were conducted in vegetation types potentially comparable to BC wetlands (Hyde *et al* 1997; Pahl *et al* 1997 & 1999), both spills originated from pipeline breaks so concentrations of product spilled were very high. In addition, the Louisiana spill (Pahl *et al* 1997 & 1999) was a gas condensate, a product very unlikely to be spilled within BC wetlands. Previous studies of spills in BC have suggested that the highest risk is from diesel spills and fuel oil spills. Spills originating from the sea are likely to be lower concentration and spread out over wider areas, depending on the wetland gradient and tidal range. Many spill situations describe various bands of oiling within the vegetation canopy due to stranding events at different tides.

#### Texas Salt Marsh Burn (Hyde *et al* 1997)

A January spill of approximately 3,000 bbl from a crude oil pipeline break resulted in extensive marsh oiling. The vegetation complex was dominated by *Distichlis* with a variety of other species including *Salicornia* and *Scirpus*, all found in BC wetlands; this would be most equivalent to the *Distichlis* - seashore saltgrass site association (Em03) identified by MacKenzie and Moran (2004). The decision to burn was based on the fact that recent rains had raised water levels within the wetland, thereby reducing potential root damage from burning and that the major growth season would follow the burning.

The burn resulted in more extensive bare areas initially but re-colonization by *Distichlis* was very rapid within the first year. Other species increased in importance over the next



six years, although the burned areas were still significantly different in biomass and species composition after six years. Extrapolations of the plot data suggest that full recovery would require 15 years from the time of the spill.

Rockefeller Wildlife Refuge, Louisiana (Pahl *et al* 1997 & 1999)

A gas condensate spill from a pipeline break contaminated an estimated 5,000 m<sup>2</sup> of salt marsh in southern Louisiana. The contaminated wetland was dominated by *Distichlis spicata* and *Spartina patens*. Plots of impacted and control vegetation were monitored over a three-year period following the spill. Following burning, *Scirpus robustus* was the initial colonizer in the burned areas. However, after three years, the species mix in the burned and unburned areas was essentially similar to that of control. After three years, the stem density was the same in the burned, unburned and control but the biomass was significantly greater than both the unburned and control areas. The authors concluded that *in situ* burning was an effective response strategy.

Inferences to BC Wetlands

Most of the burning literature relates to *Spartina alterniflora* (e.g., DeLaune *et al* 1997), which does not have a BC equivalent. Other references, particularly in high marsh areas, have greater relevance. Vegetation densities on alluvial wetland deltas are usually low, however, and it is improbable that burning would be effective or that water tables would ever be sufficiently high to protect roots systems from heat damage. Other wetlands will have to be evaluated on a case-by-case basis with consideration of effectiveness of more conventional techniques (e.g., manual cleanup, cutting), natural recovery and wildlife use of the wetland. *Carex lyngbyei*, one of the most common species in low marsh in BC, has been specifically identified as sensitive to burning (McCauley and Harrel, 1981; Moody, 1990)

## 2.5 Bioremediation of Oiled Wetlands

Bioremediation may consist of enhancing bacterial activity or fertilizing areas to promote nutrient cycling (i.e., using nutrient enrichment) or ‘phytoremediation’ where certain species of plant or enhanced plant growth accelerates the rate of degradation of oil and speeds habitat recovery (Zhu *et al* 2004). Oil biodegradation on marine wetlands is often limited by oxygen not by nutrient availability (Zhu *et al*, 2004), which can be a factor in determining if bioremediation is an appropriate cleanup option. If oil has penetrated into the subsurface, bioremediation is less effective because anaerobic conditions can be present a few millimeters below the surface. However, in some wetlands, nutrients may still be limiting to plant growth and:

*“If ecosystem restoration is the primary goal rather than oil cleanup, at least one study strongly suggested that nutrient addition would accelerate and greatly enhance restoration of the site. Abundant plant growth took place in the nutrient-treated plots despite the lack of oil disappearance resulting from the addition of extra nutrients” (Zhu et al, 2004)*

As one of the least disturbing clean up options and a treatment that would complement the ‘no response’ cleanup, the potential for bioremediation in wetland spill cleanup is considerable; however, field and laboratory tests of bioremediation have not been completed on BC wetland species assemblages. Also, as with other wetland cleanup techniques, most of the example and experimental work with bioremediation cleanup has been done on the Gulf Coast or the eastern seaboard where *Spartina* communities dominate (e.g., Lee *et al*, 2003) making results of these projects difficult to extrapolate to BC conditions.

## 2.6 Restoration of BC Wetlands

Should a wetland be significantly damaged by an oil spill or associated cleanup, and vegetation and substrate substantially removed, restoration may be warranted. There is some history of wetland restoration in British Columbia as a result of habitat compensation projects. Creation of wetlands has been relatively common in the Fraser River estuary where industrial development projects on the river have been required to create wetland habitat to replace impacted shoreline.

Wetland creation in marine environments is less common but has occurred. In Deep Bay (north of Bowser on the east coast of Vancouver) wetland habitat was created as partial compensation for wharf and parking lot construction (pers. comm., R. Russell, DFO Habitat Specialist, Nanaimo). Pickleweed (*Salicornia virginica*) was planted as plugs on a terraced area of the beach. The project was regarded as “fairly successful” and five years after planting, the cover was regarded as “considerable”. Some bare patches remained. The relatively slow colonization was attributed partly to the use of inappropriate substrate within the terrace.

A similar technique was used on the Tswassen Ferry Terminal as part of a habitat compensation program (pers. comm., B. Nato, DFO Habitat Specialist, Vancouver; Mark

West, ECL Envirowest Consultants, Burnaby). An artificial terrace was created and planted with mix of wetlands species. The plugs of the pickleweed (*Salicornia virginica*) were the only plants that survived the first year and eventually these propagated throughout the terrace area. The plug propagation was complemented by the natural seeding of an annual *Salicornia* and cover is now considered “extensive”. Colonization of the flat occurred over a 5-year period.

Adams and Williams (2004) compiled a summary of wetland creation in the Fraser delta; these restoration efforts have shown that creation of wetlands in the Fraser River, a more freshwater dominated system, typically result in wetland establishments within 1-2 years compared to marine wetland creation that is more likely to require 3-5 years (Adams, pers., comm., 2006).

The relatively slow re-colonization of artificial marine wetlands is partly attributable to lack of experience in establishing these wetlands. It does suggest, however, that a period of 3 to 5 years may be required to re-establish a functioning wetland in the marine environment of British Columbia. This represents a potential worst-case scenario should a wetland be completely destroyed by either direct oiling or by associated cleanup; that is, a 3-5 year recovery period is required to establish an entirely new wetland.

Dawe *et al* (2000) monitored the establishment of a wetlands in the Campbell River estuary on dredge spoil islands and note that 13 years of monitoring showed continued evolution in terms of wetland composition.

## 2.7 Review of Recent, Relevant Wetland Spills

Three particularly relevant spills that impacted wetlands are reviewed; these spills were selected because of relevance to BC wetland types.

### Port Madison Spill, Puget Sound (Foss 248 P-2)

On 30 December 2003, 4,620 gallons of heavy fuel oil (#6) were spilled into the waters of Puget Sound. A significant proportion of the spill stranded in the Doe-Kag-Wats salt marsh (Figure 8) on the Suquamish Tribe's Port Madison Reservation near Indianola in Kitsap County.

The cleanup plan was developed specifically for the site and



Figure 8. Oblique aerial photo of the Doe-Kag-Wats wetland that was oiled in the Foss 248 P-2 fuel oil spill. Oil penetrated as far as the logline (at right).

recognized the sensitivity of the wetland complex. It was decided that no logs would be removed as the removal would likely cause significant disturbance to the wetland substrate. Oil coatings on logs were treated by contact burning with tiger torches. Oiling in the wetlands areas was accessed using a combination flat-bottom skiffs at high tide and plywood sheets laid over the wetland for foot access. Oil was removed using a combination of cutting and raking. Both the Department of Ecology and the cleanup contractor regarded the cleanup effort as sensitive to the environmental conditions of the wetland and effective. Plant species and assemblages within the wetland do not appear to be specifically identified.

#### Selangdan Ayu Spill, Aleutian Islands of Alaska

The *Selangdan Ayu* was a bulk cargo carrier that wrecked on the coast of the Aleutian Island of Unalaska, spilling an estimated 321,052 gallons of IFO 380 and 14,680 gallons of marine diesel along with a 60,000 tons of soy beans. The fuel oil significantly contaminated one wetland (SCAT segment SKN14). The species assemblage associated with the wetland is unknown.

Oiling covers varied within the wetland (Figure 9, 10, 11) and a variety of manual techniques were used to remove the gross oiling within the wetland. The cleanup was primarily by manual means. A cleanup plan was developed specifically for this wetland and the plan incorporated techniques for minimizing trampling (Figure 12, 13).

A variety of techniques were used to remove oiled vegetation, both dead and standing. Rakes and pitchforks were used to lift up loose vegetation (Figure. 14, 15, 16).



Figure 9. Emergent wetland on 25 April 2005 in SKN14.



Figure 10. Small tar ball suspended in wetland vegetation. SKN14 on 25 April 2005.





Figure 11. Wetland area after gross removal of oiled vegetation. SKN14 on 25 April 2005.



Figure 12. Cleanup crews conducting manual cleanup of oiled section of fringing marsh. SKN14 on 25 April 2005.



Figure 13. Planking used to access "softer sections" of the oiled wetland in SKN14 (25 April 2005).



Figure 14. Cleanup of wetland using a pitch fork to lift up oiled vegetation. SKN14 on 25 April 2005.



Figure 15. Cleanup worked using a rake to remove loose, oiled vegetation from the surface of the wetland in SKN14 (25 April 2005)



Figure 16. Cleanup crews using hedge shears to cut oil wetland vegetation in SKN14 (25 April 2005)

Aerial views of the site show relatively rapid wetland regeneration following the cleanup program (Figure 17, 18).



Figure 17. Skan Bay wetland oiling, 15 December 2004 prior to cleanup



Figure 18. Skan Bay wetland following gross oil removal 13 July 2005.,

### Fidalgo Bay Oil Spill, Anacortes, Washington

During a tanker offloading operation on February 22, 1991, a shore-side booster pump failed at the Texaco March Point refinery (Hoff 1995b). A large piece of the pump casing broke and was thrown 90 feet, and North Slope crude oil began pouring from the pump. The oil flowed across a field and into a drainage ditch, and ultimately oil entered Fidalgo Bay through two culverts. 210,000 gallons of oil were estimated to have spilled, with approximately 20-30,000 gallons entering Fidalgo Bay.

Significant observations include:

- Marsh plants were relatively dormant until June, when noticeable growth occurred at both oiled and un-oiled sites. Growth continued through September.

- Areas with heaviest amounts of oil remaining on the surface showed little or no growth of marsh plants. However, areas with moderate amounts of oil had steady growth through the growing season.
- Areas that were subjected to the most foot traffic have been among the slowest to recover.
- Removal of spilled oil in marshes resulting in relatively low biological impacts is possible under certain circumstances that are related to the physical and biological characteristics of the marsh, the intrusiveness of the remedial technique, the season of the year, and other considerations.
- Removal of the oil has apparently speeded the recovery of those portions of the marsh where it occurred.
- Techniques to minimize the impacts of foot traffic and equipment access resulted in significantly lesser adverse effects on the recovery of the marsh.
- However, minimization of impacts required near constant vigilance and threat of financial discomfort.





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### 3.0 HOW ARE BC WETLANDS DIFFERENT?

#### 3.1 Conceptual Classification for Spill Response Planning

As part of the review of BC marine and estuarine wetlands types that could be affected by oil spills, we developed three generalized wetland descriptions. These categories are based on broad generalities for characteristics of wetlands, such as: morphology and size, sediment characteristics, salinity regimes, vegetation community composition and overall structure. The three settings may include common species or geomorphic processes, but have different general combinations of the features. We developed these categories to summarize the different challenges posed for spill response. Most BC wetland complexes can be categorized within one of these three settings, however, the descriptions are presented for discussion purpose only, as in the real world, a continuum of different types exists.

##### Riverine – Spatially Complex Wetland Settings

The largest in size of the three categories, these wetlands occur at the mouths of larger rivers and may include a variety of wetlands, grading from freshwater types to saltmarsh types. These areas are typically spatially complex with low-gradient, meandering river channels and numerous side-bank tidal channels. A variety of substrates are found including peats, organic-rich soils, fine fluvial sediments, fine marine sediments and sand; channels may be coarse sediment. Intertidal widths are typically the same dimensions as the alongshore length. Examples of this type of *riverine, spatially complex wetland setting* include the Fraser (Figure 6), Cowichan (Figure 5), Nanaimo and Squamish River deltas. Many of these areas have been extensively modified by creation of dykes, dredged channels and ditches.

##### Alluvial Delta Wetland Settings

Much of the British Columbia coast has high backshore relief and small watersheds. Deltas are typically small alluvial fans at the edge of a forest. These alluvial deltas commonly have a sparsely vegetated wetland fringe in the upper intertidal and supra tidal zones. This delta type is common in BC and makes up around 5-10% of the shoreline length on the Central and North coasts of BC, Haida Gwaii (Queen Charlotte Islands) and the West Coast of Vancouver Island. The unusual feature of these wetland settings is the coarse nature of the substrate; surficial sediments are commonly cobble-pebble veneers over sand, colonized by a sparse cover of wetland vegetation. Although the wetlands are associated with river mouths, it is not uncommon to see the common seaweed, rockweed (*Fucus sp.*) inter-fingered with the wetland grasses, suggesting a marine salinity regime. The combination of wetlands vegetation and coarse surficial sediment is likely to complicate cleanup efforts.

A relative and recent lowering of sea level may be the primary reason that coarse sediments, formerly in the intertidal zone, are intermixed with the wetland grasses.

Occasional storm surge inundation prevents the more terrestrial vegetation from colonizing this habitat.

#### Lagoon-Tidal flat Wetland Settings

The least common of the three wetland BC types we propose are the Lagoon-Tidal flat types. These wetlands occur in the upper intertidal areas of lagoons and tidal flats. The distinguishing characteristic is that they are little influenced by freshwater, as they are not typically associated with a watershed of any significant size. Sediments are likely to range from organics and peats to sands. They are typically not spatially complex. Examples of this type include: Sidney Spit, Esquimalt Lagoon, and Centennial Beach in Tsawwassen. The salt marshes are very often confined by barrier spits.

### **3.2 Types Descriptions and Examples**

Differences in characteristics of the three broad categories we have outlined are significant to oil spill sensitivity and cleanup options. Three types of differences between the marine wetland categories are:

- general sediment characteristics – is the wetland predominantly peat/organic soils or coarse clastics?
- species composition – what are the wetland vegetation types or specific species present?
- energy and freshwater/marine flushing – how dominant are fluvial processes, versus marine processes?

#### Riverine - Spatially Complex Wetland Setting

Examples of this category are the Cowichan River (Figure 5; Figure 19, 20, 21) or the Fraser River (Figure 6). Wetlands tend to be large in size and include significant areas of peat and organic soils. This substrate type is particularly sensitive to trampling and sediment contamination. Access by boat can be difficult on broad flats, making areas inaccessible for cleanup.

Larger estuaries are more likely to have larger proportion of man-modified shorelines, which have different concerns for spill sensitivity and cleanup options. For example, on impermeable man-made shoreline the biological sensitivity will be low and clean up techniques could include steam washing or removal of material: both techniques would be not recommended in undisturbed wetland.

Large areas of the wetland are brackish or freshwater dominated. River channels may be wide and fluvial processes will be dominant, in particular in upper areas of the wetland. Large channels also provide an access route for oil into freshwater-dominated vegetation types up-river from marine spills. Patterns of vegetation assemblages tend to be complex, with a gradation of communities following salinity tolerances across the delta.

In the upper estuary, the dominant vegetation type is likely to be an open meadow, where grasses and root-mat forming perennials occur. These species are most tolerant of

burning but least likely to be inundated by standing water (important for protecting roots from fire damage if *in situ* burning is used in cleanup).

Using the MacKenzie and Moran (2004) estuarine site associations (as shown in examples in Figures 1, 2 and 3), it is likely that all of the site associations that have been identified; along with a number of the freshwater site associations occur in the spatially complex type in BC.



Figure 19. Oblique aerial photo across the Cowichan River delta. A road (centre of photo) has essentially bisected the delta. A complex area of mudflats, channels and wetlands is apparent to the left of the road with dyked farmland in the background. A major distributary channel of the delta with associated fringing wetlands and mudflats is apparent to the right of the road. Access to central portions of the delta would be very difficult. Typically these area areas are accessed at high tide by flat boat boats or alternatively accessed by placing plywood paths to minimize trampling effects.



Figure 20. Detail of upper intertidal and log line of Cowichan estuary. Note the large accumulation of logs at the storm surge limit, and the complex pattern of different vegetation assemblages across the mid and lower intertidal.



Figure 21. Channel detail of one of the main arms of the Cowichan estuary, showing the dyked river channel, with complex wetland and mudflats behind the dyke. The area in this figure appears in the far upper right of Figure 20.

#### Alluvial Delta Wetland Setting

Most of the small stream mouths and deltas in BC would fit into this category: small overall area and small stream input, with coarse sediment alluvial fans. Typical of all areas of the BC coast, these stream deltas have limited development of peat or organic soils, and often have a veneer of pebble/cobble over fine sand/granular sediment (Figure 22). Trafficability of sediment of this type can be good, making the area less susceptible to trampling by cleanup crews or equipment. Coastal processes at alluvial delta type is marine-dominated and not strongly influenced by fluvial processes. That is, tides and wind are more significant structuring forces at these sites than are riverine forces.

Wetland vegetation may include similar species as are found in the lower elevations of the spatially complex wetlands, however the zonation is observed over a smaller area, and is usually dominated by salt-tolerant plants. Relating the vegetation to the MacKenzie and Moran (2004) site associations, the herbaceous vegetation is usually not dominated by the *Carex lynbyei* site association (Em05); as is more likely in the larger riverine types. In the alluvial fan category, the dominant vegetation assemblages are more likely to be Tufted hairgrass site association (Ed01) in upper marsh elevations, and Glasswort-Seashore saltgrass site associations (Em02/ Em03) (Figure 23 and 24).





Figure 22. Ground photo of a typical small British Columbia estuary wetland, in Anna Inlet, Haida Gwaii (Queen Charlotte Islands). Note the coarse sediments (cobble, pebble) and brown alga *Fucus* (right) interfingering with grasses and herbs of the 'low marsh' (Tufted hairgrass site association Ed01 site association, MacKenzie & Moran, 2004).



Figure 23. Small fringing wetland on the west coast of Vancouver Island, typical of the *alluvial delta* wetland type, where overall size of the estuary is small, and dominant sediment size is coarse. Peat and organic soil development is limited.



Figure 24. A typical species assemblage of smaller wetlands is illustrated in this example from the central coast of BC. Shown is a mix of salt-tolerant herbs (including *Salicornia*, *P. maritima*, sedges, *Potentilla anserine*) at the 'low marsh' elevation, with taller monoculture of dune grass (*Leymus mollis*) above.

#### Marine, Lagoon/ Tidal Flat Non Estuarine Wetland Setting

The least common of the three marine wetland categories, the Marine Tidal Lagoon type have limited fluvial processes and may be ponded, brackish water (e.g., washover lagoons behind barrier beaches), which have little intertidal variation to drying mudflats as in the Sidney Spit example (Figure 25). Sediments are usually fine sand/mud not coarse. Tidal flushing may be much reduced by the morphology of the lagoon, and these are also areas of very protected wave exposure.



The example site illustrated in Figures 26 through 29 are all from Sidney Spit and is likely typical of south coast BC, and the Strait of Georgia area in particular. The MacKenzie and Moran (2004) site associations are well illustrated in the species observed in the *Salicornia*-dominated low marsh (Figures 28 & 29) and in the *Distichlis*-dominated mid-marsh.

These vegetation types would be highly sensitive to trampling, due to the dominance of succulent herbs in the wetland, and because of the very low wave exposures, vulnerable to long oil residence times.

Figure 25a. Aerial photograph of a wetland complex developed on the lagoon side of a spit (looking East).



Figure 25b. Aerial photograph of the same wetland complex looking North.



Figure 25c. Aerial photograph of a narrow portion of the wetland complex showing a distinct “low marsh” and “high marsh”.





Figure 26. Lower edge of *Salicornia* at Sidney Spit. Note sandy/mud substrate, with standing water nearby. This is MacKenzie & Moran (2004) Glasswort-sea-milkwort site association (Em02).



Figure 28. Detail of lower limit of *Salicornia*, mixed with rockweed (*Fucus sp*) in the Glasswort – sea-milkwort site association (Em02)..



Figure 27. The Seashore saltgrass (Em03) (MacKenzie & Moran, 2004) site association at Sidney Spit.



Figure 29. Detail of sprouting *Distichlis* grass and sprigs of *Salicornia* in the Seashore saltgrass site association at Sidney Spit.



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## 4.0 REVIEW OF POTENTIAL TREATMENT OPTIONS

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### 4.1 Assessment of Treatment Applicability to BC Wetland Types

It can be expected that all wetlands and estuaries would be considered as ‘sensitive’ during oil spill response planning. In most cases, each would have its own site-specific treatment plan, treatment priority, treatment methods and endpoints. Only certain cleanup techniques will be suitable for wetlands (Table 7). Generally speaking, gentle manual techniques of cleanup (e.g., flooding or vacuuming) will not have different impacts depending on species assemblages (Table 7), and with proper implementation will be as appropriate in BC coastal wetlands as in other areas; however the impact of burning and of vegetation cutting will be influenced by the specific factors of the individual species in the wetland assemblage being treated (Table 9). Also, the time and pattern of vegetation recovery in disturbed wetlands may be dependent on the species assemblage present.

Seasonality of spill and cleanup response is another important factor to success (Hoff, 1995b and others), and in the coastal BC climate, the dormant season may be a short period during the winter months. Most BC locations have no freezing period, where root mats of wetlands would be protected by ice, from trampling or burning in cleanup.

One technique for assessing BC wetlands’ specific responses to spill or cleanup is to understand which attributes of wetland vegetation can be used to assess sensitivity to spill impacts and cleanup responses (Table 9), and then evaluate those characteristics for BC species (Table 10). For example, the succulent species (Table 10) will be most sensitive to trampling or crushing (e.g., milkwort (*Glaux maritima*), maritime plantain (*Plantago maritima*) or pickleweed (*Salicornia virginica*)). The turf-forming grasses (Table 10) might respond well to vegetation cutting as a cleanup technique (e.g., tufted hairgrass (*Deschampsia cespitosa*) or seashore saltgrass (*Distichlis spicata*)). By determining the dominant species assemblage at an impacted site, it would be possible to use specific information about species observed to assist with the response plan, or to assess the susceptibility of the site to disturbance.

All the species listed in Table 10 are commonly found in BC’s marine wetlands and all are salt-tolerant or coastal marine riparian species. In upper meadows on larger wetlands, non-marine species may also occur. Examples of freshwater riparian species found in large riverine estuaries would include: the small shrub, pink spirea (*Spirea douglasii*) and common cattail (*Typha latifolia*). These species do not occur in brackish or salty wetlands, but could be listed in a similar way as the salt-tolerant species in Table 10. That is, knowledge of the characteristics of any wetland vegetation species would be helpful to assess wetland’s sensitivity.

Wetland areas generally have a large number of seeds in the soil (Vavrek and Campbell, 1999) and those seed banks make an important contribution to plant regeneration after disturbance. Although the available dormant seeds are likely more important in freshwater wetlands, than in saltmarshes (Vavrek and Campbell, 1999), the seed bank

promotes rapid colonization after disturbance. The resulting plant community is likely to be diverse and represent the dominant species from the pre-disturbance conditions.

**Table 9. List of Attributes of Wetland Vegetation Species that Could be used to Determine Implications of Oil Spill or Clean up Options for BC Wetlands.**

| Attribute of Wetland Plant Species             | Implications to Oil Spill or Cleanup Sensitivity                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| annual or perennial                            | <ul style="list-style-type: none"> <li>• annual plants are less tolerant of oil spill, as they have less capacity to regenerate vegetatively and are likely to be non-woody</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                        |
| size of the plant                              | <ul style="list-style-type: none"> <li>• the amount of the plant impacted by oil is related to the survival of the plant.</li> <li>• smaller plants can be more easily smothered by spill, and more likely to have larger proportion of plant affected</li> <li>• larger plants could be suitable for cutting cleanup treatment where smaller plants would not be</li> </ul>                                                                                                                                                                                                  |
| reproductive strategy                          | <ul style="list-style-type: none"> <li>• seed production and distribution methods will affect how plants recolonize after spill or cleanup mortality</li> <li>• some plants reproduce vegetatively and that would influence rate of recolonization</li> </ul>                                                                                                                                                                                                                                                                                                                 |
| morphology                                     | <ul style="list-style-type: none"> <li>• many salt-tolerant wetland plants are fleshy succulents which are particularly sensitive to oil and disturbance from trampling or other damage from cleanup</li> <li>• tall, reedy or stiff grassy stems are more likely to stand above light oiling</li> <li>• grasses and other monocots with basal meristems will be suitable for cutting during cleanup where species with apical meristem are less suitable for cutting</li> <li>• plants with waxy epidermis may be less susceptible to oiling or damage in cleanup</li> </ul> |
| root/rhizome structure                         | <ul style="list-style-type: none"> <li>• sedges and grasses tend to be turf-forming perennials and plants will growback from a dense root mat.</li> <li>• complex organic structures in the soil are part of peat development and would increase susceptibility of the substrate to oil, increasing the potential of the substrate for oil retention.</li> </ul>                                                                                                                                                                                                              |
| across-shore elevation                         | <ul style="list-style-type: none"> <li>• low marsh and channel vegetation is more likely to be impacted by oil spill, coming from the marine environment</li> <li>• upper-estuary meadow are infrequently inundated, making these areas less likely to be heavily oiled.</li> <li>• Spill cleanup with burning is most successful when roots are protected in standing water and the vegetation's across-shore elevation will be a factor in determining if burning is a suitable cleanup response</li> </ul>                                                                 |
| habitat preference for salinity, wave exposure | <ul style="list-style-type: none"> <li>• aquatic species are less susceptible to damage from oiling because the oil is less likely to adhere to the plant, due to mucous or film of water</li> <li>• lowest wave exposure and lowest energy sites are the most vulnerable to oil spill affects as wave energy is too low to assist in dispersing oil</li> </ul>                                                                                                                                                                                                               |



**Table 10. Characteristics of Plants in BC Wetlands Useful to Rate Oil Spill Sensitivity and Cleanup Options.**

| Species name                                   | Common name        | Reproductive strategy           | Size *          | Morphological category         | Root/rhizome characteristics                                                                                 | Typical across-shore elevation                                               |
|------------------------------------------------|--------------------|---------------------------------|-----------------|--------------------------------|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| <i>Glaux maritima</i><br>(see Figure 30)       | Milkwort           | Perennial from rhizomes         | Small           | Succulent herb                 | Plants grow as individual plants, from runners or rhizomes, non-peat forming                                 | Upper intertidal                                                             |
| <i>Salicornia virginica</i><br>(see Figure 30) | pickleweed         | Perennial from slender rhizomes | Medium to small | Succulent, herb, salt-tolerant | Plants may grow in thick, matted bed but root mat is non-peat forming                                        | Upper intertidal, lower supratidal, brackish to fully marine                 |
| <i>Carex lyngbyei</i>                          | Lyngbye's sedge    | Perennial                       | Tall            | Reedy sedge                    | Forms dense rhizome/stolon mat and peat, clumps                                                              | Fluvial and upper intertidal, often occurs along river channel margins       |
| <i>Distichlis spicata</i>                      | Seashore saltgrass | Perennial                       | Medium          | Grass, salt-tolerant           | Sod/turf forming                                                                                             | mid-marsh to high marsh elevation                                            |
| <i>Plantago maritima</i>                       | Maritime plantain  | perennial                       | Medium          | Succulent herb                 | Individual plants, tap root, not turf forming                                                                | Upper intertidal, lower supratidal                                           |
| <i>Potentilla egedii</i>                       | Silverweed         | Perennial, spreads by runners   | Medium to small | Salt-tolerant herb             | Plants may grow in dense patches but root mat is not peat-forming                                            | mid to high marsh, brackish to freshwater                                    |
| <i>Deschampsia cespitosa</i> (Figure 31)       | Tufted hairgrass   | perennial                       | Medium to tall  | Grass, salt-tolerant           | Plants usually grow as tufted clumps                                                                         | mid to high marsh                                                            |
| <i>Juncus arcticus</i>                         | Arctic rush        | perennial                       | Medium to small | Stiff upright rush             | Grows from rhizomes but not peat-forming                                                                     | Brackish to freshwater                                                       |
| <i>Aster subspicatus</i>                       | Douglas aster      | Perennial                       | Medium          | Herb                           | Grows from creeping rhizome but not peat forming                                                             | Brackish to meadow above marine limit                                        |
| <i>Achillea millefolium</i>                    | Yarrow             | Annual                          | Medium          | Herb                           | Plants grow as individuals, usually associated with meadow grasses                                           | Meadow, above marine limit                                                   |
| <i>Triglochin maritima</i><br>(see Figure 30)  | Arrowgrass         | Perennial                       | Medium          | Herb, salt-tolerant            | Plants usually grow as individual tuft or mixed with other low marsh herb species.                           | mid to low marsh                                                             |
| <i>Leymus mollis</i>                           | Dune grass         | Perennial                       | Tall            | Grass                          | Spreads with rhizomes, may be monoculture in sand soil or mixed with other grasses and herbs in upper marsh. | Lower supratidal and meadow above marine limit, often in driftwood log line. |

\* size categories: small – average full size less than 20cm tall; medium – average full size between 20 and 40cm; tall – average full size over 40cm





Figure 30. Detail of small succulent herbs in low marsh: arrow-grass (*Triglochin maritima*), sea-milkwort (*Glaux maritima*) glasswort (*Salicornia virginica*).



Figure 31. Tufted hairgrass (*Deschampsia*) is seen in the high marsh of this boulder/cobble beach near a small stream. This example is from the mid-coast, in a small estuary on the south side of Gil Island, on the north side of Princess Royal Island and illustrates MacKenzie and Moran (2004) site association Ed01.

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## 5.0 CONCLUSIONS and RECOMMENDATIONS

### 5.1 Conclusions

1. Coastal marine wetlands and estuaries are biologically productive, ecologically and socially important areas sensitive to oil spills and oil spill cleanup. They are relatively uncommon, accounting for less than 10% of the province's coastline. Risk of oil spills in BC coastal wetlands is increasing, particularly for the north coast of BC where several new developments are proposed.
2. The ShoreZone classification identifies the occurrence of coastal wetlands on a province-wide basis but does not identify different types of wetlands. That is, there are no known inventories of BC estuaries that categorize specific estuaries as to their characteristics that determine sensitivity to oil spill and cleanup.
3. Our review of BC estuary classification and mapping systems suggests the most relevant example for use in comparing oil spill sensitivity and cleanup options is the biophysical (species/salinity/hydrology) classification developed by MacKenzie and Moran (2004). No one mapping or classification system in combination is applied for the province, although a number of different examples of either classification, mapping or specific site studies were reviewed.
4. A general three-type marine wetland classification system is outlined to describe BC wetlands and each type's general concerns regarding spill responses. Three types are: (a) *riverine, spatially complex wetland type* (e.g., Fraser River delta, Cowichan River delta), (b) *alluvial delta wetland type* (e.g., many on the west coast Vancouver Island, and throughout coastal BC) and (c) *marine lagoon/tidal flat (non-estuarine) wetland type* (e.g., Sidney Spit).
5. No specific studies of oil impacts on BC species assemblages were found. Indeed, there is not much literature on effects of oil and cleanup that can be extrapolated to BC species. Most of the research of the affects of oil spills and associated cleanup techniques has been done in *Spartina*-dominated Louisiana shorelines; however *Spartina* has substantially different morphology and growth characteristics than other BC wetland plants, making *Spartina*-specific research difficult to relate to conditions in BC.

### 5.2 Recommendations

1. The estuarine site associations defined in MacKenzie and Moran (2004) should be 'cross-walked' with the categories in the FREMP classification system, where very detailed mapping exists. This would provide a mapped classification schema for this complex and important estuary at the Fraser River delta.

2. Further development of the methodology outlined in Section 4.1 Assessment of Treatment Applicability to BC Wetland Types could be done. More examples for BC wetlands types and species assemblages could be prepared in a field 'job aid' format.
3. Studies of the oil spill effects and cleanup techniques on BC wetland species assemblages are required, preferably in the planning phase of BC coastal risk assessment, before there is a major oil spill that impacts coastal wetlands.

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