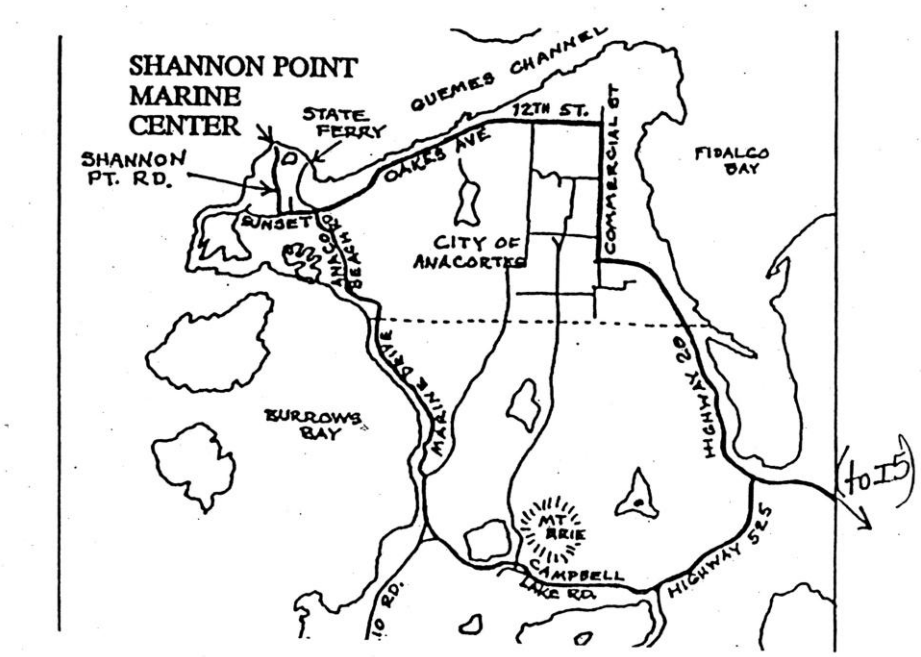
DIRECTIONS TO SHANNON POINT

Shannon Point Marine Center
Western Washington University
1900 Shannon Point Road
Anacortes, WA 98221
Phone: (360) 650-7400

1. Take I-5 to Exit 230 (Route 20W, Anacortes, San Juan Ferries exit).
2. Travel west on Highway 20 (follow signs for San Juan Island Ferry).
3. Take 20 Spur into Anacortes, which merges with Commercial Avenue (right turn merge).
4. Go down Commercial Avenue until the traffic signal at 12th Street. Note: There is no street sign for 12th Street, but is marked with a sign for the state ferry, there is a Safeway store on the right-hand side. Turn left onto 12th Street. There will be three traffic lights on this road.
5. 12th Street turns into Oakes Avenue. Stay on Oakes Avenue until you get to the third traffic signal on this road.
6. Go straight (bearing left) onto Sunset Avenue.
7. Take the third right onto Shannon Point Road. You will pass through a small residential neighborhood before reaching the marine center. The marine center is in a wooded area at the end of the road.



WESTERN WASHINGTON UNIVERSITY
BOARD OF TRUSTEES
AGENDA
August 18 & 19, 2011

THURSDAY, AUGUST 18, 2011
Location: **Shannon Point Marine Center, Anacortes, WA**
Time: **3:00 p.m.**

1. CALL TO ORDER
3:00 – 3:05

2. SPECIAL REPORT
3:05 – 4:30

A. LEGISLATIVE SESSION DEBRIEF
Presentation: Bruce Shepard, President
Sherry Burkey, Associate Vice President for University Relations
Bill Lyne, Faculty Associate to the President and Provost

B. WESTERN'S MISSION IN ACTION: COASTAL ENVIRONMENTAL PROGRAMS
Presentation: Catherine Riordan, Provost
Steve Sulkin, Director, Shannon Point Marine Center

3. EXECUTIVE SESSION MAY BE HELD TO DISCUSS PERSONNEL, REAL ESTATE AND LEGAL ISSUES AS AUTHORIZED IN RCW 42.30.110.
4:30 – 5:00

1. CALL TO ORDER

WESTERN WASHINGTON UNIVERSITY
ITEM SUBMITTED TO THE BOARD OF TRUSTEES

TO: Members of the Board of Trustees

FROM: President Bruce Shepard

DATE: August 18, 2011

SUBJECT: **Legislative Session Debrief**

PURPOSE: For Discussion

President Shepard, Sherry Burkey, Associate Vice President for University Relations, and Bill Lyne, Faculty Associate to the President and Provost, will provide an indepth debriefing of the recent Legislative Session and engage the Board in evaluation of our strategies' effectiveness and implications for the upcoming session.

WESTERN WASHINGTON UNIVERSITY
ITEM SUBMITTED TO THE BOARD OF TRUSTEES

TO: Members of the Board of Trustees

FROM: President Bruce Shepard by Provost Catherine Riordan

DATE: August 18, 2011

SUBJECT: **Western's Mission in Action: Coastal Environmental Programs**
Catherine Riordan, Provost
Steve Sulkin, Director, Shannon Point Marine Center

PURPOSE: Special Report

Purpose of Submittal:

Director Sulkin and a number of Shannon Point Marine Center faculty and students will provide information about the Center's programs and the various ways the Center serves and supports marine science and coastal environmental activities and concerns, as well as the academic mission of WWU.

Supporting Information:

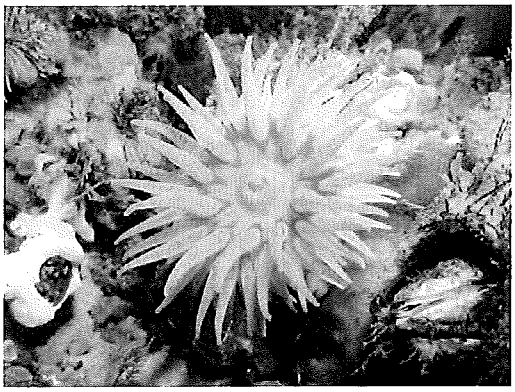
The SPMC Mission Statement and information about the facilities, in addition to information about a number of the center's programs and activities including: academic programs; research projects; *Multicultural Initiatives in Marine Science: Undergraduate Participation* (MIMSUP); and *Coastal Resources and the Ecology of Washington* (CREW).

Shannon Point Marine Center
Western Washington University

MISSION STATEMENT

The Shannon Point Marine Center (SPMC) supports and promotes the academic mission of the University with respect to its programs in the marine sciences. We pursue our mission through academic programs of education and research, two endeavors that are closely articulated at SPMC. Indeed, all education programs incorporate elements of research experience and all research programs involve the active participation of both undergraduates and Master's students. Learning opportunities for undergraduates are, and will continue to be, characterized by access to training in field and laboratory investigative techniques that are extraordinary in their level of sophistication and scope.

Academic activities at SPMC focus on support of programs on the main campus that permit students to specialize in marine science within their broader degree programs.



Such students take courses at the Marine Center offered by their home departments, benefit from contributions SPMC makes to courses offered on the main campus, and take advantage of special opportunities for independent research provided by SPMC. SPMC is thus *a main campus program* whose facilities are strategically located at a site in Anacortes that is particularly conducive to supporting study of marine science. By promoting direct access to the marine environment via our vessel fleet and the 3000' of intertidal beachfront on our campus, by providing the instructional and research benefits of holding animals and plants under controlled conditions in tanks fed by our running sea water system, and by engaging students in an environment that is designed to promote research, we are able to provide a "value added" element to the courses offered by Western academic programs and to the degree programs of Western students.

Marine laboratories traditionally have served not only their home institutions, but also have contributed to the national infrastructure for the support of marine science. SPMC addresses this obligation in a manner consistent with its academic mission by focusing on providing learning opportunities to a specific component of the national marine science community; namely, the students who attend the approximately 3000 colleges and universities that provide neither courses nor programs to satisfy their interests in marine science. In pursuing this part of its mission, SPMC will continue to

emphasize its commitment to providing educational opportunities to racial/ethnic groups under-represented in the sciences. Accordingly, SPMC operates federally-sponsored programs that provide specialized training and research experience to students from around the nation, including minority students. Such programs are designed to improve the learning environment at SPMC for all students.

It is an inherent element of the mission of a comprehensive public university that it apply its professional expertise to public issues via both scholarship and service. Given the significance of the marine environment and its living resources to the region, it is an important element of SPMC's mission to engage in scholarly research that provides new information about these resources. Such activities are carried out at the highest level of sophistication and are communicated to the scientific community and to the general public via appropriate communication vehicles. It is also a part of our mission to provide expert advice to local, State, and federal resource agencies in areas of our expertise and to participate in both general public and K-12 education on marine issues.

In order to accomplish its academic mission, SPMC continuously seeks to keep up with current trends in marine research and to maintain a facilities' base that can continue to provide to scientists the infrastructure necessary to maintain productivity and to students learning opportunities that are extraordinary in scope and sophistication. In order to be successful at this endeavor, SPMC accommodates new approaches to existing programs and explores new areas of appropriate academic activity. In all of its academic programs, SPMC will continue to engage in an assessment approach that can be used to determine our effectiveness in accomplishing our mission and to improve our pursuit of excellence in doing so.

Recipient of the 2002 Presidential Award for Excellence in Science, Math & Engineering Mentoring

Shannon Point Marine Center
Western Washington University

WORKLOAD MEASURES

2006-2010

The following summary will present data on courses offered; programs that involve undergraduate research; graduate students; research projects; visiting scientists; special events; and workload measures such as research vessel trips, external funding, and publications.

During the period 2006-2010, a total of **20** different courses were offered at SPMC for credit, contributing to the core mission of the University. Courses included Oceanography, Fisheries Biology, Marine Ecology, Aquatic Ecology, Fisheries Management Laboratory, Algae, Marine Invertebrates, Estuarine Ecology, Fundamentals of Marine Science, Ichthyology, Environmental Research, Marine Biology, Marine Pollution and Toxicology, Plankton Ecology, Pelagic Ecology, Benthic Ecology, Ecology of Invasive Species, Sediment Biogeochemistry, Marine Invertebrate Larvae and a number of Current Trends in Marine Science topics. Total annual enrollments ranged from 107-156 during the period, with credits offered ranging annually from 457-655 (total: **2815**).

In addition to WWU courses offered at the facility, SPMC hosted field trips from other courses at Western Washington University including Paleontology, Oceanography, Invertebrates and Terrestrial Ecology. Such field trips averaged 33 students per year. A consortium of local public institutions including Skagit Valley, Edmonds, and Everett Community Colleges accessed the facilities for field trips each year (serving an average of 164 students per year), with an additional 30 students per year visiting from other local academic institutions. Over the 5-year period, SPMC hosted field trips for a total of 1183 students from community and local colleges, and public education groups. These included groups from Eastern Washington University, Samish Indian Nation, Northwest Indian College, Walla Walla College, Padilla Bay NERR Interpretive Center, Oregon Museum of Science & Industry, Seattle University and the Heritage Academy (Portland). Short courses, workshops and symposia offered at SPMC served approximately 620 visitors over the five year period.

Supervised independent undergraduate research sponsored by NSF programs (REU, MIMSUP, COSEE) included 16 annually in 2006-2008 and 18 annually in 2009-2010. An additional 10 unfunded undergraduates participated in projects and publications. These 94 students were recruited from Western Washington University and from **58** other colleges and universities nationwide.

In addition to hosting graduate level credit courses, SPMC is the site for Master's thesis research on the part of students participating in the University's Marine and Estuarine Science Program. A total of **22** MESP theses were completed during 2006-2010, with **12** thesis projects currently underway.

We identify a total of **185** SPMC-based research projects completed during the reporting period or currently underway. This number includes projects carried out at Shannon Point by faculty and resident staff, students under the direction of staff, and visiting scientists. Included in this total are 94 projects involving undergraduates directly as investigators (including 77 from 58 other institutions) and 51 involving graduate students. The group of visiting investigators conducting research at SPMC included 28 senior scientists and graduate students.

Visiting investigators and students contributed significantly to SPMC's publication record during the reporting period. A total of **113** formal publications was produced, involving **190** authors and co-authors. This includes 9 resident scientists, 15 students, 2 staff and 164 visiting scientists and collaborators at other institutions.

The external funding record at SPMC during the 5-year reporting period includes support for both infrastructure (facilities development and direct support for academic programs) and research. Of the total of **$9.0 million** ($6.6 million from NSF) received during this period, **$3.4 million (38%)** supported facilities development/instrumentation ($374,488) and academic programs ($3.0 million), while **$5.6 million (62%)** supported research. (It should be noted that all research projects involve and often support the activities of students at SPMC.) In 2010 (and currently), SPMC had active funding of **$5.7 million**, including $4.5 million from NSF ($2.2 million to support facilities' development and academic programs and an additional $2.3 million to support research).

Because one of the main functions of a marine laboratory is to provide students, faculty, and visiting scientists' access to the distinctive marine environments available locally, we are providing data on use of our research vessel fleet as one measure of that activity. During 2006-2010, our three major vessels (RV ZOEA, RV FLORA, RV FAUNA) made a total of **842** trips serving **3524** on-board scientists and students. Participants came from eight WWU departments and programs and 17 other colleges, public agencies and private organizations. During 2006-2010, SPMC supported **1202** approved scientific SCUBA dives. Dives supported the research of 26 undergraduate projects, 9 Master's theses, and 14 research scientists. Dives provided collections for education and training purposes for 14 academic departments and programs. Beginning in 2006, SPMC assumed responsibility for oversight of all WWU underwater activities, including SCUBA dives by other departments (included in data above) and skin diving (48 divers participating in 137 dives).

Prior to 2010, general public education activities were limited by available facilities and staff time. Meetings and events were aimed primarily at University groups, serving a total of **1233** people in 2006-2009, including workshops, symposia, and limited public education activities. In 2010, SPMC implemented a Marine Science Public Education Initiative, resulting in service to **1753** people, plus an additional 50 in the traditional workshop/symposia activities. Public education events (61) included K-8, High School, General Public, Citizen Scientists, College Students and Professionals. Staff contact hours involved in these activities in 2010 totaled **3323**.

Shannon Point Marine Center
Western Washington University

ACADEMIC PROGRAMS

Support of Western's Undergraduate Programs

SPMC's primary focus is to support the University's undergraduate programs that provide students the opportunity to specialize in marine science or that incorporate an element of marine science into the curriculum. Our activities include on-site support of required or recommended courses in the majors of Huxley College and the Biology Department, hosting field trips at SPMC for courses offered on the main campus, providing materials and services to main campus courses, and supporting special projects of individual students

Most courses held at SPMC are offered by Huxley College and the Biology Department. Instructors include faculty members of the respective departments and visiting or resident scientists at SPMC. Typically, six to seven 5-credit courses are offered during Spring Quarter, the typical course being offered all day, one day per week to permit students maximum flexibility in course selection and to accommodate the opportunity for faculty to schedule extended field trips and laboratory exercises. Additional courses (including graduate courses) are offered during Fall and Winter Quarters. Since 1993, more than 25 different courses have been offered at SPMC. SPMC courses typically include a research experience or training in the most-up-to-date field and laboratory investigative techniques.

Field trips and provision of biota and other materials in support of courses offered on the main campus take advantage of our vessel fleet and our ability to collect and deliver marine biota.

Master's of Science in Marine and Estuarine Studies (MESP)

SPMC played a key role in the creation of MESP and has been active in its implementation. Graduate courses are offered at SPMC, as are laboratory sections of courses offered on the main campus. Visiting and resident scientists at SPMC add to the professional resources available to Western students and frequently teach courses, offer seminars, and serve on graduate committees.

The research facilities of SPMC provide support to MESP students in carrying out thesis research. Such support includes provision of laboratory space, access to and

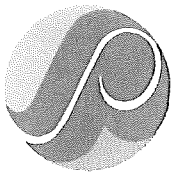
training in use of analytical instrumentation, use of the academic research fleet, assistance with field research including SCUBA, use of laboratory supplies, and direct financial support. SPMC utilizes research grants and its own self-sustaining budgets to provide graduate assistantships to MESP students. Additional support is provided during the summer to help sustain students engaged in thesis research during this important season for marine studies.

National Undergraduate Marine Education Center

Marine laboratories traditionally have served not only their home institutions, but also have contributed to a national infrastructure for the support of marine science. Marine laboratories often provide space in support of the independent research activities of faculty located at institutions remote from the environment they seek to study, most often during the summer. Although SPMC, a charter member of the National Association of Marine Laboratories, hosts visits by such scientists, we have concentrated on providing opportunities for prospective marine scientists; namely, students who attend the approximately 3000 colleges and universities that provide neither courses nor programs to satisfy their interests.

Such programs are funded by the National Science Foundation (NSF) and typically involve WWU students as well as those from other institutions. These programs are not only self-supporting, but our participation in activities that involve students from other institutions render us eligible to compete for NSF facilities' development funding that has provided important resources for all of our students.

Presently, we are operating two such programs, Research Experiences for Undergraduates (REU) and the Multicultural Initiative in Marine Science: Undergraduate Participation (MIMSUP). Both of these programs are described more fully on our webpage. Briefly, REU supports 8 students annually for a nine-week summer program of supervised, independent research. MIMSUP recruits 8 students from WWU and from around the country to spend the Winter and Spring Quarters at SPMC, taking formal courses, engaging in independent research, receiving training in laboratory and field investigative techniques including use of computer technology in word and data processing, and exploring potential career opportunities in marine science. Both programs have operated continuously at SPMC since 1991.



Shannon Point Marine Center
Western Washington University

MIMSUP

The Multicultural Initiatives in Marine Science: Undergraduate Participation (MIMSUP) program was developed to address the under-representation of ethnic/racial minority groups in marine science disciplines. Annually, eight selected students spend two quarters at the Shannon Point Marine Center taking introductory and specialized courses in the marine sciences, attending seminars and workshops, exploring career opportunities, and engaging in supervised research. They also attend a national scientific meeting. After the program, students return to their home institutions to complete their undergraduate programs.

Through 2008, 50% of the participants were Latino/Hispanic, 26% were African American, 11% were Pacific Islanders, and 13% were Native Americans and Native Alaskans. The program goal of increasing the numbers of under-represented minority students pursuing advanced degrees and entering marine science and related professions is being achieved. Through the 2008 academic program, 141 of 143 students have completed MIMSUP, with the same number either completing or currently pursuing baccalaureate degrees. Thus, fewer than 1% of participants have left school without completing degrees. Perhaps the best indication of the program's long-term success is illustrated by post-baccalaureate data. Of the 119 participants who have completed their undergraduate degrees, 13% have pursued the doctorate. Four have completed the doctorate, with two currently NIH Post-doctoral Fellows, one working as the Government Relations Manager for the National Marine Sanctuary Foundation and one with a faculty position at the University of the Virgin Islands. Eleven alumni (9%) have completed or are pursuing professional degrees in medicine, dentistry, business, environmental law or theology. Thirty-four students have completed the Master's degree, with an additional 17 currently in Master's programs (43%). Thus 65% have gone on to some form of advanced education.

MIMSUP participants have earned a remarkable number of scholarships, internships and other awards during and subsequent to their MIMSUP experience. For example, our 143 program alumni have been awarded at least 153 positions in internship programs (including 53 REU positions). They have earned 29 scholarships, 46 fellowships, 5 research grants, and 22 academic awards. Two of our alumni have been

elected to the governing boards of major societies: one as a student representative for the American Society of Limnology and Oceanography (ASLO), the other as a member of the governing board for the Society for Advancement of Chicanos and Native Americans in Science (SACNAS).

Our alumni are also making significant contributions to the sciences. This includes over 261 presentations at regional and national science conferences. These presentations won 30 best student paper awards. MIMSUP alumni are also authors or co-authors on 52 publications in the refereed scientific literature.

The following publications have appeared that relate to MIMSUP:

Bingham, B.L. (2005). Opportunities in the Marine Sciences. Winds of Change Magazine. Summer 2005: 12-16.

Bingham, B.L., S.D Sulkin, S.S. Strom, G. Muller-Parker (2003). Increasing diversity in the marine sciences through the Minorities in Marine Science Undergraduate Program. *J Geosc. Ed.* 51: 474-480.

Fellowships help minorities enter the sciences (2004). *Alaska Airlines* (in-flight magazine). November 2004.

Francisco, E. (2005). MIMSUP. Science Next Wave.

A complete data set on outcomes of the participants is available from Brian Bingham at SPMC (Brian.Bingham@wwu.edu)

Shannon Point Marine Center
Western Washington University

FACILITIES

SPMC is located on a 78-acre campus covered mostly by Pacific lowland forest and distinguished by some 3000 ft of undisturbed beachfront. The campus, including the beach, is treated as a natural laboratory with collection of specimens and disturbances of other kinds limited to professional activities. The beach is a particularly valuable resource as a field study and collection site, its value enhanced by its close proximity to our laboratory facilities. SPMC also controls a 2-acre piece of waterfront property on Mosquito Pass on the northwest corner of San Juan Island. This valuable property was donated to SPMC through a gift to the Western Foundation to serve as a study site and biological preserve. Providing a useful site for comparison with the SPMC beachfront, the Mosquito Pass Study Site will be used to develop a water quality and habitat database and as a field site for educational programs.

The SPMC academic vessel fleet is housed at a slip in nearby Skyline Marina, a site one mile from the campus that permits service year-round and provides ready access to Burrows Bay, an excellent training, collecting and research area. The SPMC fleet includes the RV FAUNA, a 26' aluminum hull with 175 hp outboard motor equipped with a pilot house and hand crank winch; the RV FLORA (19'), powered by a 125 hp outboard and equipped with a diving platform; and our new 32' inboard powered RV Zoea, with A-frame, hydraulic winch and cabin. Field activities and SCUBA are supported by a Field Support Building that provides storage, a workshop and a SCUBA locker.

The main teaching and research facilities include a 23,700 sf complex consisting of the 12,000 square foot Sundquist Marine Laboratory and the new 11,700 sf Marine Education Center facility that opened in early 2006. The Sundquist Laboratory provides wet laboratory space for courses, the marine center's running sea water holding tank room, a radioisotope lab, and facilities for the culture of marine organisms. The Marine Center's running seawater system provides high quality seawater at reasonable volumes. The ability to hold marine organisms safely and effectively in captivity is an essential component of our training and research programs. The new Marine Education Center provides administrative and office space for faculty and administrative staff, a large study/ project/ library room for students, a computer laboratory, and well-equipped

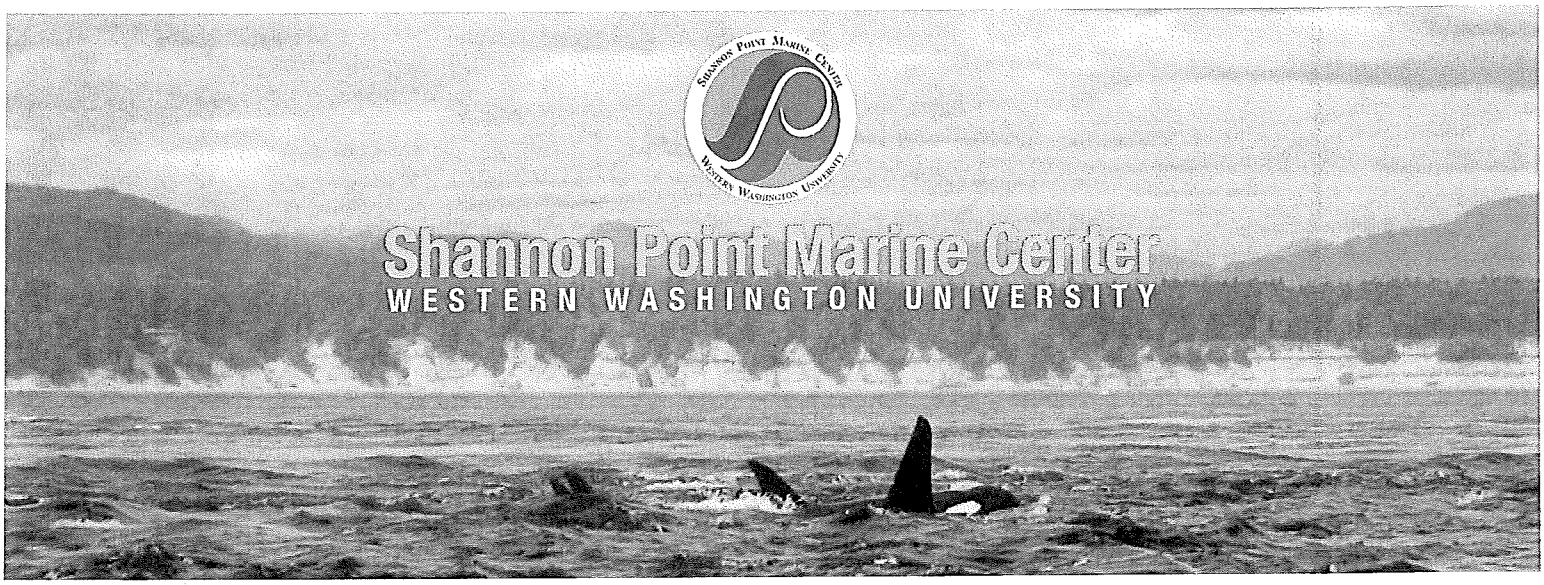
analytical and chemistry laboratories. The two facilities are closely articulated, with the main entrance to both provided in the new building, with an elevator that serves both and an integrated communications and data backbone.

Recognition of the need to maintain a sophisticated instrumentation base that can support modern analytical procedures has led to substantial attention being placed on developing SPMC's analytical capacity. The facility supports oceanographic studies (Turner fluorometer; autoanalyzer, Hydrolab system, liquid scintillation counter, and FLOWCAM), chemical analyses (two diode array spectrophotometers, three HPLC's, three gas chromatographs, CHNS Analyzer), plankton studies (image analysis, epifluorescence scope, inverted scope) and general laboratory support needs (refrigerated centrifuge, ultrafreezer, freeze dryer, microbalances). Other support equipment includes a complete video recording system (with underwater capacity), including a small ROV.

A Computer and Imaging Center networks all of SPMC's computers, including a computer classroom laboratory housing 10 computers and a second computer lab connected to a Local Area Network, four laser printers and a color inkjet printer. Also available are slide and flatbed scanners, a color slide printer, and an image analysis center.

Onsite housing is available to students and visitors, its capacity at 24 persons. The housing units are supported by the adjacent Commons Building that provides a small kitchen and indoor dining area. The Commons is also used for indoor recreation and occasionally as a meeting room.

A more complete description of facilities is available on the SPMC web site at www.wwu.edu/~spmc



MARINE SCIENCE AND THE ARTS SUMMER INTERNSHIP

Program. The Shannon Point Marine Center (SPMC) has created a summer internship for WWU undergraduates who are majoring in some aspect of the arts. The internship is part of the marine center's well-established summer program for undergraduates. The student selected to receive the internship will join 11 other students from WWU and from around the nation who will be spending nine weeks in residence at the marine center located in Anacortes, WA. While SPMC has operated undergraduate research programs in the marine sciences for more than 20 years, this is the first time that support has been provided to bring the arts to the program. It is anticipated that the student intern, in association with a faculty adviser, will be stimulated by the activities at SPMC and the marine environment to apply his/her artistic talents to whatever medium is appropriate. At the conclusion of the summer program, the intern will provide a showing of the results of the project coincident with the presentations made by the other summer interns.

The intern will be invited to participate in all group activities at SPMC that are conducted for the research interns, including field trips and workshops on application of the scientific method to marine science.

Student support will include a $4500 stipend plus a $567 food allowance and housing at SPMC for the nine week session (June 21-August 19). A $500 allowance for materials and supplies will be provided. The faculty supervisor will be provided with a $2500 stipend.

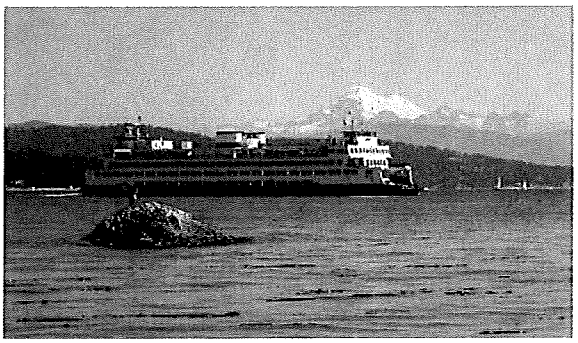
How to Apply. Applicants must be enrolled in a degree program at WWU leading to a major in one of the arts disciplines that will lead to the Bachelor's degree. Applicants should submit the on-line form available at www.wwu.edu/spmc/spmsarts.shtml, a statement of interest in the program that includes a proposed project and project space needs, undergraduate transcripts (informal acceptable), and a letter of reference from a CFPA faculty member. Materials should be submitted by April 22, 2011 to spmc@wwu.edu

Information about SPMC, its programs and facilities can be accessed at www.wwu.edu/spmc

Shannon Point Marine Center
Western Washington University

CREW

CREW
Coastal Resources and Ecology of Washington



The coastal marine environments of the Salish Sea and the living resources they support are of immense economic, aesthetic, recreational, and cultural value to the citizens of the State of Washington, the region and the nation. Recent events in the Gulf of Mexico have dramatically illustrated the need to develop and maintain a solid baseline of knowledge about our coastal resources in order to protect them, document the risks of both catastrophic and chronic damage to them, and assess their value should such damage occur. These values are almost entirely dependent upon maintaining and sustaining a healthy coastal marine environment. To assure such status, it is essential to build a baseline of knowledge now so that it is in place prior to our needing it as a remediation tool. Elements of the baseline must include a catalog of physical and biological resources, a fundamental understanding of the dynamic relationships and interactions among these resources and the ways in which they regulate system productivity and water quality, an economic and policy assessment of the potential threats to them leading to a plan to deal with such threats should they become a reality, and a public that is environmentally literate so as to make informed decisions on the protection and remediation efforts that may be necessary.

Western Washington University has a long history of supporting research and education efforts relevant to local marine environments and has built the human and physical resources upon which a more extensive and inclusive initiative can be developed. Via the CREW initiative, the University will expand and improve upon the existing baseline of information through collation of present knowledge and research in areas that require new information; provide a mechanism by which episodic events can be studied and assessed in real time; provide long-term assessments of changes in coastal marine habitats due to chronic effects; and identify areas that require new research and the public and private sources of funding that can support such research.

The University thus will contribute its expertise and the knowledge it gains from the initiative to students who will be trained in the tools used to develop and disseminate knowledge; to local, state and federal resource agencies charged with system management; to political entities charged with making decisions on activities that can impact the coastal environment; to the scientific community that will have access to the information developed; and to the general public, without whose informed support, action to sustain and mitigate will be impossible.

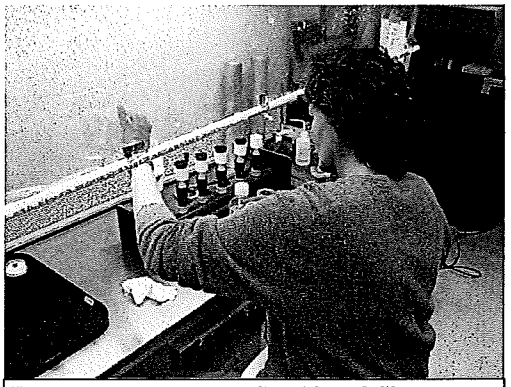
CREW will thus bring together the extensive human and physical resources that already are in place at WWU in a manner that can address coastal marine issues in new and collaborative ways and that can promote further development of such resources to apply the University's full potential in ways that strengthen communities beyond the campus.

Shannon Point Marine Center
Western Washington University

RESEARCH

ECOLOGICAL ROLE OF PLANKTONIC MICROBES IN MARINE AND ESTUARINE ECOSYSTEMS

A fundamental question regarding the productivity of the oceans involves the regulation of predator-prey relationships at the very base of the food web. Most of the energy captured from the sun in the World's oceans occurs through photosynthesis by the tiniest organisms. It is becoming increasingly clear that complex interactions that occur between these tiny producers and their almost equally tiny predators can regulate the fate and efficiency with which sources of nutrition will move through the food web in the ocean.



Undergraduate student Carol Boyd filters sea water to collect marine micro-organisms for study in Jude Apple's lab

The research of Dr. Jude Apple focuses on one aspect of these complex interactions; namely, the ecological role played by planktonic microbes in marine and estuarine ecosystems. One such study is an NSF funded investigation of interactions between the marine prokaryotic phytoplankton *Synechococcus* and its bacterivorous protozoan grazers. Apple's research combines field studies and manipulative experiments to identify protozooplankton grazers that consume *Synechococcus* in natural waters and explores mechanisms of grazing resistance, such as motility, expression of surface antigens, and other chemical defenses. This research will provide insight into the complex interactions of marine microbial food webs and further our understanding of the role of *Synechococcus* in oceanic carbon budgets.

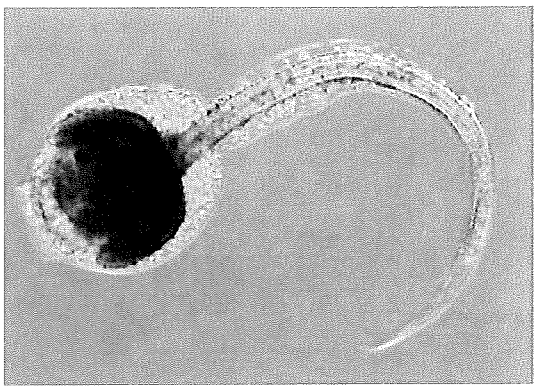
In another project, Apple is exploring the contribution of microbial metabolism to low oxygen concentrations in Bellingham Bay. This project is in collaboration with faculty and students at Northwest Indian College who have been investigating seasonal hypoxia in Bellingham Bay. Critically low concentrations of dissolved oxygen in bottom waters have a detrimental impact on water quality and ultimately Lummi Indian fishery harvest, yet the mechanisms driving this phenomenon are poorly understood. Apple's study investigates the temporal and spatial extent of hypoxic waters in Bellingham Bay and seeks to identify microbial processes as factors contributing to these processes. Results from this research may reveal linkages between hypoxia and land use in the Nooksack River watershed and ultimately lead to suitable mitigation approaches.

Shannon Point Marine Center
Western Washington University

RESEARCH

LARVAL ECOLOGY OF MARINE INVERTEBRATES: HOW IMPORTANT IS LIGHT?

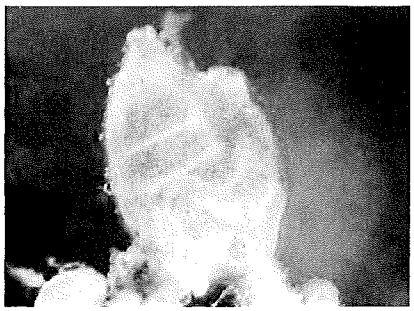
Many marine invertebrates produce larvae that disperse in the plankton. As planktonic organisms, the larvae are exposed to conditions that can adversely affect growth and survival. For example, UV in sunlight damages many organisms. The lethal effects of UV are generally attributed to DNA damage, but damage to other biological molecules (e.g., RNA, enzymes, proteins) can occur. Larvae, which are undergoing important developmental processes, may, therefore, be particularly vulnerable to light damage. Dr. Brian Bingham is investigating whether planktonic larvae of marine invertebrates are affected by sunlight and how larvae avoid the damaging effects of light.



Larval tunicate

Initial work on this question was done with a common sea squirt (*Corella inflata*). Individuals of this species (and most other sea squirts) produce larvae that spend from minutes to hours in the plankton before attaching to benthic substrates. Bingham found that light strongly affects the larvae; a 30-minute exposure was sufficient to cause lethal damage.

To demonstrate that UV was responsible for the lethal effects, larvae were exposed separately to UVB, UVA and visible light (PAR). In general, high energy UVB is known to damage animals and plants; PAR, on the other hand, is thought to be "good" light. As expected, UVB severely damaged *C. inflata* larvae. However, exposure to PAR alone also killed larvae. This was very unexpected and suggests that sunlight exposure may strongly limit dispersal and settlement of the larvae.



Adult tunicate

To determine whether *C. inflata* is unusual in its light sensitivity, Bingham and his students are testing additional tunicate species to see whether they show similar effects. To date, six species have been tested. The

larvae of five of those species are sensitive to light (UVB, UVA and PAR). Only one species (*Styela gibbsii*) is undamaged by sunlight. Its lack of sensitivity appears related only to timing of its reproduction; larvae are produced during the winter when short days and cloud cover minimize duration and intensity of exposure.

Bingham's group continues to work with sea squirts, attempting to relate larval light vulnerability to adult habitat and developmental characteristics of embryos and larvae. Workers in his lab are also branching out to other invertebrate groups to see if sunlight sensitivity is a more generally important ecological factor. Larvae that are sensitive to sunlight damage may show behaviors that place them at depths where they will not suffer damage. Such behaviors could have profound consequences on dispersal and, ultimately, the distributions of adult populations.

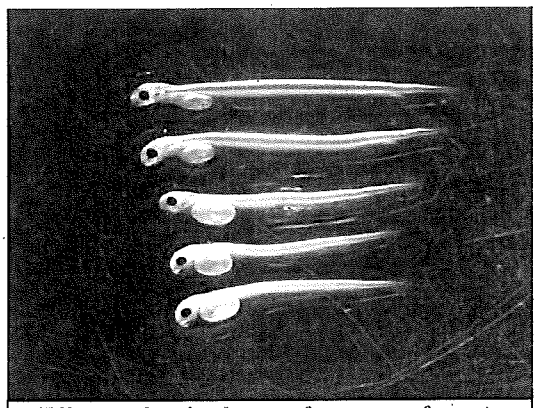
Shannon Point Marine Center
Western Washington University

RESEARCH

DEVELOPMENT OF PACIFIC HERRING BIOASSAY PROTOCOLS FOR THE STATE OF WASHINGTON

Pacific herring (*Clupea pallasi*) is an important forage and commercial fishery species throughout its range on the Pacific Coast of the U.S. and Canada. Several Puget Sound stocks of Pacific herring have suffered precipitous declines in abundance and spawning biomass during the last several decades. Indeed, the largest stock of herring in Washington State, the Cherry Point stock, is now in critical condition, with only about 10% of the spawning biomass present as compared to the mid-1970s, and the sac roe fishery at Cherry Point has been closed in recent years. While much of the decline in the Cherry Point stock may be due to natural factors (e.g., long- and short-term temperature increases and/or predation by fish and marine mammals), point and non-point sources of pollution remain as potentially significant stressors that may be acting in concert with natural stressors.

Dr. Paul Dinnel has been developing embryo and larval Whole Effluent Toxicity (WET) test protocols for future testing of possible effects of chemicals in effluents and sediments on early life stages of Pacific herring. The 7-year project has been funded by grants from the State of Washington Department of Ecology, the US EPA and industry. Testing has focused on 1) development and refinement of a 12-day embryo development test, a 4-day acute larval test and a 7 day survival and growth test, 2) intra-laboratory validation testing of all three test protocols using three reference toxicants, 3) initiation of inter-laboratory validation testing, 4) comparison of the sensitivity of the herring bioassay protocols with EPA-approved effluent tests (sea urchin embryo development test, top smelt survival and growth test, inland silverside acute test, and rainbow trout embryo development and juvenile acute tests), and 5) initial herring tests of effluents originating from four oil refineries and one aluminum smelter.



Effects on herring larvae of exposure of eggs to increasing concentrations of copper (top to bottom)

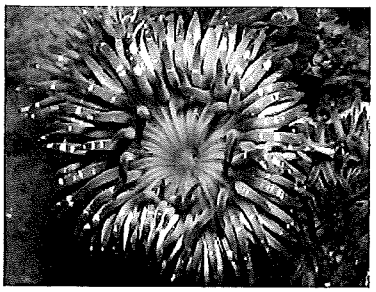
In addition to intra- and inter-laboratory validation testing using three reference toxicants (Potassium chloride, sodium dodecyl sulfate and copper sulfate), toxicity data have also been developed for nine other toxicants: cadmium, lead, silver, zinc, naphthalene, a primary sewage effluent, SeaKleen® (a proposed ballast water biocide), a creosote leachate, and a toxicant-spiked secondary sewage effluent.

The three herring test protocols developed by this program are now ready for export to commercial testing laboratories, which can use these tests to monitor the toxicity of industrial effluents, sewage treatment plant discharges, non-point sources of pollution and seawater samples collected from Puget Sound.

Shannon Point Marine Center
Western Washington University

RESEARCH

DYNAMIC NATURE OF ALGAL SYMBIOSES: CONSEQUENCES FOR HOST FITNESS IN AN INTERTIDAL ALGA-ANEMONE ASSOCIATION.



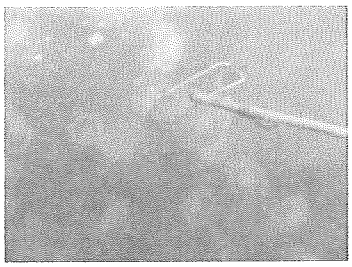
Anthopleura elegantissima is the most abundant sea anemone in intertidal communities of the northeast Pacific Ocean and thus plays an important role in the ecology of these systems. *A. elegantissima* typically contains millions of microscopic symbiotic algae in its cells. These photosynthetic algae contribute to intertidal community productivity on par with intertidal seaweeds. Both *A. elegantissima* and a related species, *A. xanthogrammica*, are unique because they may contain one or both of two distinct photosynthetic algae. This feature renders these species important as a model to help us better understand symbiotic partnerships and how they respond to a changing environment. The relative abundance of the two algae in *A. elegantissima* populations in the San Juan Islands of Washington State is being studied on a seasonal basis to provide a barometer for climate change. For example, the distributions and abundances of the two symbiont species are predicted to shift if temperature or light levels change. This prediction is based on the different physiological tolerances of the algal symbionts (one prefers cooler, low-light environments while the other does better in warmer, high-light environments). Drs. Gisele Muller-Parker and Brian Bingham are also using laboratory studies to test the relative value of each symbiont by measuring their impact on growth and reproduction of the anemone host. Anemones are being exposed to different levels of natural sunlight, and sexual reproduction, asexual division, and body growth are being monitored. Health of the symbionts will be measured in terms of photosynthetic productivity and division rate. Results of the work will provide valuable insights into the ecology of an important and abundant intertidal species, and will be important for developing testable hypotheses about how other long-lived species with multiple symbiotic partners (e.g., lichens and corals) will be affected by climate change-related shifts in symbiont complements. This research engages undergraduate and graduate students, including members of groups underrepresented in science. The project is funded by a grant from the National Science Foundation.

Shannon Point Marine Center
Western Washington University

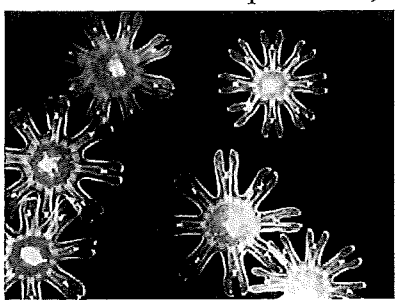
RESEARCH

THE CAUSES OF INCREASING JELLYFISH POPULATION ABUNDANCE

Jellyfish generally are considered detrimental to human enterprise because they can reduce tourism, interfere with fishing and power plant operations, kill fish in aquaculture pens, consume the early stages of fish and compete with finfish for their zooplankton prey. Jellyfish population increases have been reported in recent years from all over the World. Increased jellyfish abundance may be caused by degradation of ocean and estuarine water quality due to human activities, including warming ocean temperatures, changing salinity regimes, eutrophication, and hypoxia. The addition of hard substrates, such as rip-rap and pilings, provides more habitat for the critical polyp life history stage and over-fishing of finfish can reduce competition for food resources that permit jellyfish populations to flourish. Dr. Jennifer Purcell's research at SPMC focuses on the importance of jellyfish in the world's oceans and the probable causes of their population increases.



The current emphasis of her research is on how variations in climate affect jellyfish population size. Her work focuses on the attached polyp stage, each of which can bud off many of the more familiar pelagic adults. Laboratory experiments show that above-normal temperatures, variations in salinity, and increased light greatly increase the numbers of jellyfish produced from the attached polyp stage, thus accelerating jellyfish production. Experiments are in progress to determine the effects of acidification, a consequence of increased carbon dioxide in the atmosphere, on jellyfish production. A polyp population monitored for 3 years showed that high jellyfish production occurred in the year when temperature and light were highest. Field data of jellyfish numbers will be correlated with temperature, salinity, and zooplankton densities to evaluate which factors can best predict jellyfish population sizes. These and future results will contribute to understanding how jellyfish populations may respond as ocean conditions continue to change.



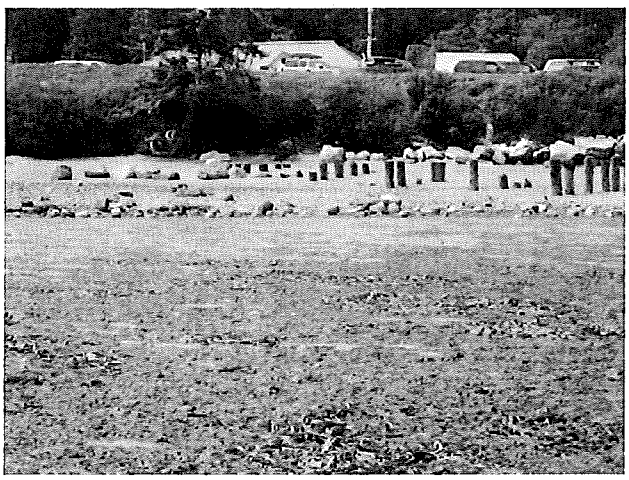
Shannon Point Marine Center
Western Washington University

RESEARCH

GREEN TIDES: HARMFUL SEAWEED BLOOMS IN WASHINGTON WATERS

Green tides are excessive growths of large green seaweeds that are becoming increasingly abundant in the Puget Sound region. The seaweeds that cause green tides grow very rapidly under the right conditions and can cause numerous environmental problems. For example, green tides can overgrow parts of eelgrass meadows, depleting habitat for juvenile finfish and shellfish. They can also accumulate on beaches and decompose, depleting oxygen in the water and causing noxious odors. Recent research has shown that some green tide seaweeds can release toxins into the environment when the seaweeds are physiologically stressed by warm temperatures or by being exposed to air during low tides.

Dr. Kathy Van Alstyne's lab is investigating the causes and consequences of green tides in the Puget Sound region. In collaboration with researchers at Seattle Pacific University, and using video surveys provided by the Washington State Department of Natural Resources, Dr. Van Alstyne and her colleagues are investigating where and when green tides occur and how often they threaten eelgrass beds. They are also studying environmental conditions, such as nutrient availability, temperature, pH, salinity, and dissolved oxygen concentrations that are associated with the formation of green tides and the effects of changes in environmental conditions on toxin production and the health and growth rates of the seaweeds.



Green algal mat at Ship Harbor, Anacortes

The field work being conducted by Dr. Van Alstyne's lab involves surveying green tide seaweeds at six sites located in Skagit, Island, and San Juan counties during

the spring and summer growing season. These surveys are being conducted with the help of Western Washington University and Seattle Pacific University students, participants in the Research Experiences for Undergraduates (REU) programs, and citizen-scientist volunteers from the Skagit and Island County Beach Watchers programs. At each of the survey sites, data sondes have been deployed to collect information about the chemical and physical properties of the water. In addition to providing valuable information about conditions associated with green tides, these data collected by the sondes are also useful to local agencies and resource managers wanting information about water conditions near the study sites. For example, the water-quality data collected in Penn Cove on Whidbey Island is expected to be used as baseline information about the water condition prior to a possible change in the location of a sewage outflow into Penn Cove.

The field work being done by the Van Alstyne lab is complemented by laboratory studies that include measurements of seawater nutrient concentrations, measurements of the nutritional content of the green tide seaweeds, and measurements of seaweed chemical defenses and toxins. Laboratory experiments are also used to examine the effects of specific environmental factors, such as nutrient concentrations, on seaweed growth and chemical composition, and the effects of seaweed toxins on other marine plants and animals. In addition, the lab is conducting analyses to determine if other chemical defenses or toxins exist in green tide seaweeds that have not been previously described.

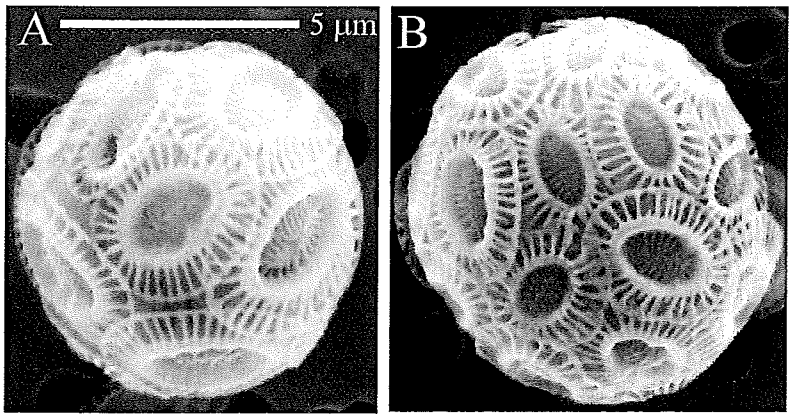
This work has received funding from the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration's (NOAA) Ecology of Harmful Algal Bloom (ECOHAB) program. More information about this research project and green tides is available at http://www.ac.wwu.edu/~kathyva/habshome.htm.

Shannon Point Marine Center
Western Washington University

RESEARCH

Ocean acidification and planktonic food webs: what lies ahead?

The concentration of gaseous CO_2 in the Earth's atmosphere has risen to unprecedented levels over the last 400,000 years, and is increasing at an exponential rate due to human activities. Approximately 30% of the CO_2 humans emit to the atmosphere dissolves into the ocean. Once CO_2 dissolves into the ocean, a series of chemical reactions ensue that alters the ocean's inorganic carbon chemistry, specifically increasing seawater CO_2, carbonic acid (H_2CO_3), bicarbonate ions (HCO_3^-), and decreasing pH and carbonate ions (CO_3^{2-}). Because of the decrease in oceanic pH, this process has been labeled 'ocean acidification'. For marine organisms that make calcium carbonate ($CaCO_3$) structures, reduction of CO_3^{2-} ions makes the process of making and retaining $CaCO_3$ energetically unfavorable. This has major biogeochemical consequences and has received considerable research attention. Less studied is the effect that increasing CO_2 has on marine organisms. For organisms that photosynthesize, CO_2 is used to make the simple sugars that fuel the marine food web. Increasing dissolved CO_2 may alter rates that phytoplankton photosynthesize and reproduce. This too has important biogeochemical implications. At Shannon Point Marine Center, Drs. Brady Olson, Brooke Love and Suzanne Strom, along with contributions from staff technicians and graduate and undergraduate students from both Western Washington University and universities across the nation, are engaged in a National Science Foundation funded project to explore how ocean acidification will affect marine planktonic food webs. We are specifically engaged in trying to answer two different questions:



Emiliania huxleyi cells grown at (A) current CO_2 (390 ppm) or (B) elevated CO_2 concentration (1000 ppm). Each cell is covered by many calcium carbonate 'plates' called coccoliths. *E. huxleyi* cells grown at elevated CO_2 were larger, produced more, but smaller, coccoliths per cell.

Identifying how calcifying and non-calcifying phytoplankton respond physiologically and biochemically to ocean acidification

For marine organisms that photosynthesize, the enzyme responsible for 'fixing' CO_2 onto larger carbon molecules to make simple sugars is currently limited by modern CO_2 concentrations and, as such, operates below its optimal capacity. Because of this, many phytoplankton respond to addition of CO_2 by photosynthesizing at higher rates. If phytoplankton photosynthesize at higher rates, other aspects of their physiology and biochemistry may change as well, such as cellular growth rate, cell size, and the cellular ratio of important elements like carbon, nitrogen and phosphorous. Our group is using a unique gas delivery system we developed in our laboratory to grow the globally distributed phytoplankton, *Emiliania huxleyi*, across a range of elevated CO_2 concentrations. *E. huxleyi* is an important player in the global carbon cycle because it is one of the few phytoplankton that produce calcium carbonate structures. Our research is showing that *E. huxleyi* cells respond in many ways to elevated CO_2, including altering their calcification rate and the number and structure of their calcified parts (coccoliths). Characterizing how *E. huxleyi*, and phytoplankton in general, respond to future CO_2 concentrations will help us understand how changing climate will affect the base of the marine food web.

Determining how zooplankton feeding and growth are affected by feeding on a diet of phytoplankton grown in acidified conditions

An epifluorescent micrograph showing a ciliate microzooplankton (green) with ingested phytoplankton prey cells (red). Ciliate is approximately 0.1 mm in length.

Microzooplankton consume approximately 70% of marine phytoplankton primary production, making them the most significant grazers in the ocean. By consuming such a substantial portion of primary production, they serve as a link between phytoplankton and higher trophic levels such as birds and fish, and their metabolic waste products are utilized by phytoplankton to continually fuel primary production. Because microzooplankton play such a prominent ecological role in the ocean, for the past 30 years researchers have been working towards understanding which factors regulate what and how much microzooplankton eat. This work has shown that prey growth rate, prey cell size, and prey nutritional quality, for example, affect the rate at which microzooplankton consume prey, and helps determine which prey items they eat. All of these prey factors have been shown to change in phytoplankton in response to ocean acidification. Using our ocean acidification system at Shannon Point Marine Center, we are currently conducting experiments with several locally isolated species of microzooplankton to determine how their growth and feeding rates will be affected when feeding on phytoplankton grown under acidified conditions. This important work will help us understand how food web structure and function will change as our ocean slowly acidifies due to human activities.

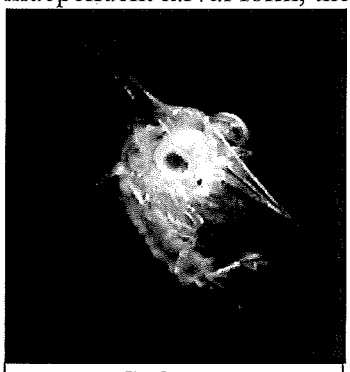
Shannon Point Marine Center
Western Washington University

RESEARCH

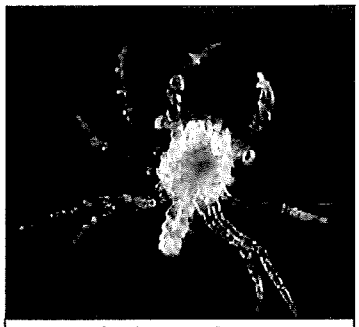
INVESTIGATING THE NUTRITIONAL REQUIREMENTS OF LARVAL STAGES OF CRAB SPECIES INHABITING THE INLAND WATERS OF THE PUGET SOUND BASIN

Given the relatively high fecundity of most crab species and the high potential for loss of larvae from the system, survival and dispersal of larvae can have profound impacts on adult population abundance and distribution. In addition, given that at certain times and at certain places larval crabs can dominate the mesozooplankton, they can have significant effects on community interactions, serving as both top down regulators of other plankton and as important prey for other invertebrates and finfish. The research of Dr. Steve Sulkin focuses on the early life history stages of crabs; specifically, investigating the factors that regulate the survival and distribution of the larval stages of crab species that occupy the inland waters of the Puget Sound basin.

Typical of many marine invertebrates, most crab species produce a free-swimming independent larval form, the zoea, that differs considerably from the more familiar juvenile and adult. Zoeae are planktonic and most are planktotrophic; that is, they must feed actively on other planktonic forms to survive and develop normally. As crustaceans, larvae have a hard exoskeleton that they must cast off periodically to grow. The period of zoeal development is thus punctuated by molting events that define a specific number of zoeal stages, the number of which varies among species. These zoeal stages can differ from one another morphologically and behaviorally and can have different nutritional requirements that must be satisfied via the diet. After a period of zoeal development, crabs pass through an intermediate post-larval form, the megalopa. The megalopa can both swim in the water column and crawl about on the substrate, eventually seeking out suitable habitat for settlement and metamorphosis to the benthic juvenile.



Crab zoea



Crab megalopa

Sources of loss of larvae to a population include dispersal away from suitable habitats, predation by other planktonic organisms, mortality imposed by unfavorable water quality conditions and nutritional stress. Research at Shannon Point has focused on the nutritional requirements and feeding behavior of

the zoeal stages. Past research by Sulkin and others has determined that larvae must feed immediately after hatching and early in each succeeding zoeal stage; that they require a dietary source of long chain omega-3 polyunsaturated fatty acids (PUFA) to develop normally to the megalopa; and that they can ingest a wide variety of prey types in a wide range of sizes. Larvae can ingest microalgae and other protists as well as small animal prey, discriminate among algal cells and reject some cell types. Although they readily ingest many types of protists, they do not appear to gain much nutritionally from doing so. The most successful prey types in laboratory culture tend to be small holoplanktonic animal prey (e.g., rotifers) and the meroplanktonic larval stages of other invertebrates (e.g., nauplii, trochophores).

Present research is focusing on the role played by prey types which themselves must feed in the plankton. This includes both holoplanktonic micro- and mesoplankton and invertebrate larvae that feed on other planktonic forms. Questions being investigated include whether the diet of such prey affects their nutritional value to larval crabs. A special case of this research involves studying the nutritional value of prey that initially are sustained by stored energy reserves provided in the egg, but who soon deplete the stored reserves and must feed in the plankton. The early lecithotrophic phase of such prey is known provide a highly nutritional diet to support larval crab development, presumably because the larvae can exploit the same stored energy reserves that sustains the prey itself. It is not known, however, whether the later planktotrophic phase of the same prey provides equal, or satisfactory, nutritional value to the larvae and how the prey's diet influences the process.

Among the algal cells that larvae can ingest are those toxic cell types responsible for red tides. Recent research in Sulkin's lab indicates that larvae will on one hand reject toxic cells of some species of algae, but ingest those of another closely-related species. This results in the paradoxical situation in which larvae will ingest cells that will accelerate mortality compared to starved controls even though they appear to possess the capacity to discriminate among (and reject) cell types. Research is addressing whether heterotrophic prey that have previously fed on toxic algae vector algal toxin to the larval crabs. Experiments are being conducted using a toxic strain that can be ingested directly by larvae and one that is rejected by them, thus not providing a direct source of toxin.

The experimental approach involves hatching larvae in the laboratory from egg-bearing females, raising the larvae individually on target prey and determining larval survival and development rates. Prey (both autotrophic and heterotrophic) are maintained in the laboratory in sufficient quantities to be available to feed larvae on a daily basis. Both toxic and non-toxic prey are characterized using appropriate analytical techniques for total lipid, C:N ratios and long chain omega-3 PUFA constituency. Such characterizations assist in comparing nutritional values among prey and in distinguishing between toxic effects and nutritional deficiencies.

Research is carried out primarily by graduate students in WWU's Marine and Estuarine Science Program and undergraduates participating in Shannon Point's Research Experiences for Undergraduates (NSF Grant OCE-0551898) and the Multicultural Initiatives in Marine Science: Undergraduate Participation (NSF Grant OCE-0228618) programs.

Shannon Point Marine Center
Western Washington University

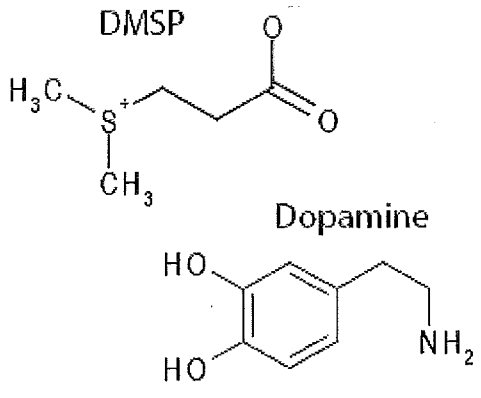
RESEARCH

SEAWEED AND INVERTEBRATE CHEMICAL ECOLOGY

Many marine plants and animals produce unusual chemicals that help them deal with environmental stresses or that are used in interactions with other organisms. Some of these chemicals help marine organisms cope with changes in the environment such as drops in salinity or increases in temperature and UV radiation, whereas others are used to prevent infection by microorganisms, overgrowth by other plants and animals, and consumption by predators. Research in Dr. Kathy Van Alstyne's lab examines how marine organisms use these unusual chemicals and how the production of these chemicals is regulated. Her recent work has focused on three groups: catecholamines produced by green seaweeds, dimethylsulfoniopropionate (DMSP) produced by seaweeds and invertebrates, and phlorotannins produced by brown seaweeds.

Dopamine is a catecholamine that is best known as a neurotransmitter and hormone in many animals. However, dopamine is also produced by the green seaweed *Ulvaria obscura* (dark sea lettuce). *Ulvaria* is the only seaweed known to produce dopamine and it produces it in copious amounts; dopamine can constitute up to five percent of the dry weight of the seaweed. Unlike animals, *Ulvaria* uses dopamine as a chemical defense against predators. Dopamine is also released by *Ulvaria* when it becomes physiologically stressed by high temperatures or dried out. Van Alstyne and her students have shown that dopamine can be harmful to other marine life at concentrations similar to those believed to be found in nature.

Dimethylsulfoniopropionate (DMSP) is a small sulfur-containing molecule that is produced in abundance by many types of green seaweeds, a few red seaweeds, and cnidarian invertebrates such as corals, soft corals, anemones, sea whips, and sea fans. Van Alstyne's lab has been investigating the role of DMSP and its two breakdown products, dimethylsulfide (DMS) and acrylic acid, in the biology of green seaweeds and invertebrates. The lab's research has found that DMS and acrylic acid are distasteful to some marine invertebrates, making them part of an activated chemical defense. They also can function as antioxidants and protect the organisms that produce them from highly reactive oxygen species (ROS) that accumulate when algae are physiologically stressed by conditions such as high levels of UV radiation, low salinities, and physical damage. The lab is currently studying how different environmental



factors affect the production of DMSP and the production of DMSP by algae that live as symbionts in marine invertebrates.

Phlorotannins or polyphenolic compounds are a group of compounds that are found in most brown seaweeds. Although they are best known for their ability to deter feeding by herbivores that consume the seaweeds, they also function as antioxidants. Van Alstyne and her lab have been studying the environmental factors that affect the production of these compounds and how these chemicals affect ecological interactions in nature. They have determined that these seaweeds are capable of using a variety of different environmental cues as signals to increase or decrease the production of phlorotannins and that changes in the chemical composition of these seaweeds affect the rates of algal-herbivore interactions.

Work on the chemical ecology of Puget Sound seaweeds in Van Alstyne's lab is currently being supported by funding from the National Science Foundation (NSF).

Shannon Point Marine Center
Western Washington University

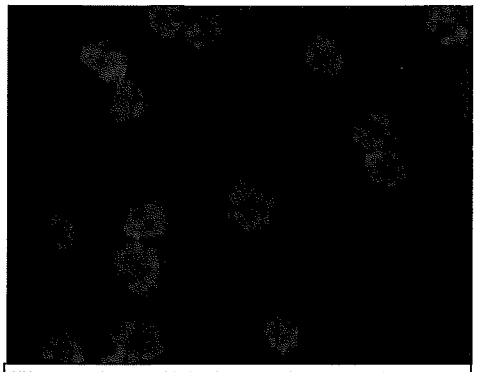
RESEARCH

THE ECOLOGY AND DYNAMICS OF MICROALGAL HARMFUL ALGAL BLOOMS (HAB)

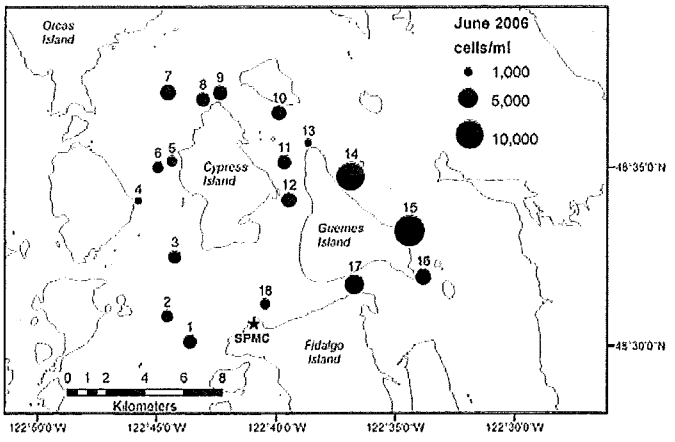
Why do some species of planktonic algae form dense, persistent accumulations (blooms) while others do not? What factors make microalgae more or less toxic and what are the selective pressures leading to the evolution of toxicity? How does the availability of resources influence microalgal toxicity toward potential zooplankton grazers? Dr. Suzanne Strom, along with students and colleagues at Shannon Point and other institutions, are engaged in two research projects addressing these questions.

Identifying Regulatory Mechanisms for *Heterosigma akashiwo* Bloom Formation

The microalgal flagellate *Heterosigma akashiwo* blooms in temperate coastal waters worldwide. Blooms of this species often cause fish kills, especially of fish in aquaculture pens. In early July 2006, a massive bloom of *Heterosigma akashiwo* formed in and moved through waters of northern Puget Sound and the Strait of Juan de Fuca. High densities of *H. akashiwo* in the waters around the San Juan Islands resulted in the deaths of thousands of penned Atlantic salmon. Additional blooms occurred in spring and summer 2007. The ECOlogy of Harmful Algal Blooms (ECOHAB) project to address this issue at Shannon Point, funded by NOAA, is a collaborative effort between the Strom lab group and Dr. Susanne Menden-Deuer (WWU, University of Rhode Island). Together, they are combining



Heterosigma (15microns in length)



Map of Heterosigma cell concentrations

traditionally separate "bottom up" and "top down" research approaches, with the goal of developing a conceptual model of how multiple factors interact to promote bloom formation. To date, *H. akashiwo* has been isolated from both 2006 and 2007 blooms, and the group is working with these local isolates to understand the physiology and ecology of this harmful microalgal species. Blooms often occur in conjunction with high runoff from area rivers. Thus an important question is how *H. akashiwo* behavior, growth and toxicity respond to salinity variation. The group is also studying the swimming behavior of this flagellate; in particular, how layers of high cell density are formed, and how potential predators (microzooplankton) respond to these layers. A third avenue of study is the use of different nitrogen sources for growth of *H. akashiwo*, and the effect of different N sources on toxicity. All questions are being addressed with multiple isolates of the flagellate, to understand the range of different responses possible within the species.

Diatom Chemical and Mechanical Defenses

In geologically recent times, diatoms have evolved to become one of the most successful phytoplankton groups in the sea, responsible for an estimated 40% of marine primary production. The sustained blooms that diatoms often generate are one attribute leading to their high primary production. Although only a few diatom species have toxins that affect humans, diatom blooms share many characteristics with blooms of "harmful" microalgae. Recently, both chemical and mechanical defenses have been hypothesized to deter or directly harm zooplankton grazers that might otherwise consume diatoms and regulate their populations. Reactive polyunsaturated aldehydes (PUAs) derived from C20 fatty acids upon diatom wounding have been shown to inhibit cellular processes in numerous marine organisms. The silica frustules of diatoms have also been hypothesized to constitute a mechanical defense against zooplankton. In this NSF-funded research project, the Strom lab group is testing the effectiveness of these chemical and mechanical defenses against microzooplankton, including large ciliates and heterotrophic dinoflagellates. Microzooplankton feeding, growth or mortality, and the cellular basis for chemical damage is being evaluated in experiments with diatoms that express a range of defense levels. In collaboration with Dr. Fred Prahl, Oregon State University, Strom's group is working to measure levels of PUAs in diatoms grown under a range of conditions. The overall goal is to test the effectiveness of these putative chemical and mechanical defenses against microzooplankton grazers. This will help us understand how and why diatom blooms form and persist.

Shannon Point Marine Center
Western Washington University

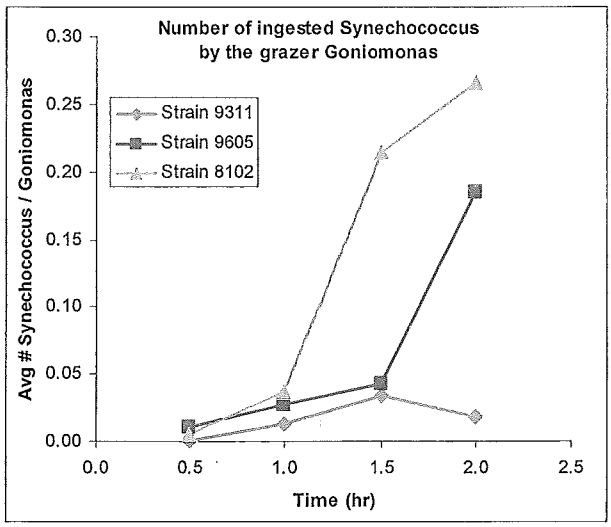
RESEARCH

THE ROLE OF CHEMICAL SIGNALING IN MICROBIAL PREDATOR-PREY INTERACTIONS

Both dissolved and cell surface-associated chemical cues dictate microbial interactions in well-studied ecosystems such as bacterial biofilms and the human immune system. Since many features of single-celled pro- and eukaryotes are highly conserved across evolutionary time, it is likely that such signaling also occurs among planktonic microbes, including bacteria, microalgae (phytoplankton) and microzooplankton. Dr. Suzanne Strom and colleagues are exploring this possibility in two different projects.

A Post-genomic Approach to *Synechococcus* – Grazer Interactions

Cyanobacteria, including *Synechococcus*, are the tiniest and most abundant photosynthetic organisms in the sea. Most *Synechococcus* produced are eventually consumed by protist grazers. There is considerable evidence that some protist grazers can detect the cell surface properties of their prey, and variation in cell surface properties can affect rates of feeding. This NSF-funded project uses marine *Synechococcus* isolates as a model organism for exploring morphological, behavioral, and chemical resistance strategies of microbial prey against protozoan grazers. In collaboration with Dr. Brian Palenik and Dr. Bianca Brahamsha, both of the Scripps Institute of Oceanography, the Strom lab is using different *Synechococcus* isolates, including genetically characterized mutants, to investigate the role of cell surface structures in modifying predation. The project draws on the recent availability of complete genomes and molecular genetics tools for *Synechococcus* to determine the key cell structures under selection by diverse protist grazers. In additional work on seasonal *Synechococcus* blooms in coastal



Southern California waters, the group is attempting to identify the major protist grazers of *Synechococcus*, and to determine whether they are feeding selectively on different *Synechococcus* strains in the plankton. Post-doctoral research associate Dr. Jude Apple is currently working on this project at SPMC.

Phytoplankton-produced chemicals as signals regulating grazer behavior

In an on-going research collaboration with Dr. Gordon Wolfe (California State University Chico), Strom is investigating the effects of dissolved organic compounds in regulating swimming behavior and feeding rates of protist grazers. Two NSF grants, originating in 1998 and 2003, have supported this research. Initial work focused on release and signaling activity of the organic sulfur compound DMSP and its cleavage products, DMS and acrylate. These compounds are produced by marine microalgae and bacteria. When released to the atmosphere, DMS molecules can act as cloud condensation nuclei, so levels of DMS production can influence cloud cover and hence climate. Strom and Wolfe have found that the DMS precursor DMSP inhibits feeding by numerous species of protist grazers, including ciliates and dinoflagellates. Even more potent are structurally similar amino acids, also produced and released by marine microbes. In extensive research, the nature of this inhibition phenomenon has been documented, including dose-response characteristics, signal compound specificity, protist grazer acclimation, and effects of these signals on whole community activity. The group has also studied differential production of DMSP and DMS by different strains of the coccolithophore *Emiliania huxleyi*, an important, planktonic microalgal species, and have documented the differential responses of protist grazers to various *E. huxleyi* strains. In on-going research in the Wolfe laboratory, the cellular mechanisms for the inhibition effect are being studied through the use of radio-labeled amino acids.

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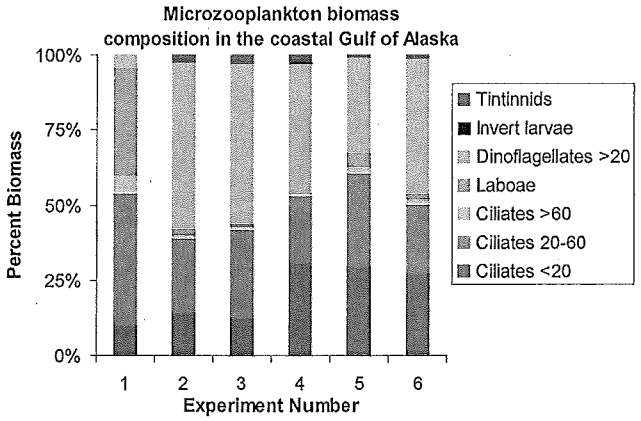
RESEARCH

CLIMATE – PLANKTONIC FOOD WEB – FISHERIES CONNECTIONS IN THE NORTH PACIFIC AND BEYOND

Over the last two decades, scientists and fisheries managers have recognized that climate fluctuations are closely connected with variations in fish production. Understanding the oceanographic and ecological mechanisms behind these connections is important for predicting future fish stocks – this approach is termed "ecosystem-based management". For the past 8 years Dr. Suzanne Strom and colleagues have participated in a multi-investigator project (U.S. GLOBal Ecosystem Dynamics, or U.S. GLOBEC) to understand climate – fisheries connections in the coastal Gulf of Alaska. Following several years of field work to study regulation of planktonic food webs by oceanographic and atmospheric conditions, the synthesis and modeling of these and other field data sets is now underway. A conceptual understanding of how production is regulated and transferred in marine ecosystems, along with quantitative models that accurately encapsulate that understanding, is a prerequisite for ecosystem-based management.

GLOBEC Northeast Pacific Synthesis Study: Links Between Climate and Planktonic Food Webs

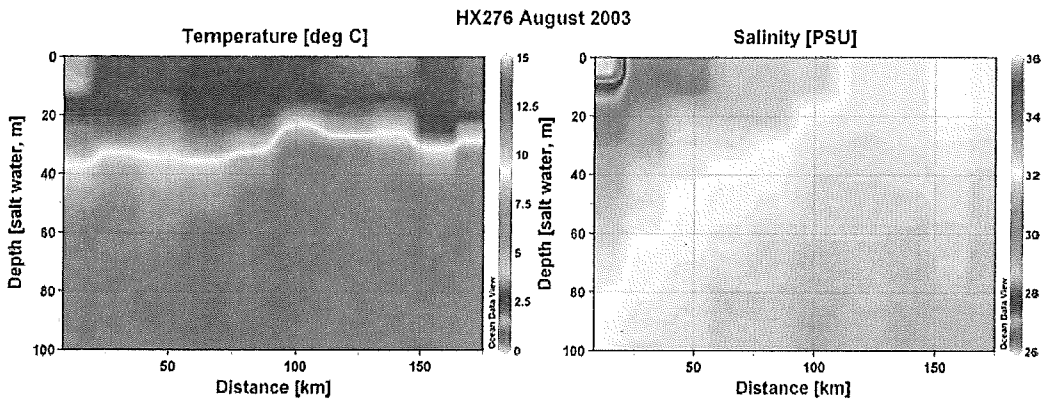
The aim of this multi-investigator project funded by NSF is to better understand climate regulation of primary and secondary (zooplankton) production on the coastal Gulf of Alaska (CGoA) shelf, including how year-to-year and spatial variation in production affect the supply of prey for juvenile pink salmon. Strom is working with colleagues Drs. Mike Dagg (LUMCON) and Russ Hopcroft, Ken Coyle and Terry Whitledge (University of Alaska Fairbanks) to synthesize plankton and climate data. The research is closely coordinated with other Northeast Pacific GLOBEC projects



investigating North Pacific climate signals, pink salmon diet and energetics, and physical – biological models of the region. Using box, statistical and 1-D ecosystem models, the project seeks to describe the planktonic food web in the CGoA study region; provide an integrated view of conditions in the CGoA during each of the field years (1998-2004), and place these conditions in a multi-decadal climate context using longer-term environmental data sets. Ultimately they will combine each year's environmental description with food web structural/and functional relationships to: (a) describe interannual variations in primary and secondary production, (b) investigate probable mechanisms driving these variations, and (c) determine their consequences for target organisms: *Neocalanus* spp. copepods, euphausiids and juvenile pink salmon.

Global-Pan Regional Synthesis: End-to-end energy budgets for U.S. GLOBEC regions

This newly funded project (starting fall 2008) will bring together numerous investigators to focus on all four U.S. GLOBEC regions: the coastal Gulf of Alaska, the California Current, Georges Bank, and the Antarctic Peninsula. The primary goal will be to construct "end-to-end" energy budgets that link annual measures of ocean conditions and associated primary production estimates, on one end, with production estimates for fish, mammals, and other top consumers on the other end. Links will be through mechanistic models of marine food webs. The proposed research addresses the overarching question: are marine food webs leading to fisheries controlled from the top-down, the bottom up, or a combination of the two? To address this question the group will (1) compare end-to-end energy budgets of the four US-GLOBEC study regions in the context of top-down v. bottom-up forcing, (2) assess the skills of the regional models in capturing basic material fluxes, (3) extract diagnostics from the regional models that will be used to evaluate the effects of climate change and fishing pressure across GLOBEC regions and (4) develop quantitative methods to compare the diagnostics. This project will be an ambitious effort to compare studies of different ecosystems as a proxy for experimental manipulations of the same system, particularly when climatic change and over-fishing provide inadvertent perturbations at the bottom and top of trophic webs. Strom and her collaborators anticipate that this comparative research will be a step toward a more global understanding of the role of climate and ocean physics in determining the success of individual marine animal species.



3. EXECUTIVE SESSION

Executive Session may be held to discuss personnel, real estate, and legal issues as authorized in RCW 42.30.110.