Budd Inlet and Oakland Bay Dioxins and Furans

2011 Sediment Results

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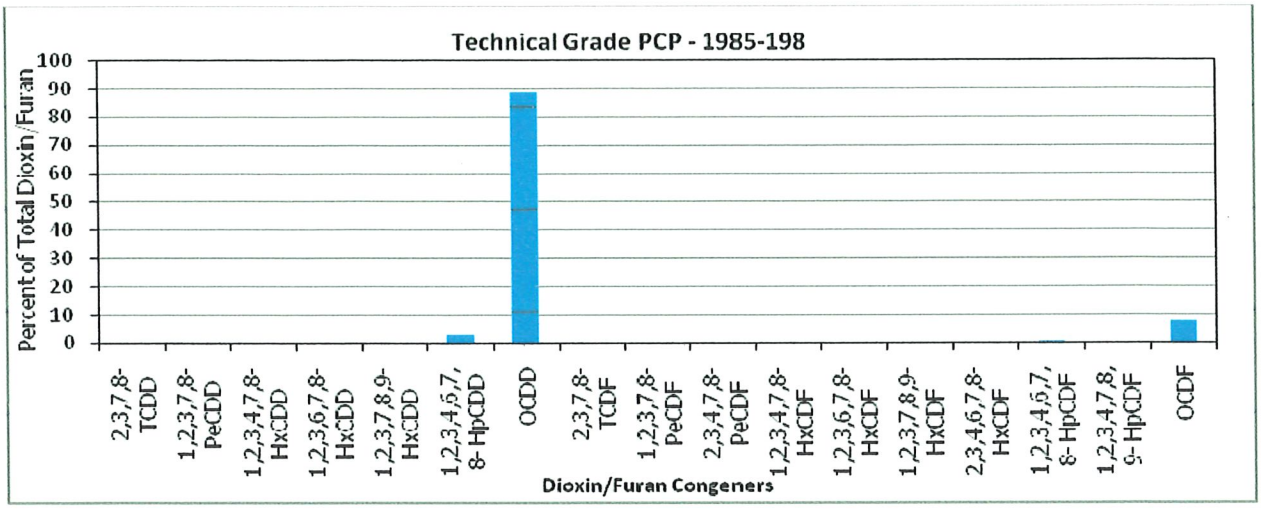

Figure 17. Technical Grade Pentachlorophenol Profile (taken from Herrera, 2010).

The same profile was seen in results from the 2007 characterization study of Budd Inlet. SAIC (2008) points to the Cascade Pole wood treatment site as the source of contamination, but notes that all wood treatment facilities present could contribute to contamination, and to narrow down the source to a single facility would be difficult.

This PCDD/F profile has been found throughout Puget Sound (Herrera, 2010). (See discussion for congener profiles for Oakland Bay below which includes congener comparison to black liquor recovery boiler emissions as well as for PCP.) Because this profile appears to be a dominant trend throughout Puget Sound, it may be advantageous to plot the TEQ-adjusted profiles from future, more extensive data sets to help identify potential PCDD/F sources.

Conclusions

Budd Inlet exhibits a variety of dynamic variables that influence PCDD/F concentrations within sediment samples. Grain size was predominantly fines, and the highest TOC (>3.5%) was found in lower Budd Inlet or where organic debris may be located. The highest PCDD/F TEQs were found also in Inner Budd Inlet, with an overall average of 24.7 ng/kg. Mixed PCDD/F results were found in the few (six) locations where the upper portion (0-2 cm) of the sample was compared to the 0-10 cm results, although the highest concentration for this study was found in the upper 2 cm portion (inner and central areas). This variability makes it unclear whether there has been change over time, but two 2011 results taken from the same general location as in 2007 had lower concentrations, which may reflect cleaner sediment because of several cleanup projects or Capital Lake drawdown events previous to 2011.

Background PCDD/F concentrations were difficult to determine because of high variability found in the samples throughout the bay. Budd Inlet's counterclockwise circulation, with over half the water refluxing in a weak gyre, distributes sediments to the lowest energy areas of the bay. It is unknown the role local disturbances may play in sediment resuspension. Since it was found that more than half of the sediment is resuspended at all times of the year (LOTT, 1998), the possibilities of elevated PCDD/F concentrations from known areas of contamination could be a function of hydraulic circulation and energy. This could be, in part, why the upper portion (0-2 cm) of samples continues to have elevated PCDD/F concentrations.

A decreasing PCDD/F concentration south-to-north trend was observed through spatial analysis. A less clear trend was noted increasing from west to east. Results from samples with high levels of PCDD/Fs from areas known for contamination masked the findings by weighting the model towards those areas.

Further investigating and characterizing sediment deposition and resuspension would help define areas where fresh versus older sediment is deposited. Low levels of PCDD/F concentrations would likely be found in areas where resuspended sediment is low, assuming no current source of contamination exists. These areas appear to be favoring the northwest portion of the bay.

Four samples in this study were below the TEQ concentration of 4.0 ng/kg as identified by the OSV Bold Survey (USACE, 2009). These samples were located in northern Outer Budd Inlet.

Profiles of PCDD/F congeners in this 2011 study matched previous investigations identifying Technical Grade Pentachlorophenol used in treating wood. Although Cascade Pole has been identified as one source of PCDD/F contamination, it is known that there were other historic sources to Budd Inlet, such as hog fuel boilers found previously along the shoreline at the Hardel lumber yard site.

Oakland Bay

Conventional Parameters

Ten sediment samples collected (each at 0-2 cm and 2-10 cm depths at five stations) from Oakland Bay contained a mix of sand (ranging from 9.5% - 68%) and fines (ranging from 31% - 90%) (Table 4). These results are consistent with the Oakland Bay Sediment Characterization Study (Herrera, 2010) which collected over 30 cores and grain size samples within the bay and Hammersley Inlet and found the distribution of sediment varies from coarse to fine along the direction of transport. Coarser material was found at the creek deltas, with finer material moving to the deeper and less hydraulic energetic portions of the bay.

Table 4. Oakland Bay Grain Size and TOC (N=10).

Percent (%)	Minimum	Mean	Maximum
Gravel	0.1	0.9	2.5
Sands	9.5	41	68
Silts	24	38	52
Clays	7.3	21	38
Fines	31	59	90
TOC	2.5	3.0	3.3

Samples in this study that contained coarser material (i.e., sand) were collected in Shelton Harbor and north of Bayshore Point (Figures 18 and 19). Goldsborough and Shelton Creeks, located in the middle and north areas of Shelton Harbor respectively, provide hydraulic energetic transport, distributing the more fine-grain sediments into the middle of the harbor and possibly further out in the bay, with Goldsborough Creek transporting the majority of the sediment input (Herrera, 2010).

Near Bayshore Point there is a deep hole maintained by intermittent intense flow, which deposits coarse materials including shells transported via bedload (transport that occurs near the bed) (Herrera, 2010). Heavy material is trapped, but fine grains are not deposited because the currents in the areas are too strong.

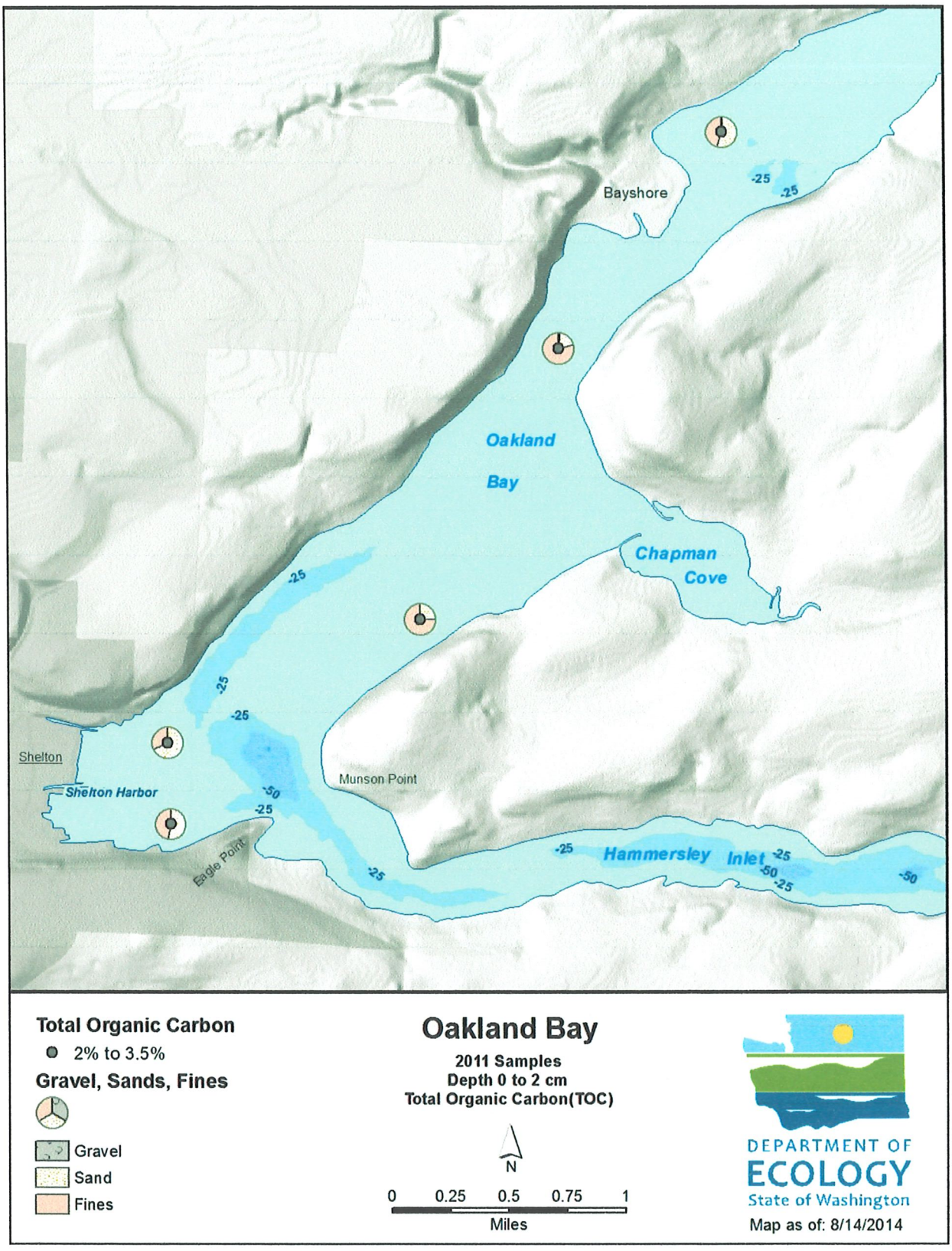

Figure 18. Percent Grain Size and TOC in Surface Sediments (0-2 cm) of Oakland Bay, 2011.

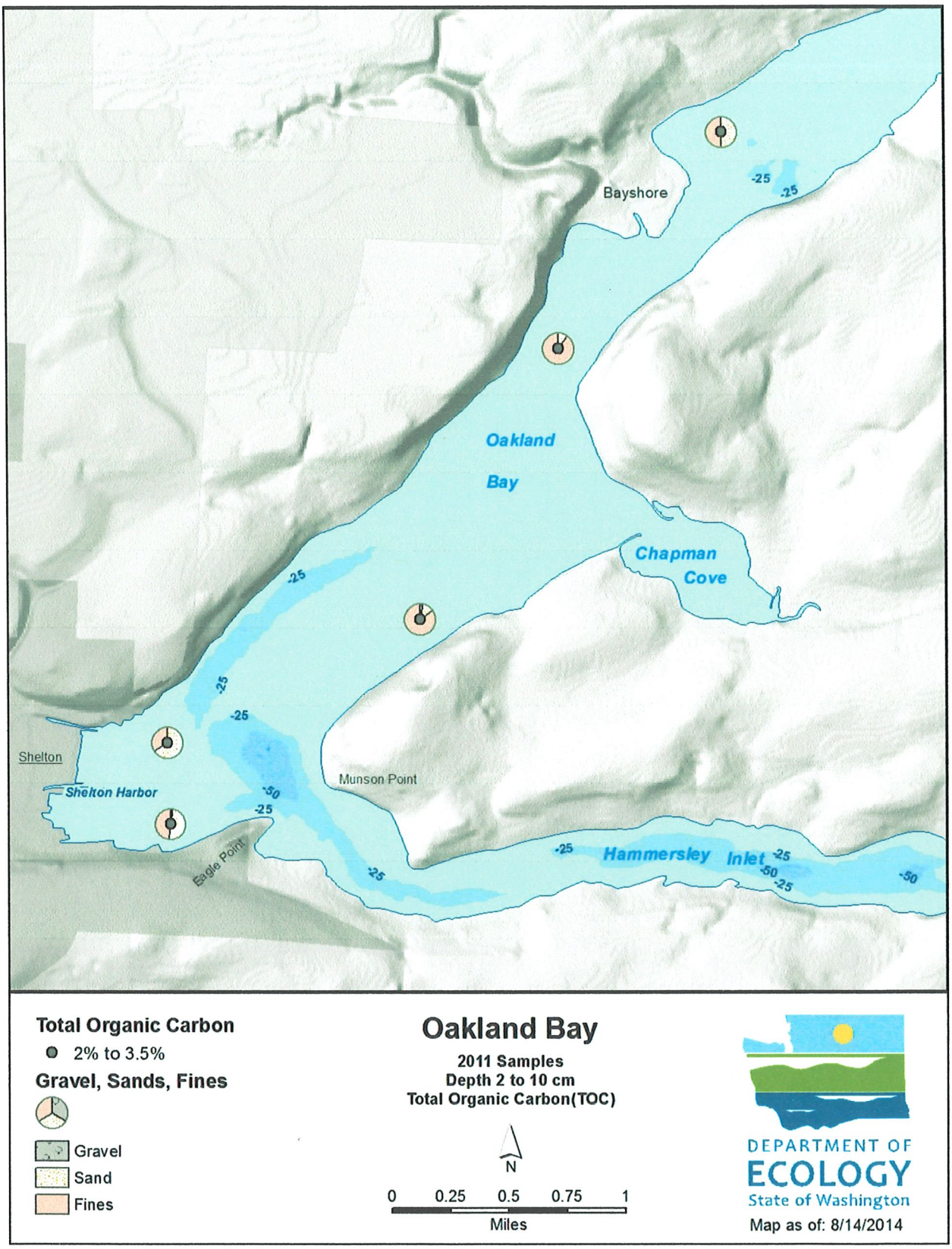

Figure 19. Percent Grain Size and TOC in Surface Sediments (2-10 cm) of Oakland Bay, 2011.

Figure 20 illustrates the difference between the upper portion (0-2 cm) and a lower portion (2-10 cm) of the Oakland Bay sediment samples collected for this study.

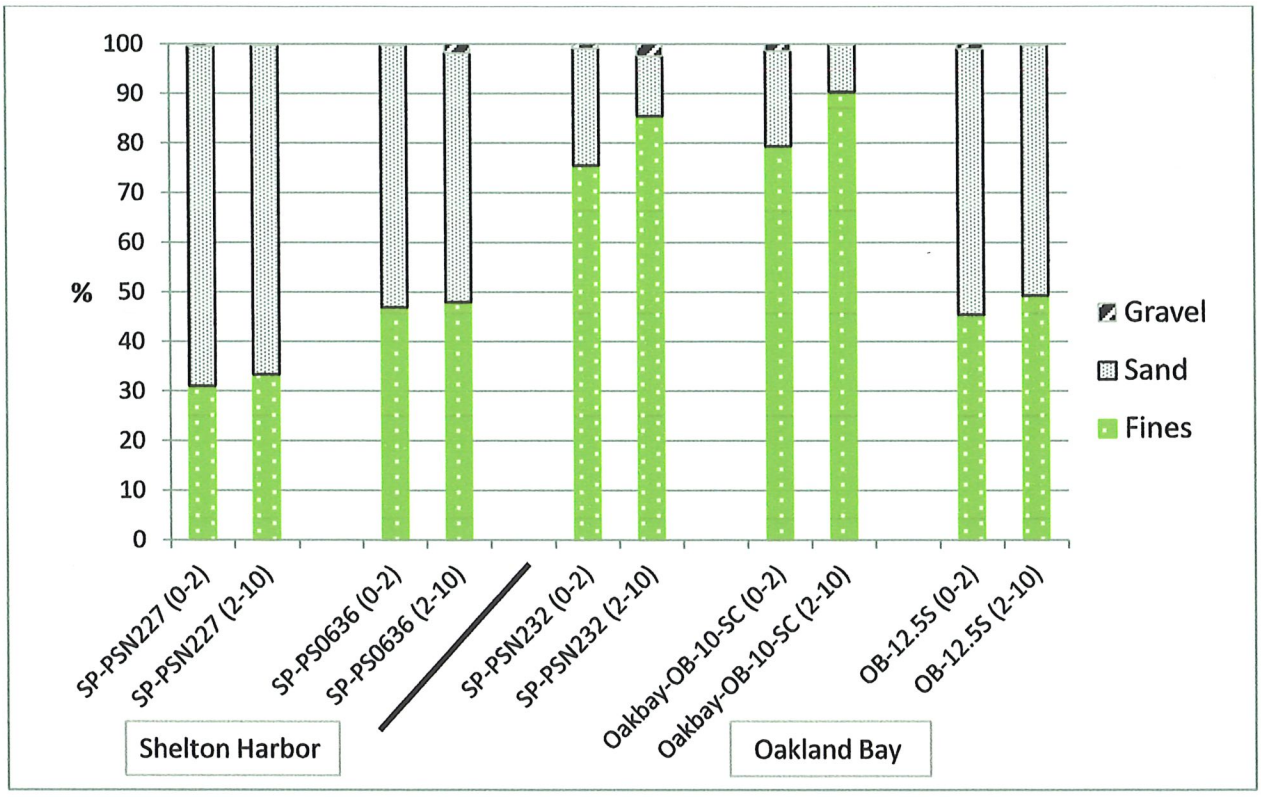

Figure 20. Oakland Bay Grain Size Compared at Different Depths, 2011.

Two of the five samples (SP-PSN232 and Oakbay-OB-10-SC) contained predominantly fines (>70%). These samples were collected within the middle portion of the bay and represent most of the bay where hydraulic energy transport is low. The other three samples (SP-PSN227, PS-PS0636, and OB-12.5S) had over 50% sand and were collected in more energetic areas such as within Shelton Harbor and near Bayshore Point as described above. Very little gravel was found within the top 10 centimeters of this study's samples, but Herrera (2010) found alluvial deposits of sand and gravel overlying fine-grain marine deposits, generally within areas of high hydraulic energy as described above.

Overall, Oakland Bay has a broad distribution of fine material. Nearly all the sediment deposited within Oakland Bay stays confined within the bay and reasonably close to where it first enters the marine waters (Herrera, 2010; Albertson, 2004).

TOC content in these samples was all within the narrow range of 2.5% to 3.3% and averaged 3.0% (Figures 18 and 19). The highest TOC content was found in the harbor area. The 2008 characterization study found that, in general, TOC values above 4% were found along the shoreline in the former pond saw area throughout the southwest portion of Shelton Harbor, which also corresponded to locations with total fines greater than 45% (Herrera, 2010). In this

2011 study, no TOC results were above 4% in the five samples analyzed, and the sample (SP-PSN227) with the highest TOC had the lowest percent fines (<35%).

TOC percentage was similar when compared at different depths, 0-2 cm and 2-10 cm (Figure 21). TOC averaged 3.1% for the top 2 cm compared to 2.8% for the 2-10 cm.

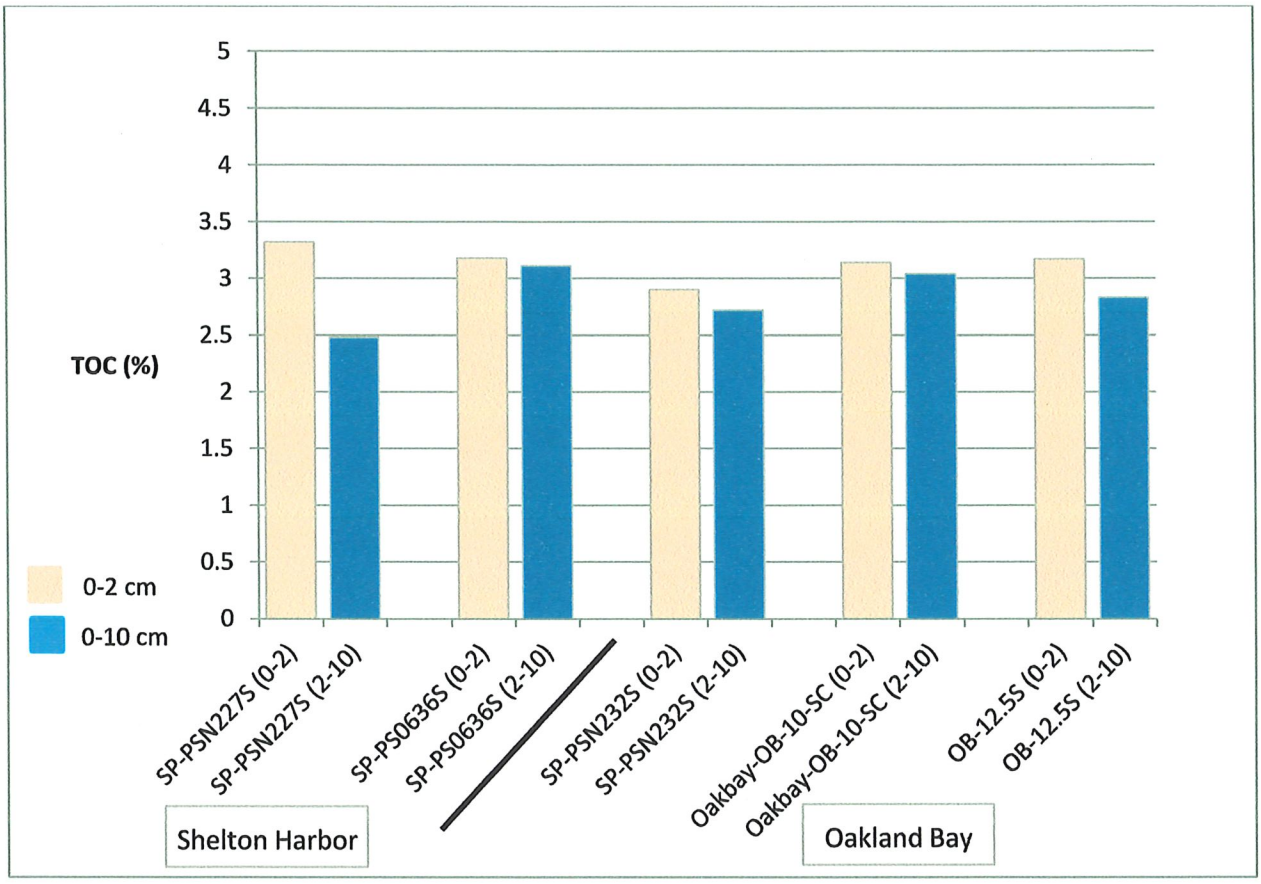

Figure 21. Oakland Bay TOC Compared at Different Depths, 2011.

TOC and fines were not much different among samples in this study, probably because of the small sample size. Herrera (2010) found TOC was generally <4% in Oakland Bay and suggests that TOC may be elevated in areas with organic debris such as wood waste. Also in agreement, Ecology's South Puget Sound study reported fine-grained sediments and highest TOC contents located in the terminal inlets (Partridge et al., 2014b).

PCDD/Fs

PCDD/Fs were detected in all Oakland Bay sediment samples (Table 5). Congener 2,3,7,8-TCDD was detected in 7 out of the 10 samples and ranged from 0.269 ng/kg to 1.61 ng/kg. Of the detected results, the average 2,3,7,8-TCDD concentration was 1.41 ng/kg.

Table 5. Oakland Bay PCDD/Fs TEQs (N=10).

	Oakland Bay	
	Shelton Harbor	Central/Outer
Number of Samples	4	6
Mean (ng/kg)	18.8	31.7
Median (ng/kg)	17.7	36.2
Minimum (ng/kg)	4.39	2.09
Maximum (ng/kg)	35.5	55.2
Maximum Location	SP-PS0636 (1106045-36)	Oakbay-OB-10-SC (1106045-37)

TEQs for these samples ranged from 2.09 to 55.2 ng/kg, with a mean TEQ of 26.5 ng/kg and a median TEQ of 29.6 ng/kg for all samples. The highest TEQs were found in the middle portion of the bay, in the two samples that contained predominantly fines and where hydraulic energy is low (Oakbay-OB-10-SC and SP-PSN232) (Figure 22). PCDD/F results for each sample are listed in Appendix C.

No pattern was evident in PCDD/Fs concentrations when comparing 0-2 cm (recent) sediments with 2-10 cm (historic) sediments. Testing was performed using a t-test and nonparametric Wilcoxon-Whitney-Mann test, $p<0.05$. Two samples had higher concentrations, and three samples had lower concentrations in the upper portions of the samples. Most samples were relatively close in PCDD/F TEQ concentration between the upper and lower portions. The small sample size limited the statistical power of the comparison tests.

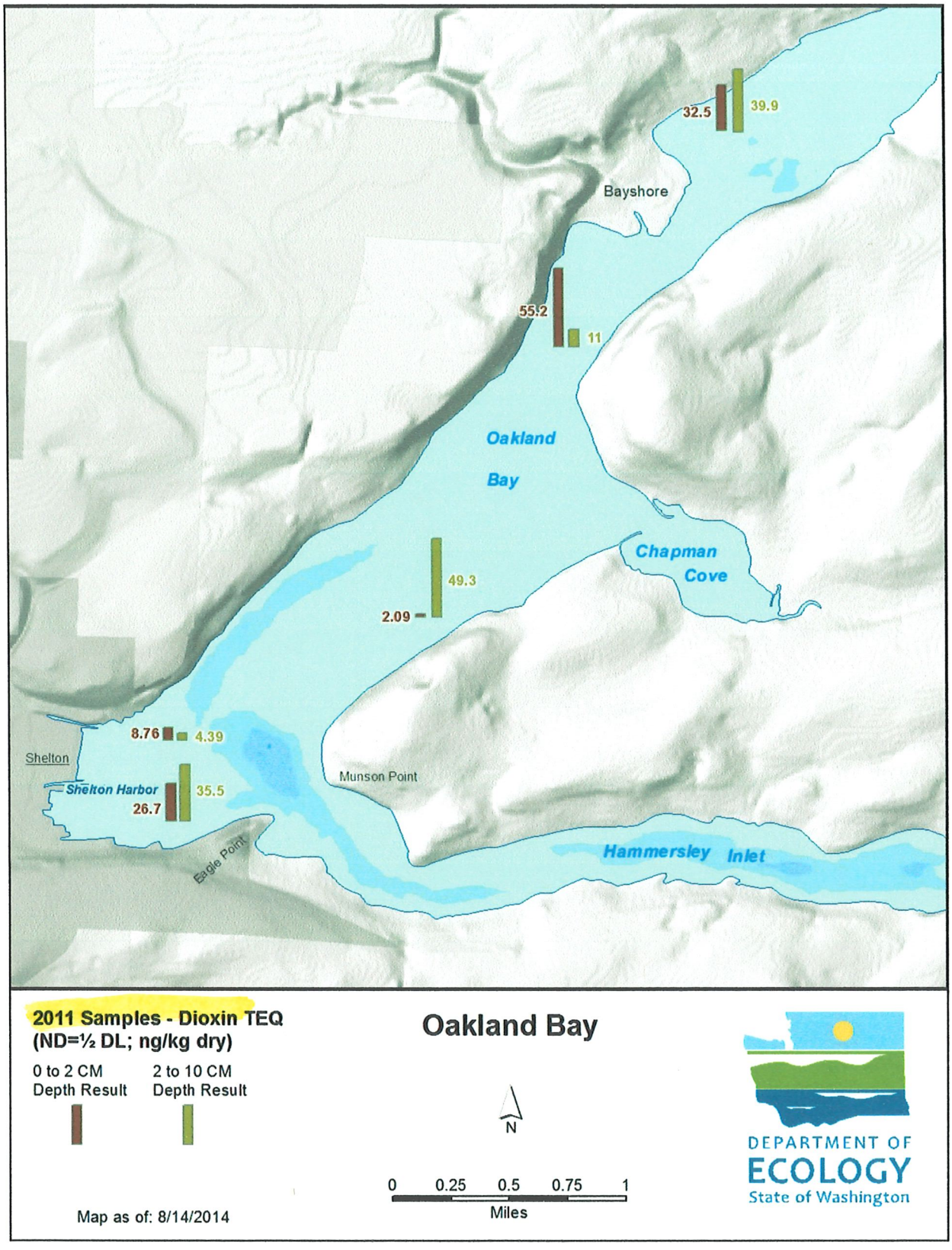

Figure 22. Distribution of PCDD/Fs Expressed as Total TEQ in Surface Sediments of Oakland Bay, 2011.

Discussion

Samples taken in Oakland Bay during 2011 showed mixed results for deciphering whether there has been a change in surface sediment concentrations for PCDD/F. The small sample size (five locations) limited the probability of seeing an effective difference between the upper (0-2 cm) and lower (2-10 cm) portions of each sample unless the differences had been large and uniform. Understanding the bay's hydraulic energy system in light of current and historical land uses may help decipher these results.

PCDD/F Results and Bay Hydraulics

Although uncertain, the different results between sample locations may be explained, in part, by the location dynamics. Hydraulics can affect the transport of sediments around the bay, and local events may explain vertical differences.

Dense seawater comes into Oakland Bay in local, high-velocity tides, flowing along a deep channel bottom from Hammersley Inlet then turning north along the western edge of lower Oakland Bay. Less dense freshwater from creeks enter the bay transporting sediment. Although some mixing occurs, the less dense freshwater tends not to mix deeply with the marine water. An effect of this is that the heavier grained sediment settles out closer to the mouths of the creeks, forming large deltas, whereas the fine-grain sediments travel further out in the bay. Some of the fine grain and colloidal fractions, but a small fraction of the total sediment load, will move out of the bay near the surface (Albertson, 2004; Herrera, 2010).

Herrera (2010) found substantial creek sediment input to Shelton Harbor. The creek sediment source could be a cleaner source, but only if confirmed within the creek itself. A recent study found PCDD/Fs measured in sediment from three streams – Shelton, Goldsborough, and Johns Creeks located in north Shelton Harbor, middle Shelton Harbor, and Bay Shore area, respectively – were very low (generally below 4.0 ng/kg TEQ) (Coots, 2013). However, two soil samples taken from a large ash mound on the bank of Shelton Creek had TEQ concentrations comparable to those reported here (21.3 and 41.1 ng/kg). Downstream of the ash mound, Shelton Creek had somewhat elevated PCDD/Fs in sediments (although well below the highest levels found throughout the bay). Based on this information, it is possible that the mound could be a potential source of PCDD/Fs, particularly during run-off periods and higher flow.

In light of the above information, one should not rule out the possibility of deposition of fines moving further out in the bay due to higher hydraulic energy found near the creeks. Core samples indicated high rates of accumulation within central Oakland Bay, implying that sediment does migrate from Shelton Harbor (Herrera, 2010). This could help explain the elevated levels found further out in the bay.

Local events near some of the sampling locations for this study may give some explanation of the mixed differences found between samples in the vertical deposition of PCDD/Fs concentrations. Two of the samples outside of Shelton Harbor may have possibly undergone local disturbances. Herrera found Bayshore Point an area of transition between disturbed and undisturbed sedimentation when analyzing core samples. Sample OB-12.5S for this study was

collected in this area. PCDD/Fs concentration results between the upper and lower portion of the sample may be within the variability possible for this area.

Current seepage and landslide activity (in 2002) (Herrera, 2010; Ecology, 2014) in the area near sample SP-PSN232 may mask the results by overlaying sediment with cleaner soil from the disturbed bank. This sample had the largest difference between the upper and lower portions of the sediment (2.09 and 49.3 ng/kg TEQ, respectively).

Only sample Oakbay-OB-10-SC appeared to be located in an area without local disturbances or high hydraulic energy (below Bay Shore in the central portion of the bay), which coincides with high fines and elevated PCDD/F in the upper portion of the sample (55.2 ng/kg TEQ). Furthermore, the concentration of 55.2 ng/kg in the upper portion (0-2 cm) of this sample was similar to the result of 53.6 ng/kg TEQ collected in the same location (0-10 cm) in 2008. The concentration in the lower portion (2-10 cm) of the 2011 sample was much lower (11.0 ng/kg TEQ).

The two samples from the inner harbor area showed lower results. Goldsborough Creek draining into the harbor area contributes substantially to the sediment deposition found in the bay and may explain these lower levels of PCDD/F.

Results and Puget Sound Background Levels

Currently Ecology's Toxic's Cleanup Program has no numeric Sediment Quality Standard (SQS) or Cleanup Screening Level (CSL) criteria for PCDD/Fs. The OSV Bold Survey (USACE, 2009) identified a TEQ of 4.0 ng/kg for a suggested PCDD/F background level in Puget Sound sediments. As reported above, all results in this 2011 study for Oakland Bay were above this level except for SP-PSN232 in the upper portion (0-2 cm) of the sample, which was at 2.09 ng/kg TEQ. This may indicate cleaner deposition, which is possible since this site is near a bank that is failing between Munson Point and Chapman Cove. The sloughing bank could be distributing cleaner soil into the bay system.

One sample (OB-10-SC) had higher concentrations at 55.2 ng/kg TEQ in the top two centimeters compared to the lower depth (11.0 ng/kg TEQ).

Overall, PCDD/Fs continue to be present in Oakland Bay sediments above acceptable levels. Figure 23 shows all dioxin results from this study, along with results from the Herrera study.

Herrera (2010) reported PCDD/Fs ranging from 1 to 175 ng/kg TEQ, with the mean highest in Shelton Harbor (42.8 ng/kg TEQ) and the mean for Oakland Bay of 32.1 ng/kg TEQ. Both this study and the Herrera study show that the continued presence of dioxin in surface sediments indicates that there is either a continuing source of dioxin or that mixing of deeper with shallower sediments has occurred through human or natural processes.

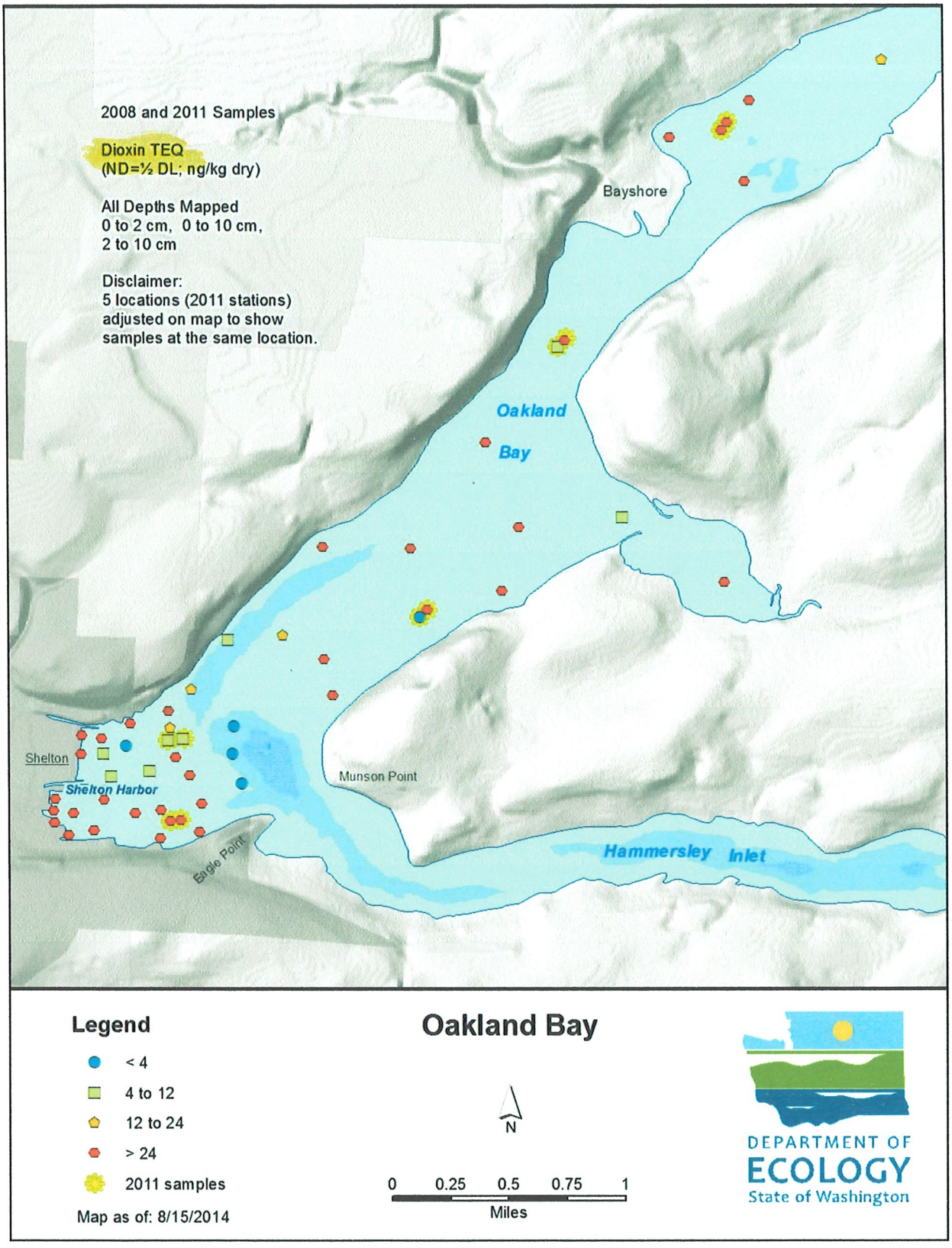

Figure 23. TEQ PCDD/F Concentrations from This 2011 Study and the Herrera Study (Herrera, 2010) in Oakland Bay.

Congener profiles

Congener profiles were used to screen for source identification and to compare the fingerprint of this 2011 study results to the 2008 characterization study by Herrera. The concentration of each individual congener (not adjusted to TEQ) was divided by the sum of the total PCDD/F concentration in a given sample. The resulting profile illustrates the relative amount of each congener observed in the each sample. TEQ-adjusted profiles were not compared in this study but may be advantageous to plot from future, more extensive data sets to help identify potential sources.

Figures 24 and 25 show the PCDD/F congener profiles for Oakland Bay sediment analysis at two depths (0-2 and 2-10 cm). Mean values are indicated by a line bar within the sample data points for each congener.

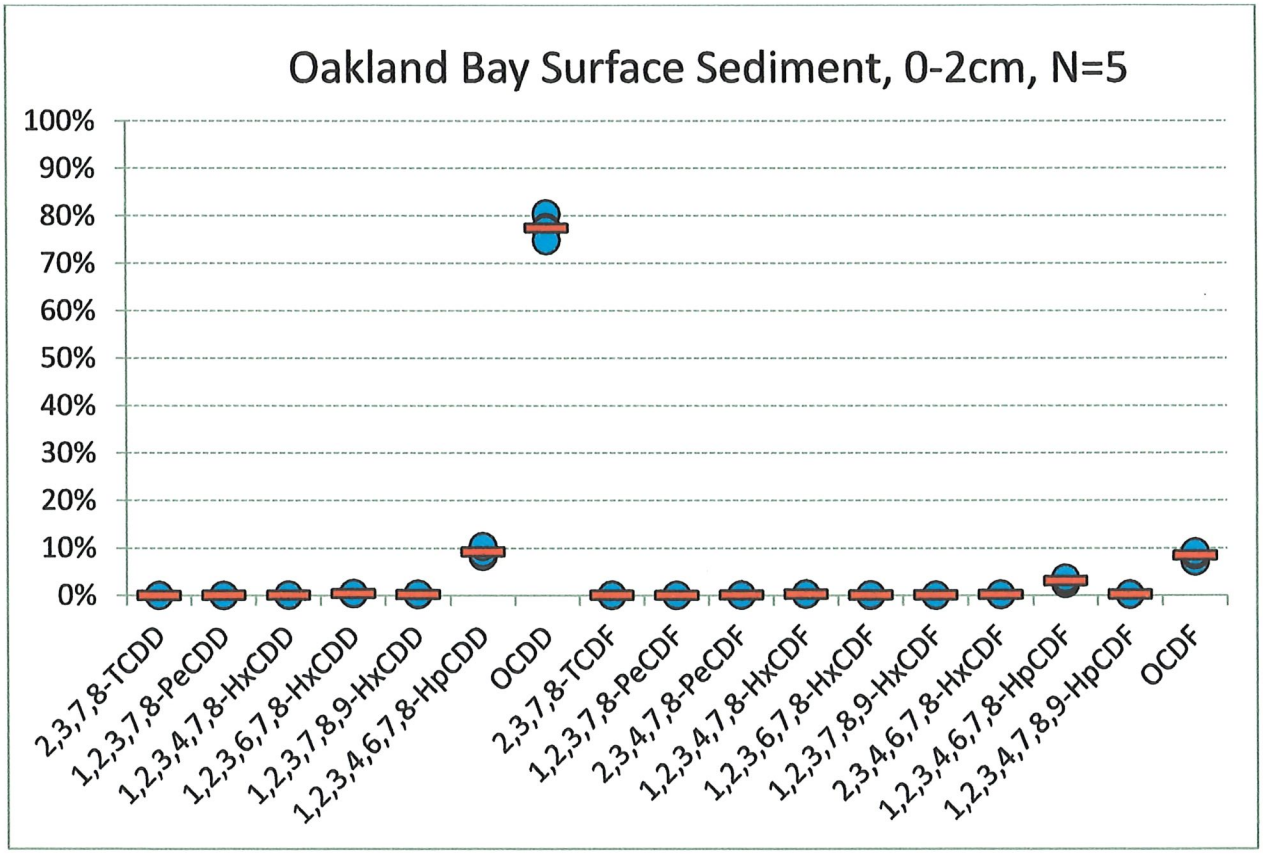

Figure 24. Oakland Bay Surface Sediment Profile, 0-2 cm. (N=5).

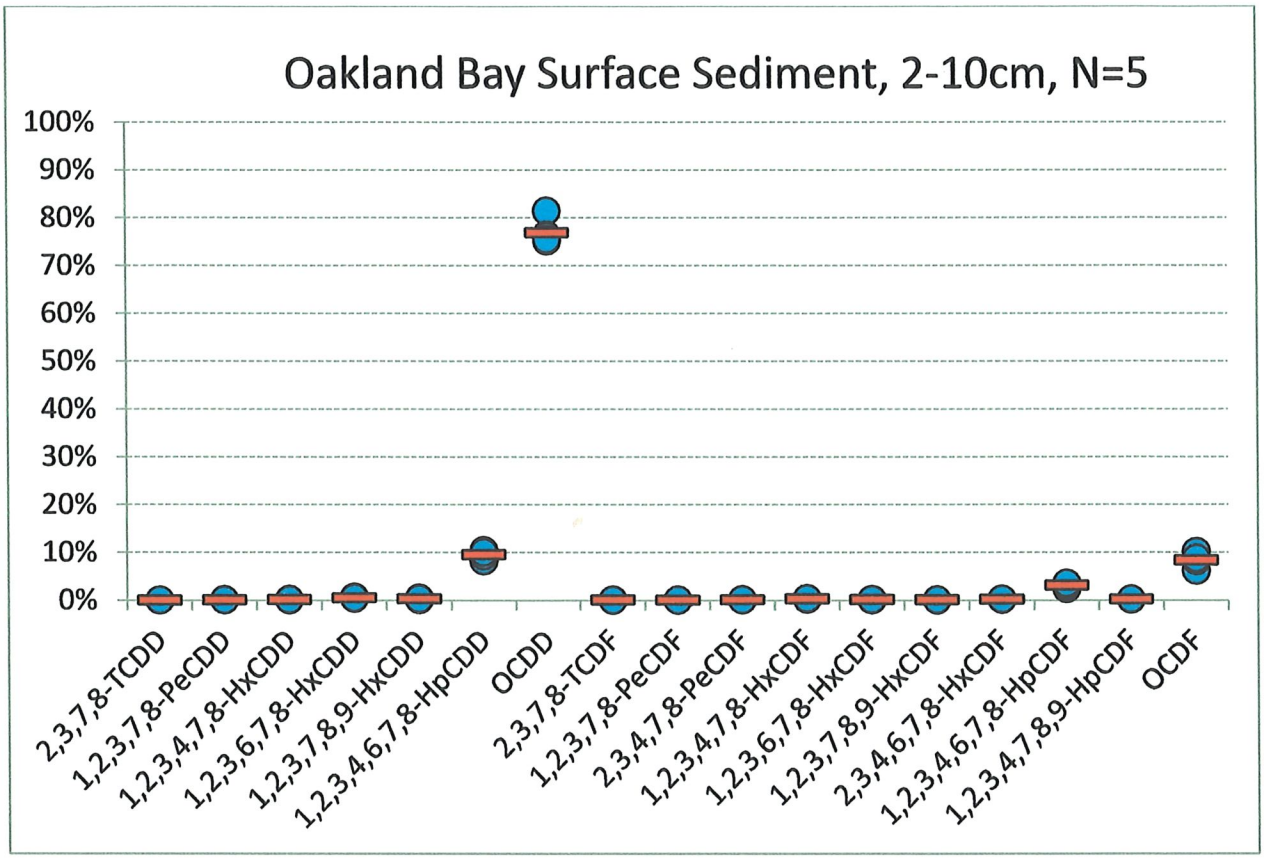

Figure 25. Oakland Bay Surface Sediment Profile, 2-10 cm. (N=5).

The PCDD/F profiles from both depths appear identical. The OCDD congener dominated the profile at a much higher percent concentration (around 75%-80%). In the absence of OCDD, 1,2,3,4,6,7,8,-HpCDD dominates the congener profile, ranging from <40% to >60%.

These profiles match profiles found in the characterization study of Oakland Bay (Figure 26). Herrera (2010) compared four sub-areas within Oakland Bay (central and outer portion of Oakland Bay, Shelton Harbor, Hammersley Inlet, and reference stations). The results of the visual profile indicated that the source of PCDD/Fs were consistent throughout Oakland Bay, including the reference areas, although concentrations in the reference samples were significantly lower than in Oakland Bay.

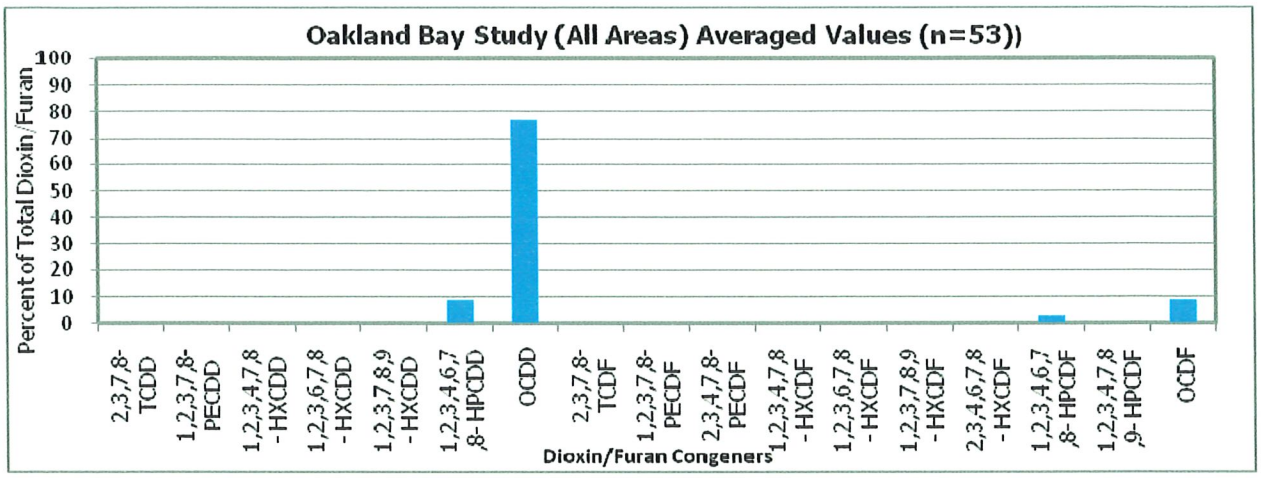

Figure 26. Oakland Bay Study Sediment PCDD/F Profile (taken from Herrera, 2010).

Data from Goose Lake and the OSV Bold Survey (USACE, 2009) background study were also compared by Herrera. The Goose Lake congener profile was similar, but did indicate greater variability than profiles of Oakland Bay (Herrera, 2010). Likewise, the congener profile for the Puget Sound background study (OSV Bold Survey) was very similar, with OCDD contributing the greatest amount to the sum total of PCDD/Fs (70% to 80%) and 1,2,3,4,6,7,8-HpCDD (around 10%).

Although these results match EPA's profile for technical grade PCP (Figure 19), there are other similar profiles. Citing information from the extensive screening by Herrera, five EPA congener profiles were similar. These included technical grade PCP, black liquor recovery boiler stack emissions, forest fires, combustion of Bleach-Kraft mill sludge in wood residue boilers, and unleaded fueled automobiles with catalytic converters (Herrera, 2010). The PCP and black liquor recovery boiler emissions appeared to match the closest, which have been linked to activities within the Oakland Bay area.

Conclusions

This 2011 study found that the limited number of samples (five locations; two sample depths) were generally in agreement with the Oakland Bay Sediment Characterization Study (Herrera, 2010). Oakland Bay has a broad distribution of fine material, and the TOC averaged 3.0%. The highest TOC was found in the harbor area, which is known for organic wood waste from former saw mills.

The highest TEQs were found in the middle portion of the bay, in the two samples that contained predominantly fines and where hydraulic energy is low. Two samples had higher PCDD/F concentrations and three samples had lower concentrations in the upper portions of the samples.

Location dynamics were examined briefly to determine the effect of recent deposition because, unless the PCDD/F concentration differences in the samples were large and uniform, the small sample size limits statistical power.

Several studies (mentioned above) determined that nearly all the sediment deposited within Oakland Bay stays confined within the bay and close to where it first enters the marine waters. However, deposition further out in the bay should not be ruled out since Oakland Bay has some of the more energetic hydraulics in Puget Sound (large tidal swings).

For this study, only sample Oakbay-OB-10-SC appears to be located from an area without local disturbances or high hydraulic energy, which coincides with high fines and elevated PCDD/F in the upper portion of the sample. That said, data gaps exist for certain areas that may have contamination sources, such as the ash mound described in a recent Ecology study (Coots, 2013).

As reported above, all results in this study for Oakland Bay were above the level of 4.0 ng/kg TEQ (OSV Bold Survey) except one, which may indicate cleaner deposition possibly due to bank erosion. Overall, PCDD/Fs continue to be present in Oakland Bay sediments above acceptable levels.

This study found the PCDD/F congener profiles in Oakland Bay matched the profiles found in the characterization study of Oakland Bay (Herrera, 2010). Although these results match EPA's profile for technical grade PCP, there are other similar profiles as described above. The PCP and black liquor recovery boiler emissions appeared to match the closest, which have been linked to activities within the Oakland Bay area. It would be difficult to determine an exact source without further sampling and analyses to match specific sources.