Marine Sediment Monitoring

Changes and Trends in Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989-2000

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PSAMP Long-term Sediment Monitoring

As part of the Puget Sound Ambient Monitoring Program (PSAMP), the Washington State Department of Ecology sampled sediments at ten fixed stations each spring from 1989 through 2000 (Figure 1). Stations were chosen from a variety of habitats and geographic locations in Puget Sound. Sediments from each station were analyzed for particle size, organic carbon content, and the presence of more than 120 chemical contaminants, as well as the types and abundances of sediment-dwelling organisms. Changes in sediment condition over this time period provide evidence for both human-driven and naturally-occurring influences on the marine ecosystem.

Figure 1. Location of 10 long-term PSAMP sediment monitoring stations in Puget Sound.

Summary of Findings

- Sediment characteristics were monitored for 12 years at 10 fixed stations in Puget Sound.
- Human-driven changes in contaminants included decreases in metal concentrations, and increases in polycyclic aromatic hydrocarbons (PAHs).
- Changes in sediment grain size and biological communities in the Strait of Georgia appear to be linked to natural variation in rainfall and river flow.
- Monitoring of fixed "sentinel" stations helps identify trends in sediment quality that raise "red flags" highlighting important environmental effects on Puget Sound.

Human-Driven Changes

Chemical contaminants in the sediments were measured yearly from 1989 through 1996 and again in 2000. The contaminants examined included priority pollutant and ancillary metals, as well as organic compounds such as polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides, polychlorinated biphenyls (PCBs), and others. The most notable changes in sediment chemistry were in metals and PAHs, and are discussed below.

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Decreases in Metals

The concentrations of most metals did not change significantly over the study period (Table 1). Those that did change generally decreased. There was a significant decrease in copper across all stations and significant decreases in metals in general at stations in Port Gardner and Budd Inlet.

Table 1. Changes and trends in metals concentrations.

Metals	Station Change 1989-1996 vs. 2000										Station Trend 1989-2000									
	Str of Georgia	Bellingham Bay	Hood Canal	Pt Gardner	Shilshole	Sinclair Inlet	Pt Pully	Thea Foss WW	Anderson Island	Budd Inlet	Str of Georgia	Bellingham Bay	Hood Canal	Pt Gardner	Shilshole	Sinclair Inlet	Pt Pully	Thea Foss WW	Anderson Island	Budd Inlet
Priority Pollutant																				
Antimony						--	--		--							--	--	--	--	
Arsenic	--	--	--	--	↓	↓	--	↓	↓	--	--	--	--	--	--	--	--	--	--	--
Cadmium						--				↓	--	--	--	--	--	--	↑	--	↑	--
Chromium	--	--	--	--	↑	--	--	↑	↑	↓	--	--	--	--	--	↓	--	--	--	--
Copper	--	↓	--	↓	↓	--	↓	--	↓	↓	--	--	--	--	--	↓	↓	--	--	--
Lead	--	--	--	--	--	--	--	↓	--	↓	--	--	--	--	--	--	--	--	--	↓
Mercury	--	↓		--	--	--	--	↓	--	↓	--	--	--	--	--	--	↓	--	↓	--
Nickel	--	--	--	↓	--	↓	--	--	--	↓	--	--	--	--	--	--	--	--	--	--
Silver	--	--	--	↓	--	--	↓	--		--	--	--		--	--	--	--	--	--	--
Zinc	--	↓	--	↓	--	--	--	↓	--	↓	--	--	--	--	↓	↓↓	↓	--	--	--
Ancillary																				
Aluminum	--	--	--	↓	--	--	--	↓	--	↓	--	--	--	--	--	--	--	--	--	--
Iron	--	↓	--	↓	--	--	↓	--	↑	↓	--	--	--	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	↓	↓	--	--	--	--	--	--	--	--	--	--	--	--	--

↑,↓ = increase, decrease (α=0.05); ↑↑, ↓↓ = increase, decrease (α = 0.01); -- = no change; blank = insufficient data. Shaded results indicate changes for all stations combined for a single compound or for all compounds combined for a single station, at α=0.05.

Table 2. Changes and trends in PAH concentrations.

PAH Compounds	Station Change 1989-1996 vs. 2000											Station Trend 1989-2000										
	Str of Georgia	Bellingham Bay	Hood Canal	Pt Gardner	Pt Gardner[oc]	Shilshole	Sinclair Inlet	Pt Pully	Thea Foss WW	Anderson Island	Budd Inlet	Str of Georgia	Bellingham Bay	Hood Canal	Pt Gardner	Pt Gardner[oc]	Shilshole	Sinclair Inlet	Pt Pully	Thea Foss WW	Anderson Island	Budd Inlet
LPAHs																						
2-Methylnaphthalene	↑	↑		--	--	--	--	--	↑			↑	--	--	--	--	--	--	--	--	--	--
Acenaphthene				--	--		--		--						--	--	--	--	--	--		--
Acenaphthylene				--	--		↑	--	--					--	--	--	--	--	--	--	--	--
Anthracene	--	--		--	--	--	--	↓	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--		--	↑	--	--	--	--		--	--	--		--	↑	--	↑	--	--	--	--
Naphthalene	--	↑		--	--	--	--	--	↑	--	--	↑	--	--	--	↑	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Retene	--	--		--	--	--	--	--	↑	--	--	--	--	--	--	--	--	--	--	↑	--	--
Total LPAH	↑	↑	--	--	--	--	--	--	--	↑	↑	↑↑	--	--	--	↑	--	--	--	--	--	--
HPAHs																						
Benzo(a)anthracene	--	↑		--	↑	--	--	--	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--		--	--	--	--	--	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Total Benzofluoranthenes	↑	↑	--	--	↑	↑	--	--	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chrysene	--	--		--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene						--	--	--	--						--	--	--	--	--	↓		
Fluoranthene	--	--	--	--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--		↑	↑	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	↑	↑		--	--	↑	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--
Pyrene	--	↑	--	--	↑	--	--	↓	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Total HPAH	--	↑	--	--	--	--	--	--	--	↑	--	↑	--	--	--	--	--	--	--	--	--	--
Total PAH	--	↑	--	--	--	--	--	--	--	↑	↑	↑	--	--	--	--	--	--	--	--	--	--

↑,↓ = increase, decrease (α=0.05), ↑↑, ↓↓ = increase, decrease (α = 0.01), -- = no change, blank = insufficient data. Shaded results indicate changes for all stations combined for a single compound or for all compounds combined for a single station, at α=0.05 (dark) or α=0.10 (light). [oc]= data normalized to organic carbon.

Increases in PAHs

As with the metals, the concentrations of most PAH compounds did not change significantly over the study period (Table 2). Most of those that did change increased in concentration. There was a significant overall increase in benzofluoranthenes and increases in PAHs at stations in Bellingham Bay, Port Gardner, and Anderson Island. In contrast, there was a significant decrease in PAHs at the Point Pully station.

Naturally-Occurring Changes

Changes in grain size and the numbers and types of sediment-dwelling organisms appeared to be linked to natural, rather than human-caused, stressors.

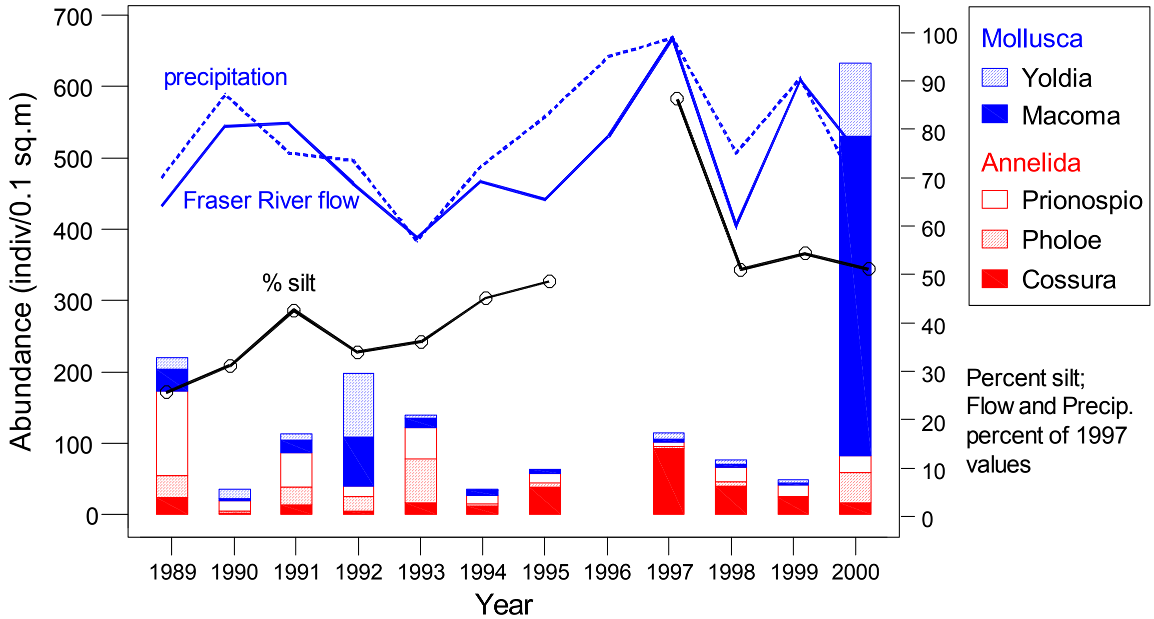

Figure 2. Changes in percent silt and abundance of dominant annelids and mollusks at the Strait of Georgia station, along with patterns in Fraser River flow and precipitation at the Vancouver International Airport. (River flow and precipitation displayed as percent of highest value) (Source of river flow and precipitation data: Environment Canada)

From 1989 through 1995, the amount of fine-grained sediment (percent silt) at the Strait of Georgia station varied between 25 and 50 percent. Between 1995 and 1997, it rose to approximately 90 percent, then declined to about 50 percent between 1998 and 2000. During the study, the community of sediment-dwelling organisms changed from one characterized by the annelid worm species *Prionospio*, *Pholoe*, and *Cossura*, to one consisting primarily of *Cossura*, a mobile burrower that tolerates living in a wide range of sediment grain sizes, and then finally to one dominated by the bivalve mollusks *Macoma* and *Yoldia*, also active burrowers (Figure 2).

Examination of the flow and discharge plume of British Columbia's Fraser River, which can carry heavy sediment loads into the Strait of Georgia (Figure 3), suggested a possible cause for the observed changes. Annual rainfall, Fraser River flow volumes, and the percent silt at the Strait of Georgia station all exhibit similar temporal patterns (Figure 2).

It is hypothesized that the changes in the sediment community observed in the Strait of Georgia were driven by above-average precipitation in 1996-1997, which increased flow in the Fraser River and resulted in increased deposition of fine sediments in northern Puget Sound. Changes in grain size are known to influence community structure.

Figure 3. Satellite image of the Strait of Georgia showing a sediment plume from the Fraser River and the location of the Strait of Georgia monitoring station. (Courtesy of SeaWiFS Project, NASA/ Goddard, and ORBIMAGE).

Changes In Puget Sound Sediments – What Does It All Mean?

Toxic metals enter the environment as waste from industrial manufacturing and mining, municipal wastewater, combustion products, and agricultural pesticides (Newman and Unger, 2003). Nationwide, freshwater and estuary sediment metal concentrations have exhibited declines, similar to those observed in this study, since the mid-1970s. These trends may reflect decreases in emissions to air and water from municipal and industrial sources following the implementation of federal clean-water and air regulations. However, despite these improvements, metal concentrations remain above sediment quality guidelines in many urban bays of Puget Sound, emphasizing the need for continued monitoring and cleanup (Lefkovitz et al., 1997; Mahler et al., 2004).

PAHs are toxic and carcinogenic chemicals formed by the incomplete burning of organic matter, including petroleum, oil, coal, and wood (Newman and Unger, 2003). Vehicles release PAHs into the atmosphere in exhaust emissions and deposit them on the ground through oil and gasoline leaks, where they are transported to streams, rivers, and estuaries in stormwater runoff. Long-term aquatic sediment core studies in Puget Sound and nationwide found that PAHs levels peaked in the mid-1940s through 1960s. Decreases were seen in the 1970s and 1980s, followed by more recent increases. It is believed that the early declines in PAH concentrations can be attributed to the switch from coal to oil and natural gas for home heating, improvements in industrial emissions controls, and increases in the efficiency of power plants, while more recent increases have been linked to increasing urban sprawl and vehicle traffic in urban and suburban areas (Lefkovitz et al., 1997; Van Metre et al., 2000, in press). Recent studies by the United States Geological Survey (USGS) have also measured high PAH concentrations in stormwater runoff from parking lots sealed with coal-tar-based asphalt sealants (Mahler et al., in press).

Changes in the sediment community in the Strait of Georgia in response to naturally occurring variation in rainfall and river flow clearly show the value of long-term monitoring for understanding the effects of stressors on the Puget Sound ecosystem. Understanding these processes at a local scale can help us understand similar changes in other regions. For example, the sediment-community changes observed in the Strait of Georgia may hold the key to understanding recent declines in San Juan Island eelgrass populations. Acting on the results of this study, investigators from the University of Washington and the USGS are conducting sediment surveys to determine if the decline in eelgrass abundance can also be linked to the deposition of fine-grained sediments from the Fraser River (Dr. Sandy Wyllie-Echeverria, pers. comm.).

The PSAMP long-term monitoring program provides a vital record of sediment conditions in Puget Sound and gives insight into the effects of both natural and human-driven stressors on the estuary. The fixed “sentinel” stations monitored in this program can raise “red flags”, highlighting important environmental changes affecting Puget Sound. These results are critical for guiding the policy and regulatory decisions needed to effectively manage and maintain the environmental health of Puget Sound.

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General information and all data generated during this survey can be accessed from Ecology’s Marine Sediment Monitoring website: http://www.ecy.wa.gov/programs/eap/mar_sed/msm_intr.html

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