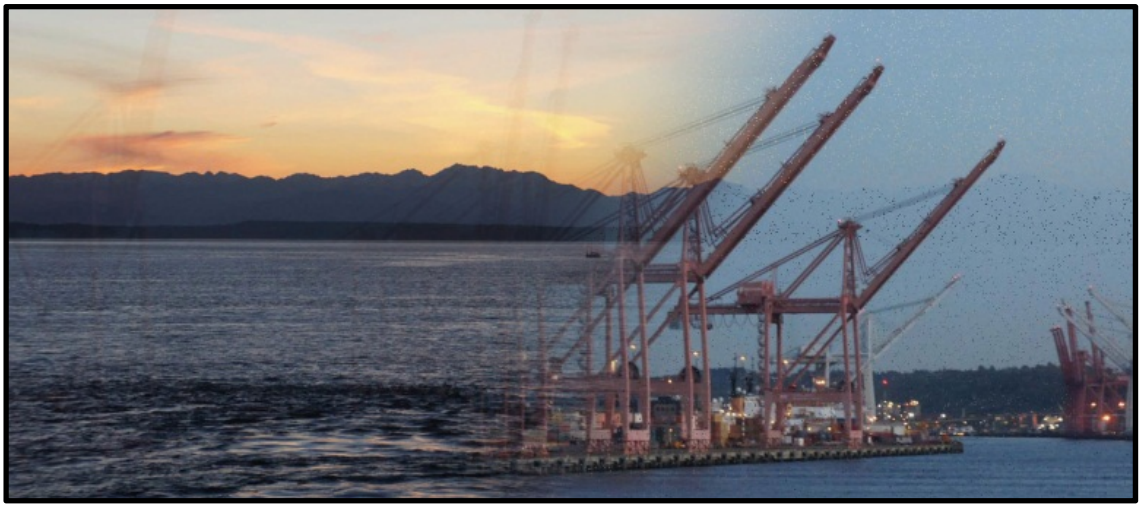
Puget Sound's Original Environmental Monitors



The Puget Sound Reacts to a Changing World

The Puget Sound and Salish Sea have been inland maritime environments since the great ice sheets retreated from western Washington over 10,000 years ago. As the ice abandoned the emerging landscape, life in all its forms moved in. Over a span of millennia, the Puget Sound area evolved as its living mosaic matured, striving for a dynamic, stable, climax. Humans were a part of the interactive natural matrix, fashioning their world locally around the Salish Sea. Several hundred years ago non-indigenous peoples discovered the great Northwest and, in their fashion, arrived to exploit its resources. The result has been a transformation nearly as great as that mediated by the ice. The environmental adjustments have challenged all the organisms living around Puget Sound with consequences still to be completely revealed.

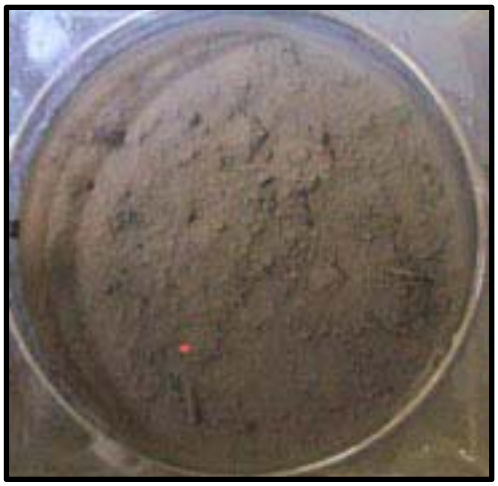
We now look across the land and seascape of the Puget Sound and ask ourselves what we have done to this extraordinary place. So many things have happened and we have no record of what was before, along with incomplete observation of what is now. Like children with an exciting new toy, we have eagerly engaged it, scattering parts in all directions and now we can't quite see how to reassemble things so we can either continue to play or start again.

How Can We Know What Our Impacts Have Been?

Predominantly, we examine the world around us through a record of observation and measurement. This is the way we transmit experience from one generation to the next, at least in the official sense. Our problem now is that the world is strongly impacted by human activity, and we have a limited base line of records to help us understand what we are doing. This holds true for the Puget Sound. Looking backwards rapidly takes us to stories and anecdotes. The value of measurements is that they provide us with a starting point for examination of the world around us that is unambiguous. Facts can free us from our fantasies and prejudices and allow us to see the world as it really is.

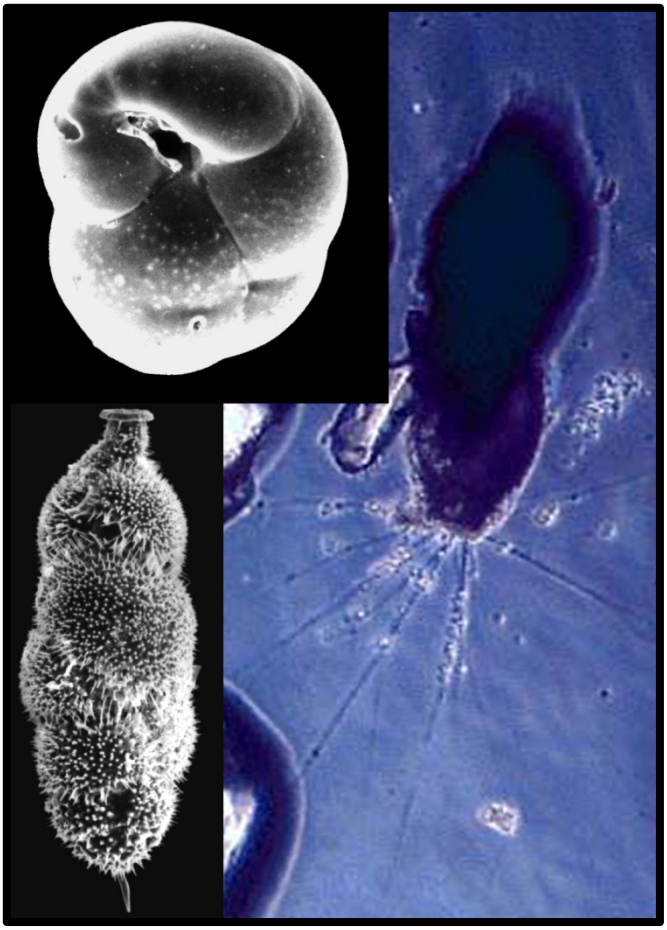
For the Puget Sound, there are so many observations and measurements over time that we would like to have. Despite conscientious efforts by government and individuals, the body of evidence takes us back only a short span of time. Too little to give the perspective we need. What was the Puget Sound

like in its climax after the last ice age and before significant human impact? How variable and sensitive was that environment to changes forced upon it? We can build hypotheses, but how can we test them?



Sea bed surface viewed in a coring tube, years of material accumulation, and home to sea bottom life

We need something to substitute for the thermometers and chemical samplers that weren't in place when we would want them to be, hundreds to thousands of years ago. Fortunately, nature maintains an archive storing remains which can provide us with proxies for the information we lack. All the physical, chemical and biological processes happening around the Sound generate debris which collects, gradually, in the sediments below the Salish Sea. Incorporated in that material are the shells of microscopic organisms called Foraminifera, tiny amoeba which live everywhere in and on the seabed reacting to the conditions around them. These foraminifera secrete a shell which can enter the sea floor archive as a record of the environment that was. Past conditions are indicated by the species of Foraminifera which are present in the sediments, and, if the shells are made of calcite, by the chemistry of the elements preserved in that mineral structure. The Foraminifera can provide a ubiquitous and sensitive tracer for the information on past environments that we wish to have. Also, living Foraminifera serve as a useful indicator of the impacts that the changing environment today has on the web of life in the Puget Sound.



A living foraminiferan to the right, empty shells (calcite) of two different species to the left. Each shell is about the size of a grain of salt on your dinner plate.

The Tracers: Foraminifera and What We Learn From Them

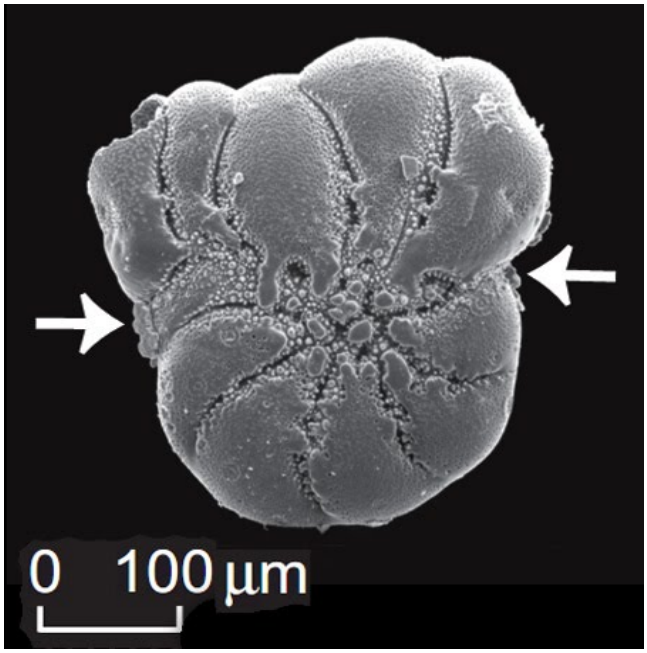
Foraminifera are micro-organisms which live both floating in the water column and creeping about within the seabed in marine environments. They are intriguing in that, simple as they are, Foraminifera create elaborate shells from either the sediment particles around them, or from calcium carbonate which they extract from the sea water they live in. The architecture of these shells is amazingly complex and varies among species. This means that the shells preserved in sea bottom sediments record for us the species which were alive at some time in the past.

Each species is sensitive to the physical, chemical and biological environment that existed when it was alive. We find very different species groupings in deep ocean versus shoreline settings, and in pristine versus polluted coastal

environments. In addition, the calcite shells of foraminifera record the chemical environment, including contaminants due to human activity.

Foraminifera in Impacted Environments

Foraminifera are affected by changes in their environment and respond quickly, having life times on the order of weeks generally. They respond as living organisms and they incorporate evidence of environmental impacts into their tissues and shells. In settings like the Puget Sound the environment is best reflected in the foraminifera that live in, and on, the sea bottom (benthic foraminifera). Persistent environmental degradation impacts the species of foraminifera living along the sea floor. Where degradation is severe only a very few species can exist.



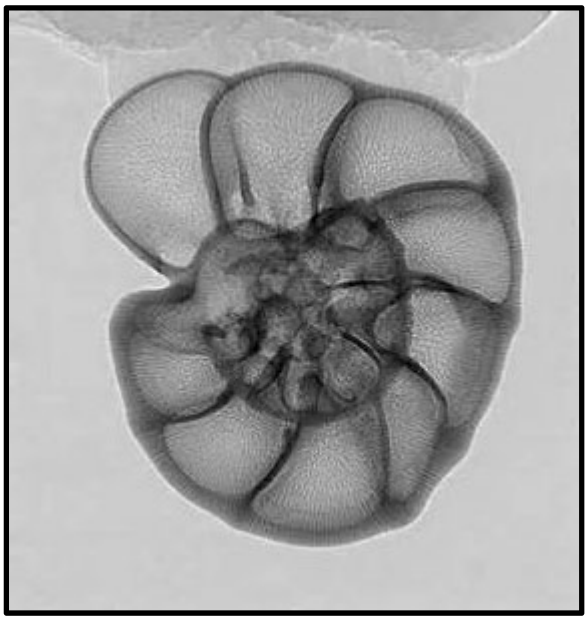
Deformed foraminifera shell (showing abnormal structure to the left). Proportion of deformed specimens often increases with ecological stress.

Example of a foraminifera shell which has been chemically eroded by reaction with acid

Where impacts are moderate or developing, the structure of foraminiferal communities is impacted in ways that influence their shell record which accumulates in ocean sediments. The result is that by looking at what shells are present in sediments, and in what percentages of species, it is possible to view environmental state backwards in time.

Foraminifera can also record the environment around them in a more individual way. Their shell is an intricate structure whose development can be derailed by pollutants or anomalous physical and chemical conditions. Deformation frequency can be an indicator of stress on the benthic community.

More specific diagnostic tools may be available in shell itself. The shell of calcareous foraminifera is reactive to acid in the environment. It will dissolve in a buffer reaction when acid is present, acting like an 'antacid' for the ocean. Acidification of ocean waters,

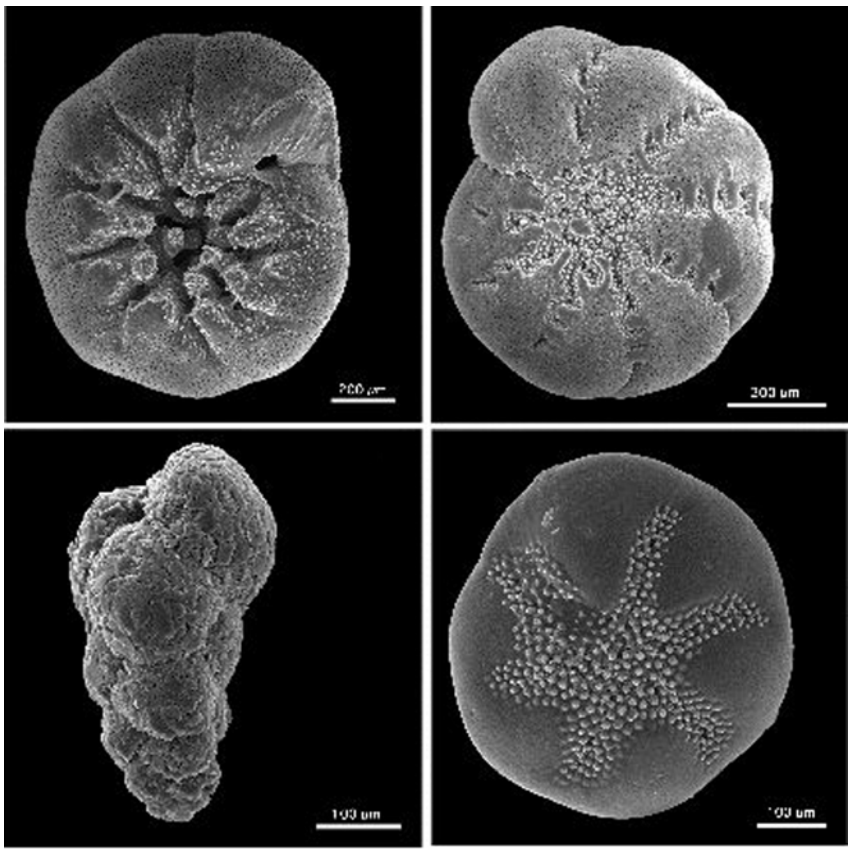


View through a foraminifera shell showing the chambers of which it is made and the calcite walls which define them. These walls are built up of layers of organic matrix alternating with the mineral calcite. A foraminifera grows by adding chambers to its shell

especially close to the seabed, is a product of both human generated fossil fuel carbon dioxide which is absorbed by the ocean, and it is product of an oversupply of degrading organic matter settling through the water column and accumulating on the bottom. This oversupply in coastal regions is often the product of run-off laced with fertilizers and other agricultural products. The decaying matter sucks oxygen from bottom waters, killing benthic life, and the organic acids produced attack the calcite shells of any organisms present. The foraminifera reflect these conditions in the state of their shells.

In more detail the shells of calcareous foraminifera are composed of layers of organic matrix and the mineral calcite. Both of these are complex compounds whose composition incorporates elements from the surrounding environment. This leaves chemical fingerprints in the foraminifera. Calcite, for example, accommodates many different metals in its structure and these can serve as indicators of human impact on the waters and sediments of the Puget Sound. Use of these 'chemical fingerprint' techniques is still under development, but advances in technology and a new generation of researchers will likely open this window to long term environmental monitoring.

Foraminifera in the Puget Sound



Common foraminifera in the Puget Sound: (clockwise from top left) Ammonia beccarii, Elphidium excavatum clavatum, Buccella frigida, Eggerella advena

Scientists have only fairly recently begun to examine the foraminiferal record of environmental change in the Puget Sound. Our view of them is limited to modern sediments and places heavily impacted by human activity. Exploration of their message over time has only just begun.

Studies of benthic foraminifera in other coastal waters, like Biscayne Bay in Florida and Long Island Sound in New York, have shown that distributions of species, and deformation of shells, can be associated with environmental stresses. Research indicates that the major stresses result from pollution released into coastal embayments and restricted bodies of water. Pollution can be organic wastes or industrial chemicals and metals. In some cases it is possible to map the changing patterns of pollution in the coastal environments by looking at how the distribution of foraminifera in bottom sediments has changed over the years.

In the Puget Sound a recent survey study by scientists at the Burke Museum of Natural History in Seattle (Martin et al., 2013, Journal of Foraminiferal Research, v. 43, p. 291-304) has revealed an

intriguing and complex story. Benthic foraminifera are common in the Sound and the species present are similar to those seen in coastal areas elsewhere which have been impacted by human activity. The data from Sound are from locations around sites identified as impacted by a variety of pollutants. Examination of sites repeatedly sampled from 1997 to 2010 showed that foraminifera present varied in species composition, with four species dominating separate groupings. Which grouping was pre-eminent varied both in space and time. The foraminifera are clearly responding to fluctuating environmental conditions and only further research will uncover what they are most sensitive to.

Much of the Puget Sound remains unsampled and this makes understanding the environmental messages the Foraminifera are reporting to us hard to explicitly decipher. When we are able to understand the Foraminiferal signals, delving into their sediment record with allow us to reconstruct in detail the environmental history of the Puget Sound. Then, we will finally be able to unravel the complete story of the Salish Sea as it responded first to the retreat of ancient ice, and then to the arrival of successive waves of human activity.