5.0 IDENTIFICATION OF POTENTIAL INJURIES

The DOI regulations (43 CFR Part 11) specify that injuries can occur to both abiotic and biological resources. The purpose of this section is to summarize available data that identify potential injuries to Commencement Bay natural resources. Potential injuries to both the abiotic and biological resources of Commencement Bay have been identified based on a review of historical data. Injuries to abiotic resources include the presence of hazardous substances in surface water and sediment at concentrations that exceed applicable guideline concentrations. Biological resources that may have been injured due to exposure to hazardous substances include benthic and epibenthic invertebrates, fish species, and birds.

5.1 INJURIES TO ABIOTIC RESOURCES

As discussed in Section 3.0 of this report, surface water (including all subtidal and intertidal sediments) is the only abiotic resource of Commencement Bay considered at this time by the Trustees to have been injured by the releases of hazardous substances. Injury definitions for surface water are provided in § 11.62 of the DOI regulations. To summarize, surface water is considered to be injured if:

- The concentrations and duration of substances are in excess of drinking water standards established by federal or state laws
- The concentrations and duration of substances are in excess of applicable federal and state water quality criteria
- The concentrations and duration of substances on bed, bank, or shoreline sediments are sufficient to cause the sediment to exhibit toxicity characteristics
- The concentrations and duration of substances are sufficient to have caused injury to air or geologic or biological resources when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments

Information regarding the injury to both major components of the surface water resource, the surface water and sediments, are summarized separately below.

5.1.1 Injury to Surface Water

As discussed in Section 3.0, injury to the surface waters of Commencement Bay has been demonstrated based on measurements of several hazardous substances at concentrations that exceeded the water quality standards for surface water promulgated by the State of Washington (Chapter 173-201A WAC). The concentrations of at least one SOC exceeded the standards in all of the waterways, except the Middle Waterway, and along the Ruston-Pt. Defiance Shoreline.

5.1.2 Injury to Sediments

As discussed in Section 3.0, the State of Washington has promulgated numerical sediment quality criteria for 40 substances that can be used to establish injury to sediments (Chapter 173-204 WAC). A number of studies have investigated the concentrations of SOCs in sediments and the data have been summarized in Sections 2.0 and 4.0. In particular, Section 4.0 of this report presents an extensive comparison of the concentrations of SOCs in sediments to the state quality standards. SOCs have been found in sediments at sufficient locations and duration, as summarized in Section 4.0, to meet the acceptance criteria for injury to sediment.

5.2 INJURIES TO BIOLOGICAL RESOURCES

The DOI regulations at §11.62 (f)(1) state that "an injury to a biological resource has occurred if the concentrations of a hazardous substance are sufficient to:

> cause the biological resource or its offspring to have undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations (§11.62 (f)(1)(I))
>
> exceed action or tolerance levels established under Section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342 in edible portions of organisms (§11.62 (f)(1)(ii))

or

exceed levels for which an appropriate State health agency has issued directives to limit or ban consumption of such organisms. (§11.62 (f)(1)(iii))"

In addition, the regulations allow for the use of injury determination approaches other than those listed above, provided they meet the following acceptance criteria (43 CFR Part 11.62(f)(2)):

- The biological response is often the result of exposure to oil or a hazardous substance
- Exposure to oil or a hazardous substance is known to cause the response in free-ranging organisms
- Exposure to oil or a hazardous substance is known to cause the response in controlled experiments
- The biological response measurement is practical to perform and produces scientifically valid results

A summary of the SOCs that have been shown in other studies to cause the specific adverse biological effects defining injury in key resources found in the Injury Study Area is provided in Table 5-1. These adverse effects have been documented in studies of exposures via water-borne substances, and via exposure to contaminated sediment, as well as in studies associating tissue concentrations with specific effects. A detailed summary of the biological effects associated with each SOC is provided in Appendix F; a review of the ecotoxicity of the SOCs is provided in Appendix D.

5.2.1 Injury Category—Death

Benthic community alterations are a well-documented biological response to environmental stress, including contamination of sediments by hazardous substances. Although not explicitly identified under 43 CFR Part 11, benthic community alterations can be established in a manner likely to meet the acceptance criteria established by the regulations (§11.62(f)(2)). Numerous laboratory toxicity tests (e.g., Becker et al., 1990) have established

Table 5-1. Summary of Injuries to Biological Resources Potentially Caused by the Substances of Concern Identified in the Injury Study Area

Substance of Concern	Injuries							
	Death	Disease	Behavioral Abnormalities	Cancer	Genetic Mutations	Physiological Malfunctions	Physical Deformities	Bioaccumulation*
Metals/Metalloids								
Antimony	Benthic Invertebrates							
Arsenic	Salmonids Benthic Invertebrates Birds					Birds		
Beryllium								
Cadmium	Salmonids Flatfish Benthic Invertebrates Birds		Flatfish Birds				Salmonids Birds	
Chromium	Salmonids Flatfish Benthic Invertebrates Birds					Salmonids Benthic invertebrates	Birds	
Copper	Salmonids Flatfish Benthic Invertebrates Birds							
Lead	Salmonids Flatfish Benthic Invertebrates Birds		Birds			Benthic invertebrates Birds	Salmonids Birds	
Mercury	Salmonids Flatfish Benthic Invertebrates Birds		Birds			Benthic invertebrates Birds	Birds	Salmonids Flatfish Benthic invertebrates Birds
Nickel	Flatfish Benthic Invertebrates							
Silver	Flatfish Benthic Invertebrates							

Table 5-1. continued

Substance of Concern	Injuries							
	Death	Disease	Behavioral Abnormalities	Cancer	Genetic Mutations	Physiological Malfunctions	Physical Deformities	Bioaccumulation[a]
Metals/Metalloids (continued)								
Zinc	Salmonids Flatfish Benthic Invertebrates Birds		Salmonids			Benthic invertebrates Birds	Benthic invertebrates Birds	
Organic Compounds								
PAHs	Salmonids Flatfish Benthic Invertebrates	Flatfish		Flatfish	Flatfish	Salmonids Flatfish	Flatfish Birds	
PCBs	Benthic Invertebrates Salmonids Birds		Birds			Salmonids Flatfish	Birds	Salmonids Flatfish
DDE/DDD	Salmonids Benthic Invertebrates					Birds		Flatfish
Chlorinated benzenes	Benthic Invertebrates Salmonids							
Hexachlorobutadiene	Benthic Invertebrates							
Phenols	Salmonids Benthic Invertebrates Birds					Salmonids Birds		
Phthalate esters	Benthic Invertebrates Salmonids		Flatfish					
Dibenzofuran								
Tetrachloroethane	Benthic Invertebrates							
Benzyl alcohol	Benthic Invertebrates							
Benzoic acid	Benthic Invertebrates							
Others								
Dioxins	Salmonids Birds					Birds		

[a] Bioaccumulation resulting in exceedence of U.S. Food and Drug Administration Action Levels or fishing closures.

that SOCs in sediments at concentrations less than those observed in some areas of Commencement Bay cause mortality of benthic organisms. Thus, alterations of benthic community structure associated with high concentrations of An SOC can be used as a measure of injury by death. Tetra Tech (1985) reported significant depressions (relative to reference conditions) in abundance of two or more major taxonomic groups (i.e., polychaetes, molluscs, and crustaceans) at the head and mouth of the Hylebos Waterway, the St. Paul Waterway, the head of Thea Foss Waterway, the Wheeler-Osgood Waterway, and along the Ruston-Pt. Defiance shoreline. In addition, depression in benthic communities has also been reported along the Ruston-Pt. Defiance Shoreline by Parametrix (1991c, 1993).

Sediment bioassays have been used extensively to determine the toxicity of contaminated sediments in Commencement Bay. As defined by 43 CFR§11.62, laboratory toxicity testing can be used to determine injury when a statistically significant difference can be measured in the total mortality rates between population samples of test organisms placed in exposure chambers containing concentrations of a hazardous substance and those in a control chamber. Tetra Tech (1985) reported that sediments from 18 of 52 sampling stations were toxic to the amphipod *Rhepoxinius abronius* in bioassays. Sediments that were toxic to the amphipod occurred at one or more stations in all areas except the Middle Waterway.

Exposure to sediments from 15 of the 52 stations sampled caused significant abnormality in an oyster larvae (*Crassostrea gigas*) sublethal bioassay. Significant oyster larvae abnormality was measured in the Hylebos, St. Paul, and Thea Foss Waterways, and along the Ruston-Pt. Defiance Shoreline. Overall, 24 of the 52 stations displayed significant adverse effects from one or both of the bioassays. For the purpose of this review, larval abnormality is assumed to result in death, because abnormal larvae will likely not survive beyond the larval stage.

Although impacts to benthic communities due to sediment-associated substances of concern are well documented for portions of Commencement Bay, additional studies should be undertaken to better define the extent of this injury, because the epibenthic and benthic communities play such an important role in the health of the Commencement Bay ecosystem.

5.2.2 Injury Category—Disease

The DOI regulations consider fin erosion to constitute an injury when a statistically significant difference can be measured in the prevalence (proportion of total individuals affected expressed as a percentage) of fin erosion in a population sample from the assessment area as compared to a sample from a control area. Fin erosion in English sole, rock sole, and starry flounder was reported in the Hylebos Waterway and at the mouth of the Puyallup River by McCain et al. (1983) and Malins et al. (1988). Fin erosion prevalence in the Hylebos Waterway was 7.0 percent for English sole and 9.0 percent for rock sole. Fin erosion prevalence in starry flounder at the mouth of the Puyallup River was 14.6 percent. In a 1982 study, Malins et al. (1982) reported fin erosion prevalence in rock sole from the Hylebos Waterway was only 2.5 percent, while the prevalence of fin erosion in English sole was only 0.3 percent.

The effect of fin erosion on the survival of these species has not been investigated in Commencement Bay. However, Cross (1985) found an age-dependent correlation between the incidence of fin erosion and decreased survival among Dover sole in southern California coastal waters. Survival rates decreased significantly for Dover sole more than 3 years old with fin erosion, but survival rates of sole with and without the disease were not significantly different for fish 1 to 3 years in age. These data provide sufficient information to establish injuries to Commencement Bay fish species due to fin erosion. However, additional evaluation may be required given the prevalence of fin erosion in Puget Sound as reported by Miller et al. (1977).

5.2.3 Injury Category—Behavioral Abnormalities

Two responses meet the acceptance criteria for injury. They are clinical behavioral signs of toxicity and avoidance. At this time, no injuries of either type have been identified in the Injury Study Area.

5.2.4 Injury Category—Cancer

The DOI regulations base the definition of injury due to fish neoplasm on a statistical comparison of the assessment area to a control area. The presence of fish neoplasms is well documented in the study area and occurs most commonly in English and rock sole. Several

studies involved the collection and analysis of these species for the presence of hepatic neoplasms and compared the incidence of neoplasms to levels of hazardous substances in sediment (Malins et al., 1982, 1984, 1985; Tetra Tech, 1985).

Malins et al. (1984) found hepatic neoplasms in English sole at a prevalence rate ranging from 0 to 4.0 percent for specimens collected off the Ruston-Pt. Defiance Shoreline and from 3.4 to 4.4 percent in specimens collected from the waterways of Commencement Bay. Tetra Tech (1985) found a similar incidence (2.9 percent) at stations throughout Commencement Bay waterways, but also compared neoplasm prevalence among waterways. The highest incidence of hepatic neoplasms in English sole was observed in Middle Waterway (8.3 percent), followed by Sitcum Waterway (5.1 percent), Milwaukee Waterway (3.3 percent), and Hylebos Waterway (2.8 percent). No neoplasms were observed in specimens collected from the Ruston-Pt. Defiance Shoreline. The prevalence rate of hepatic neoplasms reported for fish from Commencement Bay is significantly higher than the prevalence rate in non-urban reference areas and offshore areas within Commencement Bay, which is near zero (Malins et al., 1984; Dinnel et al., 1986).

Malins et al. (1984) also found statistically significant correlations between the prevalence of hepatic neoplasms in English sole and Pacific staghorn sculpin and concentrations of total PAHs (and metals for English sole) in the sediments of several urban bays in Puget Sound. Sufficient data exist to establish injuries to Commencement Bay fish species due to the prevalence of neoplasms.

5.2.5 Injury Category—Physiological Malfunctions

Few extensive studies have been conducted that explicitly identify physiological malfunctions that may affect the survival and reproductive success of fish, invertebrates, birds, or mammals that inhabit Commencement Bay. Investigations have been conducted to assess how sediments contaminated with PAHs and PCBs affect English sole and juvenile chinook salmon (Johnson, et al., 1988; Stein et al., 1991). Results of these investigations have demonstrated reproductive and immunological effects following exposure to contaminated sediment. Reduced concentrations of the female sex hormone, estradiol, and signs of inhibited ovarian development in English sole have been observed in both field populations (Johnson et al., 1988) and following laboratory exposures (Stein et al., 1991).

The inhibition of ovarian development has been shown to be related to reduced spawning in English sole populations in Puget Sound (Casillas et al., 1991).

Varanasi et al. (1993) reported that juvenile chinook salmon exhibited suppression in the immune competence when exposed to sediments contaminated with PAHs and PCBs. Alterations in the immune function could lead to lower resistance to disease and possibly reduced survival and growth.

Studies of great blue herons and glaucous-winged gulls have investigated physiological injuries (i.e., reproduction and eggshell thinning) in birds from the Injury Study Area (Calambokidis et al., 1985; Fry et al., 1987). Continuing studies on eggshell thickness and reproduction of great blue herons have been conducted in 1988, 1992, and 1993 (Norman 1991; Block, 1992; Washington Department of Wildlife 1993). Norman (personal communication, 1994) indicates that thicknesses of heron eggshells from birds suspected of feeding in Commencement Bay and nesting nearby at Dumas Bay are less than the thicknesses observed prior to the period of DDT use, and that reproductive rates are below those in other nearby colonies.

The most definitive study to date on potential effects of contaminants from Commencement Bay upon wildlife in Puget Sound was the study of glaucous-winged gulls in 1984 (Calambokidis et al., 1985; Fry et al., 1987). This study compared gulls nesting in downtown Seattle and in Commencement Bay (on top of the Simpson Pulp Mill), with colonies on Smith Island (in the Straits of Juan de Fuca), in Olympia, and with historical studies performed on Mandarte Island (west of San Juan Island in Haro Strait). Measurements included clutch size, fledgling success, growth rates, eggshell thickness, external abnormalities, hematology, histopathology, and infectious agents. Significant differences were found between many of the colonies.

In situ bioassays using juvenile crabs (*Cancer gracilis*) and several bivalve species in Hylebos Waterway did not show increases in mortality compared to organisms from a Port Susan reference area (Malins et al., 1982) However, elevated concentration of substances of concern associated with sediment were found in the tissues of both the crabs and bivalves. Caged bivalves in the Hylebos Waterway accumulated more than 15 times the concentration of total PAHs, nearly 30 times the concentration of PCBs, and more than 300 times the concentration of hexachlorobenzene compared with the Port Susan bivalves. The

concentrations of these substances were also elevated in crab tissue, although to a lesser degree (Table 5-2).

Table 5-2. Comparison of Substances of Concern Concentrations in Clams (*Macoma nasuta*) and Crabs (*Cancer gracilis*) from Hylebos Waterway and a Reference Area

Sample	Concentration (ppb dry weight)			
	Total PAHs	Total PCBs	Total Chlorinated Butadienes	Hexachloro-benzene
Clam - Hylebos Waterway	15,000	1,800	678	270
Clam - Reference Area	970	62	<2.5	0.88
Crab - Hylebos Waterway	390	910	29	120
Crab - Reference Area	150	99	<2.2	1.7

Source: Malins et al. (1982).

Although bioaccumulation, in and of itself, is not considered a measure of injury, the results of the study by Malins et al. (1982) indicate that substances of concern may be accumulating to a degree sufficient to result in physiological malfunctions, while not resulting in death. Exposure to sediment-associated substances of concern could affect growth and reproductive success in key resources in Commencement Bay. Dillon (1984) summarizes physiological and reproductive effects associated with exposure and accumulation of a number of substances of concern and serves as evidence that physiological dysfunction, which can result in decreased survival and reproductive failure, occurs in association with the accumulation of hazardous substances.

Additional studies need to be conducted to better define the extent to which exposures to substances of concern are affecting physiological functions and reproductive success in Commencement Bay species. Studies should focus on the effects of the SOCs on out-migrating salmonids and on the survival, growth, and reproductive success of various flatfishes, epibenthic and benthic species, and birds.

5.2.6 Injury Category—Genetic Mutations

At this time, no injuries of this type have been identified in the Injury Study Area.

5.2.7 Injury Category—Physical Deformities

Under the DOI regulations, injury due to histopathological lesions has occurred if a statistically significant difference can be measured in the prevalence of tissue or cellular lesions compared to samples from populations from an assessment area and a control area. Malins et al. (1984) found preneoplastic lesions in English sole livers at elevated frequencies in the Injury Study Area of Commencement Bay as compared to non-urban embayments of Puget Sound. Examples of preneoplastic lesions are hyperplasia/foci of cellular alteration, megalocytic hepatosis, and steatosis/homosiderosis. Preneoplastic lesions are similar to conditions reported in mammals that generally progress to neoplasms and are believed to be irreversible. In general, preneoplastic lesions are proliferative and regenerative and possess atypical cellular characteristics (Malins et al., 1982).

In addition to liver lesions, tumorous skin growths, angioepithelial nodules, and epidermal papillomas were reported in rock and English sole (Malins et al., 1982). Nine percent of the rock sole captured by Malins et al. (1982) in southwest Commencement Bay had these growths; some fish were also affected in both urban areas and areas of Puget Sound used to define baseline conditions.

A study of glaucous-winged gulls showed that birds from the Injury Study Area had a high incidence of traumatic lesions on their feet, liver atrophy, cellular damage characterized by iron-positive staining of hepatocytes, fatty deposits, and mild diffuse hepatitis (Calambokidis et al., 1985). These conditions are characteristic of exposure to either toxic substances or disease. It is important to note that these conditions were also reported in two relatively pristine colonies at Smith and Goose Islands.

Sufficient data exist to establish injuries to Commencement Bay fish species due to the prevalence of histopathological lesions. The data on injuries to glaucous-winged gulls, by histopathological lesions and internal whole organ or soft tissue malformation, are sparse and further studies would be required to establish injury under the regulations.

5.2.8 Injury Category—Elevated Concentration of Substances of Concern in Edible Fish and Shellfish Tissue

Biological injury as defined in 43 CFR §11.62(f)(i) also occurs when the concentrations of hazardous substances "(ii) exceed action or tolerance levels established under Section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342 in edible portions of organisms; or (iii) exceed levels for which an appropriate state health agency has issued directives to limit or ban consumption of such organisms."

Several studies have documented elevated concentrations of contaminants in edible portions of fish and shellfish from Commencement Bay (Malins et al., 1981; U.S. DOC, 1981; Gahler et al., 1982; Tetra Tech, 1985). The remedial investigation presented a public health assessment of risks from carcinogens and noncarcinogens in English sole muscle and livers and crabs from Commencement Bay assessment areas. Nicola et al. (1987) further characterized the risks to human seafood consumers in the Commencement Bay area using data on the concentration of SOCs in various species of bottom-fish and cod.

Results from risk evaluations by Tetra Tech (1985) and U.S. EPA (1985) suggest that risks due to PCB concentrations in fish and shellfish are at least 10 times higher than risks due to the concentrations of other carcinogens. For noncarcinogens, U.S. EPA (1985) determined that the ratio of exposure from consumption of Commencement Bay fish to the accepted daily intake (intake above which toxic effects would be expected over a lifetime) was greater than 1 for antimony (1.57), mercury (1.35), silver (3.92 from consumption of crabs), and zinc (1.20 from consumption of crabs). The ratio for lead was 0.99. Based on the data on the concentration of SOCs in fish and shellfish, as well as fish histopathology data, the Tacoma-Pierce County Health Department posted notices and issued a press release in 1981 advising people not to eat bottom-fish from Hylebos Waterway (Washington Department of Health, 1992). Since 1981, a total of 13 advisories have been posted, primarily in the waterways of Commencement Bay (Tacoma-Pierce County Health Department, personal communication, 1994). A summary of the SOCs found in tissue residues that have led to advisories or closures was presented in Table 2-5.

No additional studies are required to establish injuries associated with the levels of contaminants in the edible portions of fish and shellfish.

5.3 SUMMARY OF POTENTIAL INJURIES

A variety of abiotic and biological changes that can be considered injuries under the regulations have been linked to the SOCs in Commencement Bay. At least eight injuries have been documented in the Injury Study Area of Commencement Bay, including:

- Exceedance of acceptable and applicable criteria for surface water
- Exceedance of acceptable and applicable criteria for sediment
- Death
- Disease
- Cancer
- Physiological malfunctions
- Physical deformities
- Elevated concentrations of hazardous substances in edible fish tissue that have led to the posting of fishing advisories

Of the six injuries to biological resources documented in Commencement Bay, elevated concentrations leading to the posting of fishing advisories and death are the best documented. Immunosuppression and other forms of physiological dysfunction, although not well documented in the Injury Study Area, may also prove to be important injuries to key biological resources. Documenting injuries to birds frequenting Commencement Bay will require further analysis.