Completion Report

Period: 2/1/2014 - 1/31/2015

Project: R/COCC-3 - *Using Microbiota for the Evaluation and Monitoring of Puget Sound Ecosystems*

STUDENTS SUPPORTED

Coberly, Jerilyn, jerilync@uw.edu, University of Washington, Earth and Space Science, status: cont, field of study: Geology, advisor: Elizabeth Nesbitt, degree type: BS, degree date: 2014-06-01, degree completed this period: Yes
Student Project Title:
Ecosystem Degradation as Indicated by Benthic Foraminifera in Sinclair and Dyes Inlets, Puget Sound, Washington
Involvement with Sea Grant This Period:
Student researcher
Post-Graduation Plans:
Work for an environmental consulting company

Divita, Jacqueline, jacdivita@gmail.com, University of Washington, Earth and Space Sciences, status: cont, field of study: geology, advisor: Elizabeth Nesbtitt, degree type: BS, degree date: 2015-06-01, degree completed this period: No
Student Project Title: *none*
Involvement with Sea Grant This Period:
Student research assistant
Post-Graduation Plans:
Graduate school

Halsen, Chase, chase44h@uw.edu, University of Washington, Earth and Space Sciences, status: cont, field of study: Environmental geoscience, advisor: Elizabeth Nesbitt, degree type: BS, degree date: 2014-06-01, degree completed this period: No
Student Project Title:
An Atlas of Puget Sound Foraminifera
Involvement with Sea Grant This Period:
Student Researcher
Post-Graduation Plans:
Work, graduate school

Wolfley, Raeanne, rfw4@u.washington.eduMS, University of Washington, Earth and Space Sciences, status: cont, field of study: Geology, advisor: Elizabeth Nesbitt, degree type: BS, degree date: 2015-06-01, degree completed this period: No
Student Project Title:
Benthic foraminifera of Possession Sound and Everett waterways, Puget Sound
Involvement with Sea Grant This Period:
Student Researcher
Post-Graduation Plans: *none*

Zhang, Bijia, bijaz@uw.edu, University of Washington, Earth and Space Sciences, status: cont, field of study: Economic geology, advisor: Elizabeth Nesbitt, degree type: BS, degree date: 2014-06-01, degree completed this period: Yes
Student Project Title:
Foraminiferal assemblages record anthropogenic pollution in Elliott Bay, Puget

Sound, Washington.
Involvement with Sea Grant This Period:
Student researcher
Post-Graduation Plans:
Graduate school - accepted at Rice University

CONFERENCES / PRESENTATIONS

Shellfish Growers Conference presentation - Using Foraminifera as Tools to Assess Levels of Pollution in Puget Sound, public/profession presentation, 95 attendees, 2014-03-04

Burke Museum Behind the Scenes Night - live demonstrations, public/profession presentation, 700 attendees, 2014-02-17

Geological Society of America Annual Meeting, Vancouver, B.C. - two poster presentations, public/profession presentation, 8000 attendees, 2014-10-19

2014 Salish Sea Ecosystem Conference - poster presentation, public/profession presentation, 1000 attendees, 2014-04-30

University of Washington Undergraduate Research Symposium (4 presentations), public/profession presentation, 3000 attendees, 2014-05-16

ADDITIONAL METRICS

P-12 Students Reached: 3rd - 5th graders reached through "Rocking Out" UW Dept of Earth and Space Science K-12 outreach program	35	**P-12 Educators Trained:**	0
Participants in Informal Education Programs:	0	**Volunteer Hours:**	0
Acres of coastal habitat protected, enhanced or restored:	0	**Resource Managers who use Ecosystem-Based Approaches to Management:**	0
Annual Clean Marina Program - certifications:	0	**HACCP - Number of people with new certifications:**	0

ECONOMIC IMPACTS

No Economic Impacts Reported This Period

SEA GRANT PRODUCTS

Description	Developed ?	Used ?	ELWD ?	Number of Managers	Names of Managers
Illustrated Guide to Benthic	Yes	Yes	No	0	

Foraminifera of
Puget Sound

HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

ADDITIONAL MEASURES

Number of stakeholders modifying practices:

Sustainable Coastal Development

# of coastal communities:

PARTNERS

Partner Name: Burke Museum Geology Division

Partner Name: Green River Community College

Partner Name: North Seattle Community College

Partner Name: Washington Department of Ecology

IMPACTS AND ACCOMPLISHMENTS

Title:
Type:
Description:
Recap: *none*
Comments: *none*
Related Partners: *none*

PUBLICATIONS

Title: **Distribution of Foraminifera in the Southern Puget Sound, Washington State, USA**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: *none*
Abstract:
The Puget Sound is the southern portion of the Salish Sea, a complex fjord system located in Washington State, USA, and British Columbia, Canada. Puget Sound is regularly flushed with normal marine waters because of a significant tidal flux. Over the last 150 years the entire Puget Sound system has been subjected to significant anthropogenic impacts. The Puget Sound region continues to have rapid population growth and is home to 6 million people. The combination of rapid growth and a history of anthropogenic impacts highlight the need for the development of biologic models to track the health of the Sound. Unfortunately, there are few published studies of

foraminiferal distribution in the Puget Sound. This paper marks the first published record of the foraminiferal fauna in the southern portion of the Puget Sound.
The South Sound is the most distal to open marine connection, and is characterized by narrow channels, restricted inlets, and islands. As a result, despite the tidal flux, water residence times average 36- 64 days depending on season. Surface salinity varies seasonally, but bottom water salinity is stable with an annual range of 25-29 ppt. Surface temperatures during the winter sampling period ranged from 7-10o C. A series of 125 grab samples were collected in the South Sound during December and January in the years 1988-1991 by Robert Harmon (Shoreline Community College). Oceanographic settings range from restricted shallow bays to open inlets with depths from 1-150 meters. Sediment composition ranges from gravel to mud. Generally shallow water samples contain higher percentages of coarse clastic and deeper samples are mud dominated. Shallow samples contain appreciable amounts of plant material. All samples contained at least a limited foraminiferal fauna with a total of 19 genera and 25 species identified. Of these 15 species are calcareous and 10 are agglutinated. Species dominance is high in all samples with most dominated by a few species. The most common species are Elphidium excavatum, Buccella frigida, Elphidiella hannai, Eggerella advena, and Lagenammina arenulata. Other species occur in high abundance in isolated samples but generally comprise a small part of the fauna. Some samples show sediment indicators of low oxygen conditions. However, the absence of Ammonia beccarii prevents the use of the Ammonia-Elphidium hypoxia indicator. The Foraminifera distribution in these samples provides a baseline for mapping faunal changes in future sampling. Future work will include examination of samples collected by the Washington Department of Ecology in summer 1999 and 2011 and new winter re-sampling program to evaluate seasonal effects.
Citation:
Frederick, D., Nesbitt, E., Martin, R., 2014. Distribution of Foraminifera in the Southern Puget Sound, Washington State, USA. in: Marchant, M. and Hromic, T., eds., International Symposium on Foraminifera FORAMS Chile 2014 Abstract Volume, p. 35.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **DISTRIBUTION OF FORAMINIFERA IN THE NISQUALLY DELTA AREA OF THE SOUTHERN PUGET SOUND**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: *none*
Abstract:
The Puget Sound is the southern portion of the Salish Sea, a complex fjord system located in Washington State, USA, and British Columbia, Canada. Puget Sound is regularly flushed with normal marine waters because of a significant tidal flux. Over the last 150 years the entire Puget Sound system has been subjected to significant anthropogenic impacts. The Puget Sound region continues to have rapid population growth and is home to 6 million people. The combination of rapid growth and a history

of anthropogenic impacts highlight the need for the development of biologic models to track the health of the Sound. Foraminifera have shown promise as indicators of environmental status of estuarine waters. Unfortunately, there are few published studies of foraminiferal distribution in the southern portion of the Puget Sound.

A set of 51 grab samples were collected near the Nisqually River delta by Robert Harmon (Shoreline Community College) in 1982. Oceanographic setting range from tidal channels within the Nisqually delta to open inlets. Depths range from 1 to >100 meters. Sediment composition is dominated by fine sand with coarser clastics in shallow near shore water. Close to the Nisqually River delta mud is comprises a significant portion of the sediment. Some samples contain significant amounts of plant material. Of the 52 samples 43 contain at least a limited Foraminiferal fauna. Of these samples 7 contained 1-116 specimens. The remaining samples contained sufficient foraminifera to conduct 300+ counts. The most common species are Elphidium excavatum, Buccella frigida, Elphidiella hannai, Eggerella advena, and Lagenammina arenulata.(check this) The Foraminifera distribution in these samples provides a baseline for mapping faunal changes in future sampling in this area of the Puget Sound.
Citation:
Dreher, Brittany E., Frederick, Daniel L., Martin, Ruth A., and Nesbitt, Elizabeth A., 2014. Distribution of Foraminifera in the Nisqually Delta area of the southern Puget Sound. Geological Society of America Abstracts with Programs, Vol. 46, No. 6 p. 144.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **TOXICITY IN SINCLAIR AND DYES INLET (PUGET SOUND) SEDIMENTS AS INDICATED BY BENTHIC FORAMINIFERA**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: *none*
Abstract:
Sinclair and Dyes Inlets surround the city of Bremerton, Washington, and contain some of the most contaminated sediments in Puget Sound. The city is home to the Puget Sound Naval Shipyard, a designated U.S. federal Superfund site; sediments there are contaminated with PCBs, PAHs and toxic metals. Ostrich Bay, an embayment off Dyes Inlet, was the site of a Naval Ordnance facility where munitions were manufactured and destroyed, with by-products washed and dumped into the bay. In addition to industrial pollutants, agricultural and recreational uses of the surrounding land introduce their own contaminants, particularly fecal coliform, phosphorus and metals. This study utilized foraminifera to assess the condition of the benthic ecosystem. Foraminiferal assemblages from forty-two sediment samples were analyzed and correlated with data on sediment quality and chemistry. Of those samples, 20% were barren of foraminifera, and in the rest, species richness was low, averaging fewer than four species per sample in both inlets. The Shannon diversity index averaged 0.98 in Dyes Inlet and 1.07 in Sinclair Inlet. Many samples contained large percentages of calcareous foraminifera that showed signs of dissolution.

Samples that were barren of foraminifera and those that showed pronounced dissolution displayed high levels of Total Organic Carbon (TOC); the decomposition of organic material may have resulted in anoxic conditions and low pH. The former may explain the lack of foraminifera in samples, and the latter may be responsible for the dissolution of foraminiferal tests. Comparison of foraminiferal diversity and toxic metal concentrations demonstrated a negative correlation between the two. Several samples in both inlets contain numerous euhedral crystals of gypsum. These samples displayed high TOC and were either barren of foraminifera or showed very low diversity. Analysis of sulfur isotopes indicate the gypsum is the result of sulfate reduction, either from decomposition of organic matter or from industrial processes. Thus, foraminiferal assemblages in marine waters surrounding Bremerton are responding markedly to conditions in the sediments, establishing the efficacy of using foraminifera as a tool for monitoring benthic ecosystems in Puget Sound.

Citation:
Martin, Ruth A., Nesbitt, Elizabeth A., Coberly, Jerilyn, Zhang, Bijia, 2014. Toxicity in Sinclair and Dyes Inlets (Puget Sound) as indicated by benthic foraminifera. Geological Society of America Abstracts with Programs, Vol. 46, No. 6, p. 144.

Journal Title: *none*

Title: **Foraminiferal assemblages record anthropogenic pollution in Elliott Bay, Puget Sound, Washington.**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: https://expo.uw.edu/expo/apply/312/proceedings/result?student_name=Zhang&commit=Search
Abstract:
This study investigated the effects of environmental pollution in Elliott Bay, Central Puget Sound, by analyzing foraminiferal assemblages collected from 1998 and 2007. Foraminifera are single-cell microorganisms with shells (tests) made of calcium carbon or agglutinated sediment. They live on the seafloor sediment (benthic) or float in the water column (planktic), but for this study only benthic foraminifera were used. Many foraminifera are sensitive to changes in the physical parameters of their environment and thus, thus they can be good indicators of pollution. Elliott Bay is surrounded by the city of Seattle with its large maritime industrial presence. City development and economic growth near Elliott Bay led to a focus on environmental concerns. On the southern shoreline of the Bay there are many heavy industries and Federal Superfund sites that had discharged large amounts of industrial pollution from the Duwamish River into Elliott Bay. In our study, sediment samples collected by the Washington State Department of Ecology were processed and foraminiferal assemblages were obtained from 16 samples. The species composition, species richness and density (number of individuals per sample) for each sample were analyzed. Comparisons were made between those collected in 1998 and those collected from exactly the same sites in 2007. The results show that there are 12

different species found in the Bay dominated by Elphidiella hannai, Ammotium planissimum and the pollution-tolerant Eggerella advena. Large population of Eggerella advena in Elliott Bay, and the exclusion of other less tolerant species, indicates a physically stressed environment. By comparing foraminiferal assemblages from Elliott Bay with samples from less anthropogenically impacted locations within the Puget Sound, we can assess the degree of environmental damage to Elliott Bay.
Citation:
Zhang, Bijia, 2014. Foraminiferal assemblages record anthropogenic pollution in Elliott Bay, Puget Sound, Washington. University of Washington Undergraduate Research Symposium. Seattle.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **Ecosystem Degradation as Indicated by Benthic Foraminifera in Sinclair and Dyes Inlets, Puget Sound, Washington**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: https://expo.uw.edu/expo/apply/312/proceedings/result?student_name=Coberly&commit=Search
Abstract:
This study aimed to analyze benthic foraminiferal assemblages to determine if environmental changes from pollution and other factors have affected the health of the Bremerton area marine ecosystems. Foraminifera are shelled, single-celled microorganisms that can act as good indicators of environmental change. Sinclair and Dyes Inlets border Bremerton and are connected by the Port Washington Waterway in Kitsap County, Washington. Bremerton is the home of Puget Sound Naval Shipyard and is listed as a federal Superfund side due to accumulations of industrial pollution. Additionally, agricultural and residential pollutants have been released into Dyes Inlet from local streams. Foraminifera were collected from 40 sediment samples provided by the Washington State Department of Ecology from 1998-2012. Samples were analyzed for foraminiferal species composition, diversity, and density (number of individuals/gram sediment). Results show 22 species were found, however most samples had low diversities and densities. Ten samples contained no foraminifera. In addition, numerous euhedral gypsum crystals were found in 13 samples in both inlets. Gypsum is a calcium sulfate mineral, and occurrences of subaquatic gypsum crystals in non-evaporitic settings are unusual. Samples with gypsum showed either lower foraminiferal densities or no foraminifera present. Sulfur isotope analysis of the crystals indicates they formed in a sulfate-reducing environment. The comparatively high Total Organic Carbon (TOC) values in gypsum-containing samples suggests that decomposition of organic material may lead to this sulfate-reduction. Additionally, significant dissolution observed in the calcium carbonate shells of many foraminifera indicates pH values of the sediment were low. This dissolution can also result from the degradation of organic matter. Thus, foraminiferal assemblages within Dyes and Sinclair Inlets are responding markedly to conditions in sediments, establishing the efficacy of using foraminifera as a tool for monitoring benthic ecosystems in Puget

Sound.
Citation:
Coberly, J. 2014, Ecosystem Degradation as Indicated by Benthic Foraminifera in Sinclair and Dyes Inlets, Puget Sound, Washington. University of Washington Undergraduate Research Symposium. Seattle.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **An Atlas of Puget Sound Foraminifera: Technical Aspects of Photographing Microscopic Subjects**
Type: Workshops, Proceedings, Symposia Including Highlights/Summaries of (please note: document number reflects the year the proceedin Publication Year: 2014
Uploaded File: *none*
URL: https://expo.uw.edu/expo/apply/312/proceedings/result?student_name=Halsen&commit=Search
Abstract:
The purpose of this project is to develop and refine a technique for taking photographs to be included in an atlas of the foraminifera of Puget Sound. Foraminifera are shelled single-celled organisms that live at the sediment/water interface in marine environments. Their sensitivity to environmental conditions makes them useful in monitoring ecosystems on the sea floor. The atlas will contain photographs and detailed descriptions of each foraminifera species. Despite their importance as an environmental monitoring tool, foraminifera have never been comprehensively studied in Puget Sound. This catalogue will become a useful tool for future workers in research and environmental monitoring. Key to this atlas is the inclusion of clear, accurate photographs of each species of foraminifera. Scanning Electron Micrographs yield excellent images, but these often do not portray the organism as it is viewed through a light microscope. Thus, the inclusion of photomicrographs is essential. Photography becomes quite technical when dealing with objects of a microscopic scale while still trying to produce a clear image with depth of field. With the Puget Sound Foram Project we work with specimens that can be as small as a tenth of a millimeter in size, so producing a high quality publishable picture takes time and a specialized technique. Using a light microscope, each specimen has to be photographed several times, focusing at a different depth each time. Once all of the layers have been captured, the pictures are then synchronized and edited in such a way that we get one final image that has both clarity and depth of field. In addition, each specimen must be photographed from two or more angles to illustrate critical features. Photography for research purposes can be a complicated and lengthy process but is essential for not only supplementing data but conveying vital information.
Citation:
Halsen, C., 2014. An Atlas of Puget Sound Foraminifera: Technical Aspects of Photographing Microscopic Subjects. University of Washington Undergraduate Research Symposium, Seattle.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **Rapid deterioration of sediment surface habitats in Bellingham Bay, Washington State, as indicated by benthic foraminifera**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2015
Uploaded File: *none*
URL: *none*
Abstract:
Abstract: Foraminiferal assemblages in sediment grab samples were utilized to evaluate the impacts of anthropogenic activities on benthic habitats in Bellingham Bay and Strait of Georgia, Washington State, U.S.A. Ninety-three samples taken in 1987, 1997, 2006 and 2010 yielded 35 species of foraminifera from 22 genera. Assemblage composition and diversity data indicate a marked deterioration between 1987 and 2010, contrary to published Chemical and Toxicity Indexes, but analogous to the situation with macrobiota. Correlation of diversity with chemical pollutants and metals did not identify any significant correlations, however, an unrelated but highly relevant study of bottom water dissolved oxygen concentrations and pH in Bellingham Bay suggests eutrophication with accompanying hypoxia and acidification may be part of the cause.
Citation:
Nesbitt, E.A., Martin, R.A., Martin, D.E., Apple, J., in review. Rapid deterioration of sediment surface habitats in Bellingham Bay, Washington State, as indicated by benthic foraminifera
Copyright Restrictions + Other Notes:
Journal Title: Marine Pollution Bulletin

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

No Leveraged Funds Reported This Period

COMPLETION NARRATIVE

Uploaded File: Nesbitt_5615_completio....1.pdf, 13194 kb

Using Microbiota for the monitoring and evaluation of Puget Sound Ecosystems Nesbitt_(R/COCC-3)

Introduction

This project was designed to take advantage of sediment samples, cores and data obtained from the Washington Department of Ecology to develop a low-cost, reproducible tool utilizing utilizing benthic foraminifera, microscopic shelled protists that inhabit the sediment, on or under the surface or creep up vegetation. In order to do this, we hired a full-time post-doctoral fellow experienced in this field as Project Manager and University of Washington undergraduates to conduct the research and outreach activities.

What we have accomplished

From February 1, 2014 to May 20, 2014, we continued to support five students who were with us in Autumn 2013 doing research on Puget Sound foraminifera. Three of those students graduated in June, 2014, but the other two are continuing with us. One former participant who graduated at the end of Autumn Quarter (2013) is now working on the project as a graduate student (not funded by this grant). In April and June, 2014, Washington Department of Ecology (WDOE) collected 76 more samples, bringing the total we have to ~800.

Figure 1. Students supported by WSG funds work in the micropaleontology lab at the Burke Museum.

Our initial investigation, *Distribution of foraminifera in Puget Sound, Western Washington, U.S.A.,* an analysis of foraminifera of Puget Sound written by the Principle Investigator. Dr. Elizabeth Nesbitt, and post-doctoral fellow, Dr. Ruth Martin, was published in the *Journal of Foraminiferal Research*, v. 43, p. 291-304. This paper became the first published regional inventory of foraminifera in Puget Sound. It highlighted the need for detailed examination of individual embayments in Puget Sound.

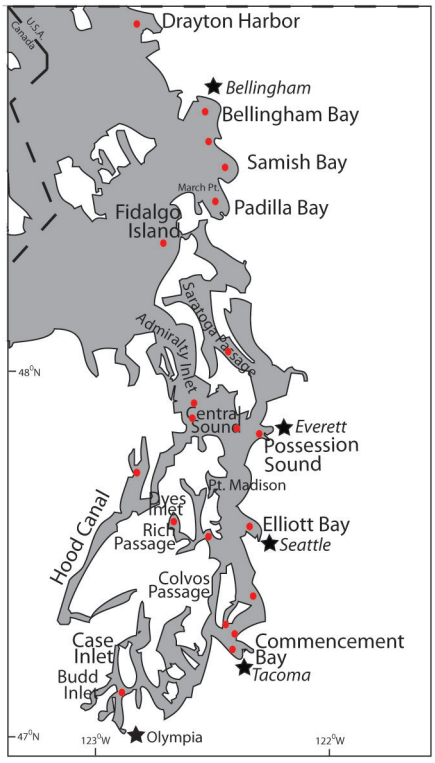

Figure 2. Sample locations used in our initial study of Puget Sound foraminifera.

For our first focused study of a single embayment, we started in north Puget Sound with the partially enclosed Bellingham Bay. Our work there documents a striking deterioration of foraminiferal assemblages in the bay between 1997 and 2010. Many of the stations within the bay saw the reduction or even total loss of foraminifera during those years, and throughout the Bay there was a dramatic decrease in diversity. The WDOE reports a similar pattern in the benthic invertebrates.

Our study cannot pinpoint a single factor as being responsible, however correlation with a study on hypoxia in Bellingham Bay done by Jude Apple at Western Washington University (now at Padilla Bay National Estuarine Research Reserve

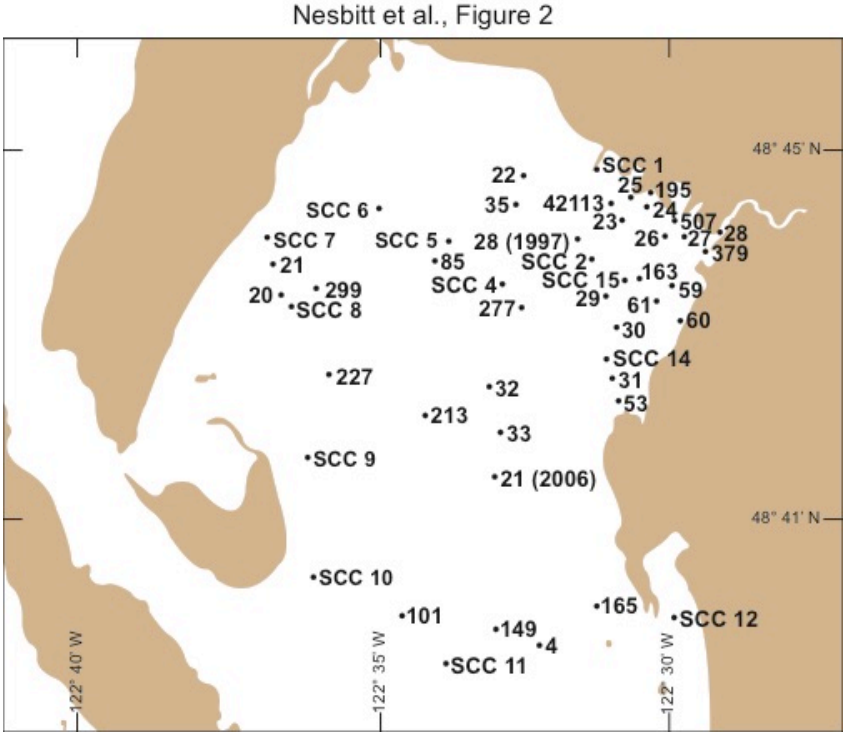

Figure 3. Locations of stations investigated in Bellingham Bay.

suggests that low oxygen levels may be at least partly responsible for the decline. The resulting paper, *Rapid deterioration of sediment surface ecosystems in Bellingham Bay as indicated by benthic foraminifera,* by Elizabeth Nesbitt, Ruth Martin, David Martin and Jude Apple is presently in review by the journal *Marine Pollution Bulletin.*

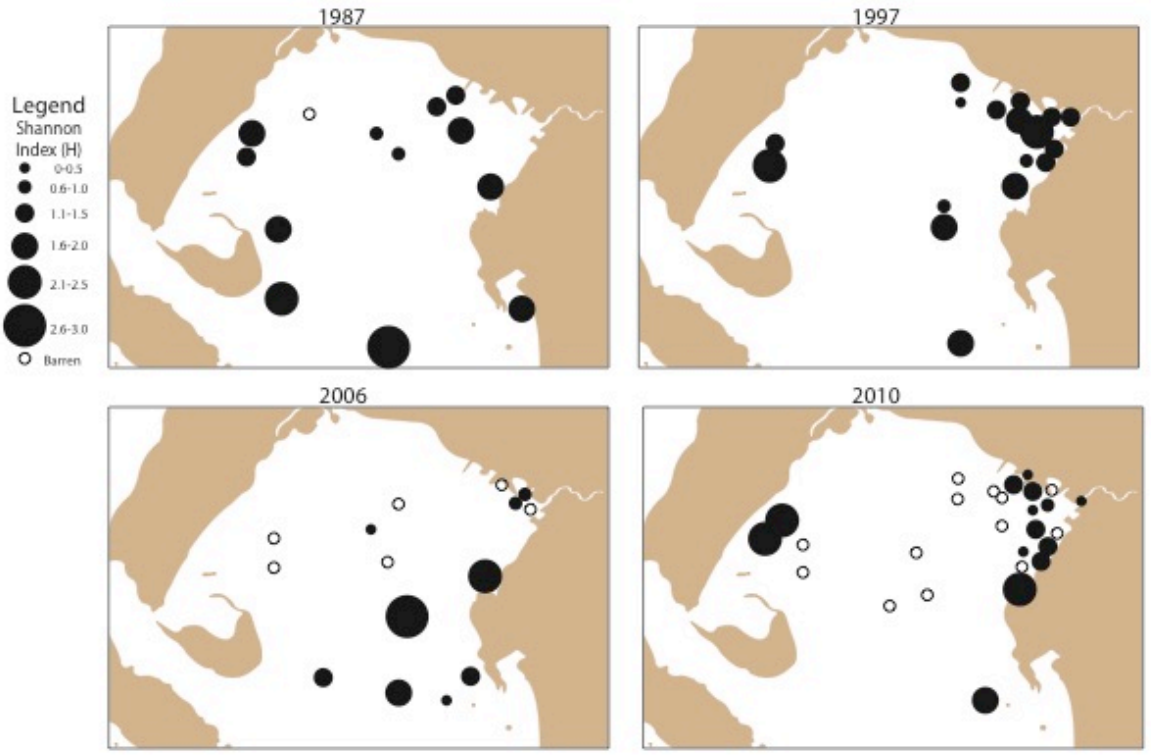

Figure 4. Diversity in Bellingham Bay in the sampled years. The size of each dot indicates diversity as measured by the Shannon Index. Note that in later years, diversity falls dramatically.

Student work continues by also focusing on specific areas, with the intention of using foraminiferal assemblages and sediment parameters supplied by WDOE to identify problem areas and assess probable causes as well as assess effects of any mitigation efforts that have been undertaken. The areas being studied by students and the significance of each are:

- Sinclair and Dyes Inlets –Naval Shipyard and associated manufacturing. Superfund sites. Also agricultural and recreational effluent.
- Elliott Bay, Duwamish Waterway – Heavy anthropogenic impact, including manufacturing, recreation, urban run-off. Superfund sites
- Possession Sound – manufacturing and recreation effluent, agricultural and urban run-off.
- Hood Canal – agricultural and domestic effluent, hypoxia due to slow circulation, Bangor Naval base, superfund site.

Work on Sinclair and Dyes inlets has progressed to the point that the post-doctoral fellow and PI have submitted a paper, *Foraminiferal evidence of toxicity in Sinclair and Dyes Inlets, Bremerton, WA, U.S.A.*, to the journal *Coastal, Estuarine and Shelf Science.*

Outreach

Three students presented their work on this project at the UW Undergraduate Research Symposium on May 16, 2014. Poster presentations were given on Sinclair and Dyes Inlets, Elliott Bay, and on the preparation of an Atlas of Puget Sound foraminifera.

Each year the Burke Museum hosts a "Behind the Scenes" evening in which museum members are allowed to explore the usually unseen areas of the museum and talk to researchers. An entire room in the Geology Division was devoted to the Puget Sound Foram Research Project, where we set out microscopes, cameras linked to iPads, photographs, research posters, and equipment. All students participated in the evening, interacting with the public, explaining various aspects of our work and demonstrating equipment and techniques. Approximately 700 members of the public toured the museum that evening.

Figure 5. Foram Project student Bijia Zhang demonstrates aspects of the Project to Burke Museum "Behind-the-Scenes" visitors.

One student participated in the UW Department of Earth and Space Science K-12 outreach program “Rockin’ Out”. Students in this program do presentations in local schools, highlighting their research and the relevance of work being done in the university to everyday life.

Another aspect of outreach is our association with Dr. Kathryn Hoppe (Green River Community College) and Dr. Tracy Furutani (North Seattle Community College) who are using our project to design their own research projects for their community college students. They will share their results with us for incorporation into our data. In February, 2014, Dr. Hoppe and Dr. Furutani presented their plans at the joint ASLO/AGU/Ocean Society Ocean Science Meeting in Hawaii, with encouraging responses.

Finally, on April 12, 2014, a new exhibit, *Imagine That!,* opened at the Burke Museum focusing on Burke collections and academic research. The Puget Sound Foram Research Project was an interactive component of the exhibit. Eight volunteers trained by the PSFRP post-doctoral fellow, Ruth Martin, demonstrated and explained the work and assisted members of the public with microscopes and other equipment. Since exhibit closed on October 26, 2014, these demonstrations have become an ongoing part of the Burke’s Biodiversity exhibit. Microscopes used in the exhibit were purchased with WSG funds.

Figure 6. Burke Museum volunteer works at the on-going public demonstration station in the Burke Museum Biodiversity exhibit.

Challenges

The biggest challenge we have met is time. Many aspects of the project took much longer than we anticipated at the start. For example, many samples are so full of organic matter that they are extremely difficult to process. Others have very few foraminifera compared with the volume of sediment and it is necessary to float these in trichloroethylene before they can be picked. This chemical is difficult to obtain, taking weeks to ship and arrive when ordered.

Since pH was not measured when samples were recovered, we hoped to use the elemental ratio of boron to calcium in foraminiferal shells as a proxy. Thirty-two samples from Bellingham Bay and Sinclair Inlet were analysed in the Keck Collaboratory at Oregon State University. Unfortunately, boron levels in our foraminifera were too low to obtain meaningful results.

The "Atlas of Puget Sound foraminifera" (now titled *An Illustrated Guide to Benthic Foraminifera of Puget Sound)* also took far longer than expected. This is due to difficulties with producing publishable photographs of these near-spherical microscopic organisms and to taxonomic confusion in the literature. Although foraminifera are microscopic, they have more depth than a microscope can focus at one time. It is thus necessary to take a series of photographs at different depths, then make a composite image using image stacking software. In the end, the Paleontology Division of the Burke Museum purchased software, Helicon Focus, which automatically stacks and combines a large number of raw images for each specimen, resulting in a single high quality image. Capturing the numerous images necessary, however, is not automated, so requires a great deal of time. The *Guide,* with 47 species described, is now published at https://depts.washington.edu/forams/, and is a work in progress.

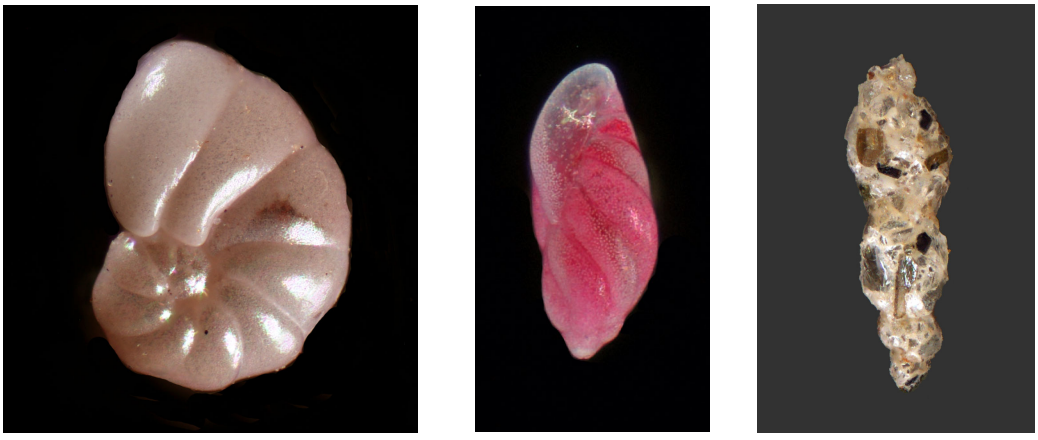

Figure 7. Examples of images of foraminifera produced using Helicon Focus image stacking software. It is difficult to produce microphotographs of these organisms because of their height, which is large compared to most microscopic organisms.

Development of a monitoring tool has also proved challenging, due to the complexity of Puget Sound itself, and to the composition of foraminiferal species assemblages. No single pollutant we have compared with our assemblages stands out as a cause of degraded foraminiferal assemblages. In addition, researchers in other estuaries and coastal areas use a pollution index that utilizes the ratio of two foraminifera species not present in Puget Sound. Our monitoring tool will thus not be a simple ratio of one species to another, but will incorporate assemblage composition, density and diversity information for the species that are present. It will, therefore, add substantially to the body of knowledge for using foraminifera as tools for environmental assessment globally. For instance, it is clear from work in Bellingham Bay that the presence of large numbers of the agglutinated taxon *Eggerella advena* coupled with a paucity of calcareous species, or a high percentage of partially dissolved calcareous specimens, is indicative of poor bottom conditions, most probably due to a combination of factors such as chemical pollutants, high acidity and low oxygen. The effects of these stressors may not be simply additive, but compounding, which is why the results are devastating to the foraminifera and causes are difficult to identify. Since foraminifera are low on the food chain, being consumed by snails, sand dollars, tiny fish and anything else fairly small; anything that perturbs this level must also reverberate throughout the ecosystem. It is clear, then, that Puget Sound foraminifera have a story to tell about the environment in which they live, and that story is a useful tool in the assessment of the well-being of the Sound.