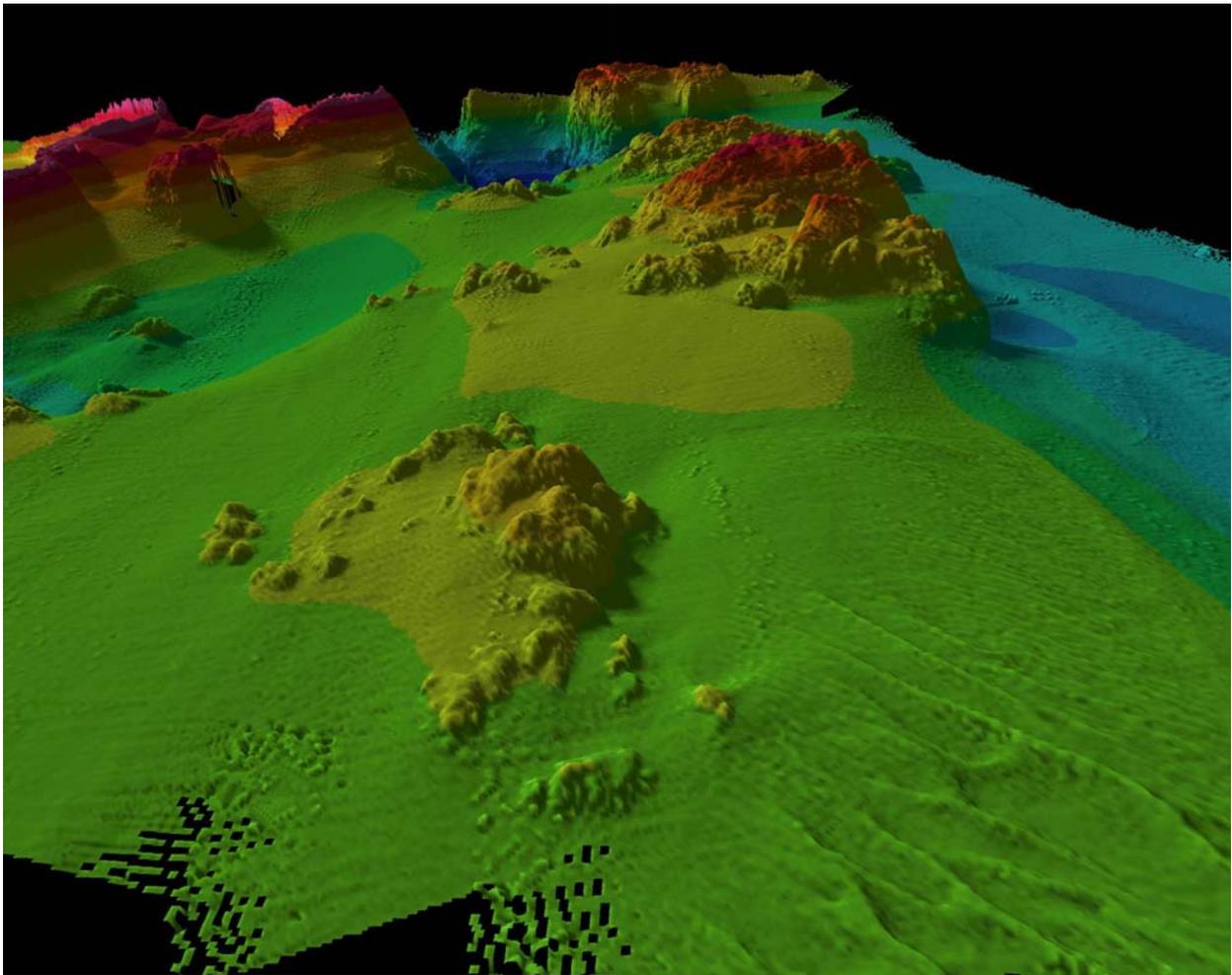


# Washington State Seafloor Mapping Workshop Proceedings

January 22-23, 2008  
Seattle, WA



## **Washington State Seafloor Mapping Workshop Steering Committee Members**

NOAA Northwest Fisheries Science Center  
NOAA Sanctuary Program  
Olympic Coast National Marine Sanctuary  
Tombolo Institute  
U.S. Geological Survey  
Washington Department of Ecology  
Washington Department of Fish and Wildlife  
Washington Department of Natural Resources

### **Acknowledgements**

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**Cover image:** Three-dimensional bathymetric map image courtesy of Tombolo Institute.

## Table of Contents

I.	Executive Summary	4
II.	Introduction	7
III.	Workshop Agenda	11
IV.	Summaries of working groups	13
	a. Outer Coast	
	b. Puget Sound	
V.	Summaries of panel sessions	18
	a. Cost panel	
	b. Models for partnerships	
	c. Manager and policy-maker discussion	
VI.	Presentation Abstracts	22
	a. Mapping technologies and techniques	
	b. Status of West Coast mapping efforts	
	c. Data distribution	
VII.	Inventory of mapping effort	60
VIII.	Conclusion	61
IX.	Posters	62
X.	Participant list	64

## I. Executive Summary

On January 22-23, 2008, a group of state and federal natural resource and science agencies, along with private industry partners convened the Washington State Seafloor Mapping Workshop in Seattle.<sup>1</sup> This workshop, attended by over 120 scientists, managers, and policy makers, highlighted seafloor mapping technology and products, discussed status of mapping efforts, determined data gaps and priorities and developed partnerships and next steps to advance comprehensive mapping of Washington State's marine waters. Current technologies can accurately map bottom depths and seafloor geology that are as detailed as terrestrial maps of forests, grasslands, and mountains. Like on land, seafloor maps have great potential to inform scientists, managers, and citizens when making decisions on developing, protecting, or restoring the marine environment. Seafloor mapping data can be used to:

1. Improve navigation and commerce.
2. Characterize benthic habitats.
3. Manage fisheries, plan resource surveys, and designate marine protected areas.
4. Monitor environmental change such as sea level impacts.
5. Predict sediment and contaminant transport, load and other coastal processes.
6. Manage sediments and coastal erosion.
7. Evaluate sites for nearshore or offshore infrastructure such as alternative energy.
8. Assess earthquake and tsunami hazards.
9. Model circulation and inundation from storm surge or tsunamis.
10. Understand geologic history and change.

Some of Washington's waters have already been mapped with high-resolution Multibeam Echosounder Sonar bathymetric (MBES) and backscatter imaging. The Center for Habitat Studies of Moss Landing Marine Labs (California State University) partnered with the Canadian Geological Survey to map marine benthic habitats in the San Juan Islands. This project collected and interpreted the complex seafloor MBES data of the San Juan Islands and resulted in detailed seafloor maps that identified rockfish, lingcod, and sand lance habitats as well as potential geological hazards. Other sections of Puget Sound and the Washington coast have also been mapped by NOAA, the US Geological Survey, Army Corps of Engineers, and the University of Washington. Many of these efforts are project-specific investigations or have specific missions that guide the use of the data. As a result, the data is not integrated nor coordinated to best facilitate availability and wide use by managers, scientists and citizens. Existing data, if collected at an appropriate resolution and made publicly available, could assist in producing comprehensive maps for Washington.

The US Navy, through an agreement with NOAA, restricts the distribution of high-resolution seafloor data and resulting maps or data products collected or funded by NOAA. This data restriction greatly impairs the ability of Washington to form partnerships with NOAA and other organizations that will effectively advance high-resolution seafloor mapping and release data to resource managers and the public. Even if this existing data was made available, many of

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<sup>1</sup> Participants on the steering committee included: Tomolo Institute; U.S. Geological Survey; National Oceanic and Atmospheric Administration (NOAA); Olympic Coast National Marine Sanctuary; and the Washington Departments of Fish and Wildlife, Natural Resources, and Ecology.

Washington's waters have not been mapped at all or were surveyed long ago with less accurate techniques. These areas will require new or increased mapping efforts.

Since mapping provides a critical foundation for ocean and coastal management, completing seafloor maps for state waters of California, Oregon, and Washington is a priority of the West Coast Governors' Agreement on Ocean Health. California established a consortium of partners and is already mapping its marine waters using high-resolution sonar. Meanwhile, Washington and Oregon are investigating what it would take to advance seafloor mapping. In Washington, the workshop attendees suggested a consortium of agencies, organizations, and governments would be needed to develop a shared strategic plan that will leverage activities and acquire the \$20-30 million dollars estimated cost for mapping state waters.

During the workshop, participants divided into two work groups: one for Puget Sound and one for Washington's outer coast. These groups discussed uses for data; status and gaps in data; planned data collection efforts; criteria for prioritizing data collection; and partnerships and opportunities for leveraging mapping. The following provides a brief summary of their discussions:

- **Data Uses:** Many important needs drive the need for seafloor mapping data: ecosystems, hazards, baselines, understanding processes, sea level rise impacts, and predictive models of coastal evolution. Mapping data will also assist with prioritizing future or additional research. For example, delineating hard substrate versus other bottom types can help fisheries managers focus additional research on particular habitats.
- **Prioritizing Data Collection:** The outer coast group suggested establishing priority areas for mapping by tying the data to particular management needs, which will help drive data collection for specific areas. However, participants also recognized the need to have comprehensive, complete data. For Puget Sound, the group's possible prioritization criteria were urban areas and threatened ecosystems. Both groups recognized that it is more cost-effective to map deeper waters versus the nearshore, shallow waters. The groups suggested that costs and importance be balanced for initial efforts and that a combination of approaches will be needed to advance comprehensive mapping.
- **Partnerships and Leveraging:** Federal and state agencies, tribes, non-government organizations, academic institutions, and foundations can all play a role in forming a strong partnership to advance mapping. Partnerships should examine gaps in data collection and overall programs of various agencies; align resources and priorities to advance a joint effort. Online resources and data portals can assist in leveraging planned federal mapping activities and in disseminating information. Regionally, all three states should leverage proposed activities for offshore areas as a way to obtain necessary data. The states can utilize the West Coast Governors' Agreement as a way to coordinate regionally. Navy restriction on distribution of NOAA and NOAA-funded data prevents free exchange of information collected in waters deeper than 50 meters. It prevents the scientific and resource management community from adequately meeting their missions and goals including: protecting society and property from coastal hazards and climate change impacts; assessing and managing the sustainability of marine resources and

ecosystems; restoring damaged marine and coastal habitats, species, and processes; and properly siting the uses and development of ocean and coastal resources.

## **Workshop Recommendations and Next Steps**

The work groups also developed recommendations for advancing seafloor mapping in Washington. Overall recommendations and next steps from the workshop were:

- Develop a broad consortium of partners to advance comprehensive seafloor mapping efforts for Washington.
- Produce a white paper summarizing the findings and recommendations of the workshop - include summary map that shows status and gaps of Washington data.
- Work with partners to clarify data holdings affected by Navy high resolution data restriction and work with the US Navy and NOAA to rescind or relax data restriction issues on NOAA data. This will allow access to existing data as well as cultivate partnerships for future mapping efforts.
- Recommended resolution varies with the purpose for the data, but many stated a need for 2 meter bathymetric resolution to allow widest and best use of data. Participants recommended utilizing California's standards as a starting place for establishing standards in Washington to enable regional comparisons of the data and maps.
- Develop a strategic plan for the mapping of all Washington marine waters. This strategic plan should include status of mapping efforts; cost and time estimates for completing mapping of state waters; general criteria for setting mapping priorities; and plan for data dissemination. In addition, this plan must establish standardized data parameters, resolution, and mapping products. The strategic plan would provide a foundation for securing public and private partnerships, leveraging funding, and advocating a shared vision to decision-makers.
- Implement the plan by creating an initiative/consortium that utilizes partnerships to leverage funding, coordinate activities, conduct demonstration projects as well as education and outreach, involve local constituencies and other important efforts (e.g. Puget Sound Partnership, Puget Sound Nearshore Partnership, tribes), and advocate for additional resources necessary to produce comprehensive, high-resolution seafloor maps for Washington State. Develop a leadership group with broad representation of various state and federal agencies, academics, non-governmental organizations, tribes, and others to promote the strategic plan, and monitor data collection, processing, and distribution. Groups involved must commit to sharing data.
- Leverage, evaluate, and use all existing high resolution data (e.g., University of Washington *R/V Thompson* data). Process this data to produce new, comprehensive map sets. Create digital data sets such as GIS layers to facilitate incorporation and comparison with other types of coastal and ocean data.
- Evaluate state and federal permitting of activities to require release of high-resolution seafloor data collected in support of permitting projects.
- Explore widely new and existing funding sources to support mapping.
- Capture nearshore data more extensively by flying terrestrial LIDAR during lowest tidal cycles.
- Make data available to public and resource managers in standardized format.

## **II. Introduction**

The first Washington State Seafloor Mapping Workshop was convened at NOAA's Sand Point facilities in Seattle January 22-23, 2008. This workshop was open to anyone interested in sea floor mapping. Over 120 participants attended representing 35 different federal and state government agencies, 21 academic institutes, 13 non-governmental organizations, 13 out-of-state state government agencies, 9 industry or consultant groups, and 3 tribes. The basic objectives of the workshop were:

- To highlight advanced technologies for imaging the seafloor and resulting products such as high-resolution maps of depths, substrates, and habitat. Summarize uses of these map products for resource managers such as restoration of Puget Sound and management of ocean resources.
- To foster discussion on the status of mapping and planned mapping efforts in Washington and other areas along the West Coast.
- To determine data gaps and priorities for future mapping efforts.
- To develop partnerships to advance mapping in Washington.

### **About Seafloor Mapping**

The mapping of the depths of marine waters dates back centuries with early surveyors sending lead weights to the bottom and recording the length of the line paid out. By systematically accruing these depth observations, the contours of the seafloor, or bathymetry, could be visualized on a nautical chart similar to a detailed contour map of the land that depicts the mountains and valleys of the terrain. The simple line method of determining depths was used into the 20<sup>th</sup> century but eventually was replaced by sonar systems during the mid-1900s. Nowadays, new sonar, navigation, and other technology can accurately map the seafloor yielding high-resolution information on the bathymetry and the composition of the seafloor itself. The first day of the workshop focused on the available new technologies, information recently collected along the west coast, and means to store and distribute the high volumes of data and products that result from these detailed mapping efforts. Summaries of these presentations are found in Section VI.

### **Missions and Priorities Related to Washington Seafloor Mapping**

In the past few years, several partnerships have formed at the local, state, regional, and national level to improve marine resource management and coastal ecosystem health. While each effort has a unique focus and mission, their plans and priorities all contain components that emphasize the need for improved mapping or scientific research to aid management of coastal and ocean resources.

#### State and Regional Level

The *West Coast Governors' Agreement on Ocean Health* launched a new, proactive regional collaboration among Washington, Oregon, and California to protect and manage the ocean and coastal resources along the entire West Coast, as called for in the recommendations of the U.S.

Commission on Ocean Policy and the Pew Oceans Commission. The Agreement underscores the importance of managing activities that affect our oceans as an ecosystem. **One of the key research priorities is to complete seafloor mapping of the state waters of the West Coast by 2020.**<sup>2</sup>

*Washington's Ocean Action Plan* outlines recommendations for enhancing the state's management of Washington's outer coast and ocean. The action plan, released in December 2006, was developed by the Washington State Ocean Policy Work Group, a diverse group convened by the Governor's office to examine ocean policy issues in the state. Currently, a team of state agencies called the State Ocean Caucus works to act on the recommendations contained in this report. **Recommendations included support for increased benthic habitat mapping and assessing coastal and ocean resources to facilitate ecosystem-based management.**<sup>3</sup>

The *Olympic Coast National Marine Sanctuary's Intergovernmental Policy Council* consists of the four coastal treaty tribes (Hoh Indian Tribe, Quinault Indian Nation, Quileute Indian Tribe, and Makah Indian Tribe) and the State of Washington as a forum for communicating and providing policy recommendations regarding the management of marine resources of the Olympic Coast National Marine Sanctuary. The intent is to bring together state, tribal, and federal governments to discuss policy, to plan management initiatives, and to provide management direction to the Sanctuary. In October 2007, this group passed a resolution to support an **ocean research and monitoring initiative to guide their initial activities, which includes habitat mapping**, rockfish assessments, and monitoring buoys.<sup>4</sup>

A Memorandum of Understanding signed by Washington's Governor and British Columbia's Premier in June 2007 set goals to work together on ocean and coastal issues including: **sharing information about ocean and coastal resources**; developing common data inventory, systems, and indicators of ocean health; and sharing best practices for protecting marine habitat. The Memorandum of Understanding enabled the formation of the *British Columbia-Washington Ocean and Coastal Task Force* to work on these and related issues. The task force's goals are to increase communication between governments on oceans and coastal issues, foster collaborative activities to improve the health of shared marine waters, monitor and report on progress to protect our marine waters. **Activities will include promoting the exchange of technical and scientific information**; identifying priority transboundary issues and recommending collaborative actions; and sponsoring and participating in international conferences and workshops on issues of mutual interest.

The *Puget Sound Partnership* is a new Washington state agency tasked with restoring Puget Sound to health by 2020. The agency consists of an appointed leadership council, an executive director, an ecosystem coordination board, and a science panel. These groups maintain

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<sup>2</sup> For more information on the West Coast Governors' Agreement on Ocean Health, see: <http://westcoastoceans.gov/>

<sup>3</sup> For more information on the State Ocean Caucus, see: <http://www.ecy.wa.gov/programs/sea/ocean/>

<sup>4</sup> For more information on the Intergovernmental Policy Council, see: [http://sanctuaries.noaa.gov/news/features/0107\\_octribes.html](http://sanctuaries.noaa.gov/news/features/0107_octribes.html)

representatives from a diverse group of interests and regions. In 2008, the Partnership will develop an action agenda to guide coordinated local, federal, state, tribal, and private activities toward this goal based on sound science. Accurate and detailed seafloor maps would aid these efforts including setting environmental baselines and evaluating change over time, evaluating habitat quality and quantity, and planning restoration efforts.

### Treaty Tribes

In the mid-1850s, a series of treaties were negotiated with tribes in the region. Through the treaties, the tribes gave up most of their land, but also reserved rights to fish and hunt on their usual and accustomed grounds. In 1974, the Boldt decision reaffirmed their treaty-protected fishing rights. The ruling, which has been upheld by the U.S. Supreme Court, established the tribes as co-managers of the resource entitled to 50 percent of the harvest of salmon and shellfish in the state. Tribes actively participate in research and management coastal and marine resources, including working to improve, restore, and protect key coastal habitats. Many tribes want increased basic data collection and research on the status of marine resources and benthic habitats to improve co-management of these resources. There are twenty-two treaty tribes in western Washington.

### Federal Level

*NOAA's National Ocean Service (NOS)* works to observe, understand, and manage our nation's coastal and marine resources. NOS measures and predicts coastal and ocean phenomena, protects large areas of the oceans, works to ensure safe navigation, and provides tools and information to protect and restore coastal and marine resources.

The *Office of Coast Survey (OCS)*, part of NOAA's National Ocean Service (NOS), conducts hydrographic surveys to measure the depth and bottom configuration of water bodies, to produce the nation's nautical charts and ensure safe navigation in the U.S. Exclusive Economic Zone, an area of 3.4 million square nautical miles that extends 200 nautical miles offshore from the coastline.

The *Olympic Coast National Marine Sanctuary (OCNMS)*, also a part of NOS, encompasses the northern outer coast of Washington. It is mandated to protect marine resources through research and education, which includes a major emphasis on seafloor mapping and habitat characterization.

The *Western Coastal and Marine Geology (WCMG) Team of the U.S. Geological Survey (USGS)* studies the Pacific Coast of the Western United States, adjoining ocean waters, and other waterways. Team scientists conduct marine research, monitor ocean processes, and provide information about geologic hazards, environmental conditions, habitats, and energy and mineral resources. USGS activities help managers at all levels of government and in the private sector make informed decisions about the use and protection of national coastal and marine resources.

The *President's U.S. Ocean Action Plan* includes actions to coordinate ocean and coastal mapping such as:

- Inventorying mapping programs and prioritizing mapping needs.
- Coordinating and leveraging resources and efforts across the Federal sector and with industry, academic, NGO and non-federal entities.
- Assessing and reporting on needs for more effective development, delivery, and application of geospatial data, tools, products and services.
- Developing shared and standard mechanisms for distributing data, tools, products, and services.

The *National Academy of Sciences* published a 2004 report entitled, “A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting.” Among their findings, the report argued that comprehensive mapping of the coastal zone requires: 1) improved coordination and collaboration among federal, state, and local agencies, academic researchers and the private sector and 2) increased data collection, particularly, bathymetric data.

### III. Washington Seafloor Mapping Workshop Agenda

The workshop was organized to present first a review of the latest seafloor mapping technologies and methodologies and to identify data gaps through a review of mapping projects active within the State of Washington. To accomplish this 18 scientists and managers active in seafloor mapping efforts along the west coast of North America made presentations on mapping technologies, techniques and products; status of efforts in various regions; and methods for data distribution. The agenda of the meeting including panel discussions and breakout groups is provided below:

#### Tuesday, January 22, 2008

Start	End	Topic	Specific Topic	Presenters/Facilitators
8:00	9:00	Registration		
8:30	9:00	Welcome and Introduction		Gary Greene
		Relationship to West Coast Governors' Agreement and other state initiatives		Jennifer Hennessey
9:00	10:30	Technology Talk	Acoustic Mapping and Imaging	Mark Holmes
		Technology Talk	Optimal Mapping and Imaging (LIDAR)	Ralph Haugerud
		Technology Talk	Nearshore Techniques	Eric Grossman
		Technology Talk	Modern Processing Techniques and Software	David Finlayson
		Technology Talk	Groundtruthing	Guy Cochrane
		Technology Talk	Habitat Classification Schemes	Gary Greene, Tom Mumford
10:30	11:00	Break		
11:00	11:15	Products and Applications		Sam Johnson
				Sheila Semans, Rikk Kvitek, Sam Johnson
11:15	11:45	West Coast Mapping Experiences	California	
11:45	12:00	West Coast Mapping Experiences	Oregon	Chris Goldfinger
12:00	1:00	LUNCH		
1:00	1:30	West Coast Mapping Experiences	British Columbia	Vaughn Barrie
1:30	1:50	West Coast Mapping Experiences	NOAA's –Northwest charting	Dave Neander
1:50	2:10	West Coast Mapping Experiences	Washington Outer Coast	Ed Bowlby
2:10	2:30	West Coast Mapping Experiences	San Juan Islands	Gary Greene
2:30	2:50	West Coast Mapping Experiences	Puget Sound	Pete Dartnell - Mark Holmes
2:50	3:15	Break		

		Session 1 – breakout groups	Discussion topics	
3:15	4:45	Group 1- Puget Sound Group 2- Washington Outer Coast	1) Needs and uses for data and products. 2) Identify current and planned mapping activities. Update summary maps. 3) Identify data gaps and discuss relationship to needs and uses of data.	Facilitated Discussion
4:30	6:00	Poster Session		
6:30	8:30	Social – Location	Wedgewood Bar and Grill	

### Wednesday, January 23, 2008

Start	End	Topic	Specific Topic	Presenters/Facilitators
8:30	8:45	Plenary- summary of day two agenda and assignment for morning break-out groups		
8:45	10:00	Session 2 – Breakout groups Group 1 - Puget Sound Group 2 - Outer Coast	Discussion topics: partnerships, leveraging opportunities, and data priorities and needs.	Facilitated discussion
10:00	10:30	Break – posters		
10:30	10:45	Regroup and synthesis of breakouts groups		All
10:45	11:15	Past and projected costs		Gary Greene & Sam Johnson
11:15	12:00	Data distribution		Rikk Kvitek, Liz Clark, Kathy Taylor
12:00	1:00	Lunch and Posters		
1:00	1:30	Summary of workshop findings		Jennifer Hennessey & Wayne Palsson
1:30	2:00	Models for Public/Private Partnerships and roles of various entities		Panel
2:00	2:30	Facilitated discussion with invited policymakers, panel, and audience on next steps		Panel: Usha Varanasi, Roger Parsons, Bruce Jones and others
2:30	3:00	Summarize next steps and any commitments by groups		All

## **IV. Summaries of working group sessions**

Participants divided into two work groups based on geographic area (Outer Coast and Puget Sound) to discuss status of mapping efforts, needs, barriers, and opportunities; to determine how best to pursue mapping in Washington State water; and to develop recommendations for priorities for future mapping and for improving state mapping in strategic, coordinated fashion. These working groups reported on what is known about current mapping efforts and data gaps; what types of data and data products are needed; how to develop partnerships to leverage resources; and suggested priorities, funding and recommendations for future actions. See below for summaries of these panel discussions.

### **Outer Coast Working Group**

The Outer Coast Working Group addressed mapping of state and offshore waters along the outer coast from the Oregon Border to the Canadian Border outside of the Strait of Juan de Fuca but including the Olympic Coast National Marine Sanctuary (OCNMS). The list below summarizes the results of this working group's discussion.

#### Status of current and planned mapping efforts and data gaps

- Data gaps include the southern half of the OCNMS, nearshore areas including the intertidal zone, spawning areas, forage habitats, and shellfish habitats.
- Present-day restrictions on collecting and distributing multibeam bathymetric and backscatter data due to Navy/NOAA security restrictions.
- Current and planned mapping activities include joint Army Corps of Engineers Joint Airborne LIDAR Bathymetry Technical Center of Expertise planning for the Oregon/Washington coast from a distance of 500 meters onshore to 1,000 meters offshore subject to weather and clarity of water to take place in summer 2008 including the use of possible other sensors (e.g., hyperspectral).

#### Data collection and product needs

- A standard high-resolution (1-5 meter) habitat characterization scheme with emphasis on corresponding biological communities.
- Baseline maps for use in the design of marine conservation and protected areas and to use in reference areas for monitoring management practices and focusing groundtruthing efforts.
- Environmental assessment for proposed mapping activities.
- Seamless shelf and nearshore Digital Elevation Model (DEM) images for hazards assessment including the modeling for flood and tsunami inundation and run-up, location of landslide and tsunami generation sites, positions of dynamic bedforms, and fault locations (catalog faults and landslides).
- Maps to help in groundfish stock surveys and long-term monitoring efforts.
- Maps for locating and identifying rare habitats, Essential Fish Habitats, and for locating and zoning of activities with potential conflicts.
- Maps that would be useful in high-resolution oceanographic circulation modeling.

- Mapping products need to be very accessible to the general public and resource managers alike, in a usable format, in order to inform decision makers.
- Metadata needs to be a part of any map product.
- Data should be of the quality useful for nautical chart updates and to identify wash rocks.
- Funding needs to be identified that will support any mapping effort.
- A mapping resolution needs to be identified that would allow for repeat surveys and that will address primary objective of the mapping effort.
- Baseline maps for use in detecting environmental changes such as sea level-rise, coastal erosion, etc.
- Establish a clear mapping objective based on the end user of the maps.
- Establish better coordination and communication between mappers, researchers and decision-makers to assure that informed decisions are made.
- Educate the public and managers on the compelling need to do the mapping and assist in improving ocean literacy.
- Historical survey data useful in any mapping efforts needs to be inventoried and assessed for availability.
- All data types including remote sensed geophysical, in situ observational, physical, chemical, and biological data.
- Correlation of map data with abundance of biological species, not just presence or absence of species.
- Maps that show sediment transport processes, nutrient and larval transport directions including circulation data related to bathymetry (basic currents and energy physical oceanographic data).
- Diverse maps that range from navigation corridors to wave environments based on depth and source.
- Identify key indicator species and species interactions on the maps through rigorous groundtruthing.
- Maps that show seasonal beach morphology changes and inter-annual variation.

#### Partnerships and Opportunities for leveraging and advancing seafloor mapping

- Initiate a web portal as a “geospatial one-stop store” to show what data is available, display maps and announce planned mapping activities that can be used to share surveying mechanisms such as exists for federal agencies (e.g., <http://www.geodata.gov>, see Oceans and Coasts Community section; similar to “chat room/market place”.
- Coastal tribes need to be a partner as there is a priority effort along with Sanctuary to identify funds for mapping purposes; Northwest Indian Fisheries Commission can contribute to GIS work.
- Involve undergraduate and graduate students in mapping activities including data collation, research, and management support.
- Use contract vessels with contract in place to undertake mapping effort.
- Partner with NOAA’s National Geophysical Data Center (NGDC) to house data and maps.

- Involve Navy and tribes to obtain permission for NOAA and other partners to collect and release high-resolution bathymetry data in water depths greater than 50 meters, the highest priority areas for the Olympic Coast National Marine Sanctuary.
- Use West Coast Governor's agreement as vehicle to communicate with regulatory and science agencies on mapping needs and what can be brought to the table to accomplish mapping tasks (establish a semi-permanent body for coordination).
- Involve Olympic Coast National Marine Sanctuary as a major partner to leverage vessel time (NOAA ships *McArthur II* and *Rainier* and new sanctuary vessel) for mapping effort and to assist Sanctuary in outfitting vessels with proper mapping gear (i.e., elimination of technology gap).
- Partners should be able to re-focus federal and state plans based on data gaps, needs and desires in any mapping effort.
- State, tribal, academic, and non-governmental organizations - partners need to address insurance bond and security requirements (a hindrance to scientific cooperation and advancement) of federal government so all partners can participate in any mapping effort.
- Partner with permitting and regulatory agencies that could charge industry (e.g., cable or energy companies) for data collection and offset cost for mapping efforts.
- Need to involve non-governmental organizations and other private foundations in mapping effort, make them a major stakeholder (e.g., Packard Foundation, Paul Allen, biotech industrial community).
- NOAA's charting group should be involved in any effort to map along with industry and private groups that could bring resources to table; consideration of mapping should include nautical charting and other priorities (navigation charts could be improved by effort).

#### Priorities for data collection and data products

- Obtain any available mapping data and collate in a standard format (needs to be done prior to obtaining new data).
- Critical data collection lies between the shoreline out to 1,000 fathom (~3,000 meter) depth, although deeper water more cost effective (trade-off between cost and importance)
- Initially hard bottom substrate versus soft and other substrate types should be delineated in order to set priorities for research.
- Tie management needs into priorities of mapping effort.

#### Recommendations

- Work on lifting Navy security restrictions for data distribution of NOAA data.
- Evaluate state and federal permitting of activities to require release of data collected in support of permitting projects.
- Package - multiple needs to advocate for outer coast, develop combined strategy.
- Make data available to public and resource managers and in standardized format.
- Standardize data parameters. Coverage more important than resolution, but need highest resolution for the data purpose (e.g. habitat mapping).

## **Puget Sound Working Group**

The Puget Sound Working Group addressed mapping of State waters along the inner waters of Puget Sound including the Strait of Juan de Fuca and the San Juan Islands. The list below summarizes the results of this working group's discussion.

### Status of current and planned mapping efforts and data gaps

- Extensive ongoing mapping in San Juan Islands through collaboration of Tombolo Institute and Geological Survey of Canada
- Significant ongoing mapping in Puget Sound and eastern Strait of Juan de Fuca by NOAA Office of Coast Survey. USGS and Tombolo Institute will try to process backscatter data and groundtruth some of these data to develop a comprehensive showcase map folio(s)
- Local USGS mapping offshore the Elwha and Skagit River deltas as part of the USGS Coastal Habitats in Puget Sound Project.

### Data collection and product needs and issues

- Many important needs – ecosystem function and restoration, tsunami and earthquake hazards and hazard assessments, baselines for monitoring change, understanding coastal processes, sea-level rise impacts, developing predictive models of coastal evolution.
- Seamless onshore-offshore maps (topographic/bathymetric, habitats, geology) are very important for coastal zone managers.
- Consensus is needed on common standards (e.g., 2 meter for bathymetry), products, and classification schemes, but there should also be some flexibility in development of interpretive products (e.g., geologic maps).
- "Time stamp" of mapping data is essential in dynamic nearshore zones.
- Need to further clarify issues with Navy - data holdings and data restrictions.

### Partnerships and Opportunities for leveraging and advancing seafloor mapping

- Seafloor mapping data for limited areas probably exists in numerous places (public agencies and private sector). Sidescan data used to find derelict fishing gear is a good example discussed in the breakout sessions. There is need to find and make these data publicly available, and also create a policy which ensures that future data collection for public needs result in public domain data.
- Washington State, via the Department of Natural Resources, manages state-owned aquatic lands and desperately needs seafloor and habitat mapping. Although Washington presently has limited resources to pursue mapping, they need to assume leadership in defining a mapping strategy and budget, and in promoting a budget request.

### Priorities for data collection and data products

- We live in a digital data world! Building GIS layers and making them widely available is the now and the future. Hard-copy paper maps will continue to be important, but a mapping activity cannot end with a hard copy product.
- Digital layers and hard-copy maps must be generated following established standards and protocols.
- Nearshore data is most important for critical ecosystem management needs, but is also the most expensive and challenging data to collect, commonly requiring more time (and money) and different tools.
- Given limited funding, urban areas and threatened ecosystems should receive the highest priority for mapping.

### Recommendations

- Seek and reach consensus on mapping standards, resolution, and products.
- Promoting seafloor mapping requires several activities
  - development of a strategic plan
  - development of a business plan
  - development of demonstration products
  - development of education/outreach
  - identification of local constituencies (e.g., tribes, counties)
  - collaborative development of mapping priorities
- Present and promote seafloor mapping to important stakeholders in state and local governments and non-governmental organizations, including the Puget Sound Partnership, Puget Sound Nearshore Partnership. In addition to ecosystem-management groups, identify other interest groups for support (e.g., hazard assessments). Promote the message that “*It is more expensive not to do the mapping than to do the mapping.*”
- Develop leadership group with representatives of various state and federal agencies, academics, non-government organizations, etc. Develop consortium to monitor data collection and advertise data availability and sharing. Investigate the Puget Sound LIDAR Consortium as a viable operational model.
- Explore new funding sources, such as the Department of Homeland Security or the Environmental Protection Agency.
- The mapping community must leverage and use all existing data (e.g., mapping data collected on University of Washington education cruises on the *R/V Thompson*).
- Encourage collection of terrestrial LIDAR data during the lowest tidal cycles as an important approach to mapping shallowest Puget Sound.

## V. Summaries of Panel Discussions

Three panels were convened in plenary sessions to address topics about past and present cost of mapping, data distribution, private/public partnerships, and managers and policymaker perspectives. The sections below provide summaries of each panel discussion.

### a. Past and Projected Costs

#### Panel Members

- Gary Greene, Head, Center for Habitat Studies, Moss Landing Marine Labs and Director, Tomolo, Orcas Island, WA
- Sam Johnson, Chief Scientist, Western Coastal and Marine Geology, U.S. Geological Survey, Pacific Science Center, Santa Cruz, CA
- Ed Saade, President, Fugro Pelagos, Inc., San Diego, CA
- Sheila Semans, Manager, California Coastal Mapping Program, California State Coastal Conservancy, Oakland, CA

#### Summary of Panel Discussion

The panel warned that the costs for undertaking mapping surveys were increasing because of rising oil prices and other inflationary activities. It was apparent that the sooner a mapping effort was initiated the less costly it would be. Cost-sharing ideas were put forth in order to stimulate initiating partnerships. The group highlighted that when government, academia, non-governmental organizations, and industry worked together such as occurred in California the price of undertaking an expensive survey could be shared by several entities thus reducing the individual cost. In-kind support from government agencies is considerable in modern-day mapping exercises. The group indicated that collaboration with government agencies can complement the task of mapping.

An overall recommendation of the panel was that cooperation and joint mapping activities needed to be seriously considered in order to obtain the most comprehensive and cost effective mapping program for Washington. The panel encouraged early development of a consortium that could take advantage of present or planned seafloor mapping in the region and start to investigate mechanisms that would lead to daisy-chaining funds.

### b. Models for Public/Private Partnerships

#### Panel Members

- Ralph Haugerud, USGS, Dept. Earth & Space Sciences, University of Washington
- Jan Newton, University of Washington, NANOOS.
- Ed Saade, President, Fugro Pelagos, Inc., San Diego, CA
- Sheila Semans, Manager, California Coastal Mapping Program, California State Coastal Conservancy, Oakland, CA

## Summary of Panel Discussion

Ralph Haugerud pointed out that when undertaking a mapping survey with LIDAR that it was important to have a single contractor collect the data under one contract and specifications (it's cheaper this way) and to establish a consortium to obtain funds, guide the survey effort, to let contracts and to do the quality assurance and quality control of the data. The consortium he worked with charges ten percent overhead. In regard to funds, Ralph indicated that it was always desirable to have a single entity with lots of funds to underwrite the costs. He went on to say that it is best to do large areas (more cost effective) and to have all the work done at a common specification so the data fits together well. He also stated that it is helpful to build up internal data processing and quality control expertise.

Ed Saade of Fugro Pelagos, Inc. of San Diego stated that his company does a lot of work for NOAA, and whenever they can, they combine operations with governments and other organizations to reduce costs of operations. In addition, Fugro likes working with the university community, especially those training students in mapping as this provides excellent technical people that they can hire. Fugro works hard at trying to build cross-agency awareness that allows for partnering and cooperation among entities with similar interests.

Jan Newton explained the activities of the Northwest Association of Ocean Observing Systems (NANOOS), a regional physical oceanographic observation system whose members include government, academia, non-government organizations, and industry (e.g., Boeing for infrastructure support). NANOOS presently operates with \$400,000 per year plus grants money and has priorities such as coastal hazards, ecosystem management, and maritime navigation. NANOOS operates under the philosophy of "all-for-one" and does not duplicate the work of others, but synthesizes data and can be considered the glue that sticks all things oceanographic together.

Sheila Semans, representing the California State Coastal Conservancy (SCC) and the California Ocean Protection Council, reported on the California Seafloor Mapping Program (CSMP) and the partnerships that have developed in the effort to map all of California state waters. Aside from the strong agency/ university/ industry partnership that has developed for the CSMP, Sheila reported on the importance of soliciting the participation of the regional associations forming under the Integrated Ocean Observing System (IOOS) as they are striving to become the regional centers of expertise and can help integrate seafloor mapping data into regional ocean circulation modeling or ecosystem evaluations. Sheila also emphasized that for California it was critical to have government agreement on the objectives of the CSMP in order to secure funding. Management applications should be identified and developed up front. Because of California's extensive coastal zone, industry has been a big partner in the program and have helped delivered the message for the need of seafloor mapping in Washington DC, and have brought cutting-edge technology to the program. Sheila also pointed out that it was important to involve the universities in this process, and continue to build a mapping workforce in the future. She recommended that Washington State consider partnering up with NOAA to take advantage of the IDIQ (Indefinite Delivery, Indefinite Quantity) contracting process that allows the state to contract—through NOAA—with industry hydrographic firms at no cost to the state. This contracting vehicle allows the states to acquire data through private industry, includes technical

oversight by NOAA (Coastal Services Center and Office of Coast Survey), and involves the federal agencies in the mapping program while possibly leveraging funds and programmatic objectives.

### **c. Managers and Policymakers Perspective**

#### Panel members

- Sarah Dzinbal, Asst. Division Manager (Operations), Washington State Dept. Natural Resources
- Sam Johnson, Chief Scientist, Western Coastal and Marine Geology, U.S. Geological Survey, Pacific Science Center, Santa Cruz, CA
- Bruce Jones, SSHIAP Section Manager, Northwest Indian Fisheries Commission
- Roger Parsons, NOAA, FOSS Coordinator
- Fred Piltz, Senior Environmental Scientist for U.S. Mineral Management Service (MMS)
- Usha Varanasi, Director, NOAA Northwest Fisheries Science Center

#### Summary of Panel Discussion

Sarah Dzinbal explained that work on ocean policy in the state is moving forward and that seafloor mapping research needs to move ahead rapidly. She suggested that an all-encompassing state agencies meeting be set up in Olympia to organize mapping efforts in Washington. Another option would be to enlist the help of Sea Grant fellows. This would be a long-term effort and require considerable leg work but interns can help with the costing out of a program. She said that DNR could put forth a state budget request but need to do this by May.

Usha Varanasi inquired about the substance of the plan. She felt that, to move ahead, there needs to be serious planning, strategizing, and prioritization in order to be successful. She noted that the momentum existed at the workshop, and that we should move ahead before this momentum decreased. However, she cautioned that to map everywhere for everything might be the wrong approach and that selected areas should be considered. Her advice was to ask comprehensive questions and use the best technologies. Look for a backdrop for all changes. Also, she stated that there needs to be a serious outreach and education component to the mapping effort.

Roger Parsons, NOAA Integrated Ocean and Coastal Mapping (IOCM) Coordinator and Co-Chair of the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), recommended that the group look at the National Research Council's publication on national mapping needs (A Geospatial Framework for the Coastal Zone - National Needs for Mapping and Charting) in order to understand the challenges facing the seafloor mapping community. Roger also suggested that the workshop participants look at the Long Island Sound Seafloor Mapping Workshop recommendations. He advised the participants to get as many interested federal and state agencies involved as possible including FEMA, which has considerable coastal mapping interests and resources. Roger pointed out that data collection was the easiest part of a mapping exercise and the most expensive; however, data management and dissemination and development of mapping products and tools are equally important. Any mapping effort needs to be driven by all parties - government, private sector, etc. He noted that there still is a lot of "white area" (data gaps) to be filled. At that same time, any mapping effort should focus

available resources. The majority of ocean and coastal mapping requirements will need to be defined at the regional level and addressed at the regional level with federal, state, academic and non-government organization involvement.

Fred Piltz of the Mineral Management Service stated that his organization is interested in detailed seafloor maps that can be used to regulate the placement of structures associated with resource extraction. He is also a federal co-lead to the West Coast Governors' Agreement on Ocean Health. This could be a great mechanism for emphasizing the needs of the region. Coastal mapping and alternative energy has traction now and could be used as a focus for this group. Fred mentioned that the Department of Interior pushes for and supports the production of map portfolios and this might be something that the participants may want to consider. He suggested that the group kick off a strategic planning meeting later this year and that a large meeting be held this summer to produce a business plan or strategy for mapping Washington State waters.

Bruce Jones, Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) Section Manager representing the tribes, likened the workshop event to the early days of the Timber, Fish, Wildlife Forest Management Agreement (TFW). He suggested the group form a coalition and move forward. Bruce thought that we should make a concerted effort to educate the State legislature and their staff through a targeted workshop and that the tribes would support such an effort. He suggested that standards in approach be established and the resulting data be made accessible to the public. A single, dedicated source for information sharing is needed, as there appears to be many different data portals available. We need to answer the "so-what" questions of the information gathered, explain how the maps can be used, how they will change management, and what are the costs.

Sam Johnson of the USGS said that there are few "no-brainers" that sea-floor mapping is one of those "motherhood and apple pie issues" that almost everyone supports once they learn about it. He emphasized the fact that we need to get organized in a clear way and to promote our effort to the community. The next step was to develop a strategy and move ahead.

## VI. Presentation Abstracts

All PowerPoint presentations used with these talks are available for viewing online at the following website: <http://www.ecy.wa.gov/programs/sea/ocean/seafloormapping.html>.

<b>Presentation Abstracts</b>	
<b>a. Mapping Technologies &amp; Techniques:</b>	
Acoustic Mapping and Imaging	Mark Holmes
Optimal Mapping and Imaging (LIDAR)	Ralph Haugerud
Nearshore Techniques	Eric Grossman
Modern Processing Techniques and Software	David Finlayson
Groundtruthing	Guy Cochrane
Habitat Classification Schemes	Gary Greene & Guy Cochrane
Products and Applications	Sam Johnson
<b>b. Status of Mapping Efforts:</b>	
California Mapping Status	Sheila Semans
Oregon Coast Mapping Status	Chris Goldfinger
British Columbia Mapping Status	Vaughn Barrie
NOAA's hydrographic charting in Pacific Northwest	Dave Neander
Washington Outer Coast Mapping Status	Ed Bowlby
San Juan Islands Mapping Status	Gary Greene
Puget Sound Mapping Status: University of Washington	Mark Holmes
Puget Sound Mapping Status: US Geological Survey	Pete Dartnell
<b>c. Data Distribution:</b>	
California's State Waters Mapping	Rikk Kvitek
Interactive Habitat Database for Pacific Coast Ocean Observing System	Liz Clarke
Washington Coastal Atlas	Kathy Taylor

## a. Mapping technologies and techniques

### A History (short) and Fundamentals (shorter) of Acoustic Mapping and Imaging of the Seafloor

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The past two decades have been marked by major technological advances in our ability to map and measure the shape and character of the seafloor with unprecedented accuracy, precision, and efficiency. Two very different types of bathymetric mapping systems have evolved which permit operations to be carried out at vessel speeds of 8-10 knots and more: Hull-mounted swath bathymetry systems and towed side-scan sonar systems. The Kongsberg-Simrad EM300 installed on *R/V Thomas G. Thompson* is a modern example of the former group of imaging systems. Towed systems such as SeaMARC family and the DSL-120 are examples of the latter.

Wire or lead-line soundings were used well into the 1900's. This time-consuming method could determine water depths with precision and accuracy, but primitive (by today's standards) positioning techniques often limited the quality of the data. In coastal waters, the use of horizontal sextant angles by a skilled survey crew could result in very accurate positioning and in this way many of the early navigation charts were created. Interestingly, it was the sinking of *Titanic* that spurred interest in the development of the use of acoustics to detect icebergs and from there it was a short step to develop what became known as echo sounders. These devices were developed so that they could produce continuous sounding profiles, and collection of these data along closely-space tracks could be used in turn to generate contour maps of the seafloor. This process still required a high degree of cartographic and artistic skill; early practitioners of the art of depicting seafloor physiography using echo-sounding records were Bruce Heezen and Marie Tharp at Columbia and Tom Chase at the USGS.

For detailed studies of seafloor morphology and reflectivity a better technology was needed, and this was provided, naturally, by the Defense Establishment. In the 1960's the U.S. Navy adopted SASS (Sonar Array Sounding System), a swath mapping system developed by General Instruments. Other companies joined the fray, and by the mid-1980's there were systems such as Sea Beam, Atlas Hydrosweep, and the Simrad EM12. These systems were generally characterized by having operating frequencies in the 12 to 15 kHz range, which somewhat limited their resolution capabilities. Over the next decade or so higher frequency systems were developed, such as the Kongsberg-Simrad EM300 (30 kHz) system on [the *R/V*] *Thompson*. Smaller higher frequency systems such as the Reson SeaBat family were developed for small boat use in shallow water and for use on ROVs and AUVs. Launch-based systems such as that employed on NOAA's *Rainier* also came into operation. The general pattern of development of these hull-mounted systems was to decrease the individual beam width from almost 3° on the

original Seabeam systems to 1° and less on the most modern systems. Increasing the number of beams and the total effective swath width was also a primary concern. The table below summarizes the characteristics of some of the hull-mounted systems that have been used on academic vessels.

System Name	Across-Track Beam Width	Number of Beams	Frequency	Swath Width (Degrees)	Swath Width (% of Depth)
Seabeam	2.7°	16	12 kHz	42.7°	78
Hydrosweep	1.7°	59	15.5 kHz	90°	200
EM12	1.8°	81	13 kHz	90°	200
EM300	1.0°	135	30 kHz	135	400

In the early 1980's a group under Don Hussong at the Hawaii Institute of Geophysics developed SeaMARC, a shallow-tow side-scan sonar capable of obtaining both backscatter imagery and bathymetry. Over the years similar systems have been developed by both industry and academic institutions. Examples are TAMU<sup>2</sup> and the DSL family of deep-tow side-scan sonars. An advantage of these side-scan systems, and of the smaller hull-mounted systems as well, is that they can be easily transferred from platform to platform. The much larger transducer arrays used by, for instance, the Kongsberg-Simrad EM300, are permanent installations.

The utility of all bathymetric/imaging systems was greatly increased by the simultaneous development of GPS and precision vessel orientation systems such as the Applanix POS-MV series. These companion technologies permit accurate georeferencing of the swath data even under adverse sea conditions; without them the quality and accuracy of the swath data would be seriously compromised.

The high-resolution accuracy and precision of modern hull-mounted systems make them ideal for applications such as:

- seafloor morphology and bottom texture determination
- pre- and post dredging surveys
- marine archeological studies
- production of navigation charts
- fisheries research
- benthic habitat mapping
- physical oceanographic modeling
- siting of offshore structures
- and on and on (Gary limited abstracts to only two pages)

Naturally, the sophistication of modern bathymetric imaging systems such as the EM300 on [the *R/V*] *Thompson* require a significant amount of post-processing in order to derive the maximum amount of information from the raw data that contain bathymetric (depth) information but also, and equally importantly, amplitude (backscatter) information. It is the ability of these swath systems to acquire and record these two types of information that make them such powerful tools for such a wide variety of seafloor studies. The recorded data also incorporate roll, pitch, yaw, and heave compensations from the POS/MV, together with GPS/DGPS positioning information. Most systems also have the capability to automatically determine sound velocity profiles for

correcting the acoustic data; CTD casts before, during, and after the surveys can also provide SVP corrections.

EM300 data files are processed on board [the *R/V Thompson*] using MB System in order to provide large and small-scale plots and pdf files of the bathymetric imagery. If computer facilities on the ship are equipped to provide further processing then a number of other important steps are taken. These steps are usually carried out in shore labs post-cruise. Caris™ is used to make tidal corrections, correct for datum offsets, and for gridding (as well as other functions). Data visualization, overlays, and 3D views are performed using Fledermaus™. Data processing is iterative, and the exact steps and choice of software packages are a function of the actual objectives of the individual project.

Modern swath bathymetry/imagery systems provide marine scientists and engineers with a means of visualizing and characterizing the sea floor with precision and efficiency. The Kongsberg-Simrad EM300, for instance, provides depth accuracy of 17 cm or 0.2% (rms) of the depth, whichever is greater. In Puget Sound, the total swath width (depth dependent) permits mapping up to almost 14 km<sup>2</sup> hr<sup>-1</sup>. Deriving maximum value and meaning from the data has been made possible by the development of GPS positioning, inertial ship motion sensors, and software processing and visualization packages.

## Nearshore Surveys with LIDAR

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LIDAR, also known as airborne laser swath mapping (ALSM) is an attractive technology for mapping bathymetry of the nearshore region. Swath widths are not depth-dependent, aerial surveying avoids the hazards associated with boat work in surf and shallow water, and the active, monoscopic laser rangefinder works well on featureless beach surfaces that render photogrammetry near-useless.

Three classes of LIDAR instrument are relevant to nearshore mapping in Washington. A) Small-footprint, discrete-return, infrared LIDARs dominate the commercial surveying marketplace. Optimized for surveys of topography and forest canopy, they generate up to  $10^5$  XYZ positions per second, with 3-20 cm vertical accuracy and 0.3-1 m horizontal resolution. B) Large-footprint, full waveform, green LIDARs (LADS, SHOALS, CHARTS) have been developed for bathymetric surveying. These instruments generate circa  $10^3$  XYZ positions per second with 0.2-1 m vertical accuracy and ~4 m horizontal resolution and can survey to depths as great as 25 m. C) A single small-footprint, full waveform, green LIDAR (EAARL) is in routine operation for research in North America. EAARL sacrifices the depth penetration of the large-footprint instruments for lower power consumption and lower operating costs; measurement rate is  $\sim 3 \times 10^3$  positions per second with horizontal resolution of 1-2 m. Similar sensors will soon be available in the commercial sector.

The Puget Sound LIDAR Consortium (PSLC) has completed commercial infrared LIDAR surveys for all of the inland marine nearshore of Washington with the exception of San Juan County and westernmost Whatcom County, which are to be surveyed this winter. The infrared laser does not penetrate water, thus these surveys generally provide coverage above MHW. A few areas—e.g., head of Port Susan, mouth of Nooksack River, parts of Nisqually delta—have been surveyed at low tide. The standard product has been a 6-ft resolution DEM. This winter's surveys will provide a 3-ft DEM.

In 2001, 2002, and 2003, PSLC, USGS, City of Seattle, King County, and Washington DFW sponsored tests of LADS, SHOALS, and CHARTS that resulted in nearshore bathymetry for most of the King County shoreline, the shores of Possession Sound between Clinton and Edmonds, part of the west shore of Camano Island, the Skagit delta front, and the east shore of Hood Canal near Lofall. We learned the following: (1) Penetration to 20 m depth is feasible in April and late September, though not during mid-summer algal blooms. (2) Resolution, accuracy, and productivity are predictably less than for commercial infrared LIDARs. (3) Non-commercial operation of CHARTS makes it difficult to define costs and guarantee instrument availability. (4) As of late 2003, idiosyncrasies of the CHARTS processing software resulted in failure to map some areas of very shallow water and bare tide flat. (5) As of late 2003, collection of data referenced to an ellipsoidal vertical datum could not be guaranteed. (6) The requirement that data

be collected while flying straight lines, coupled with the steep, sinuous nearshore of Puget Sound, makes mapping of this region with these instruments very expensive.

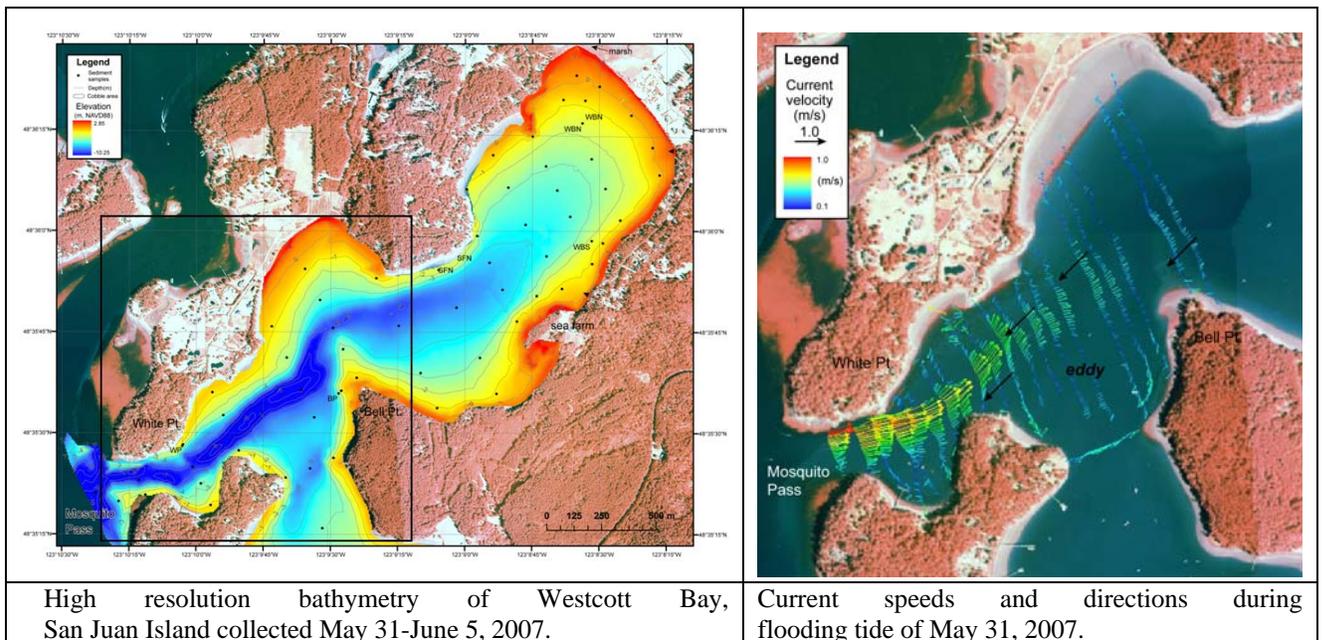
Besides a steep, sinuous nearshore, Puget Sound has a large tidal range and generally calm conditions and easy access that make small boat operations relatively inexpensive. This suggests that when planning further nearshore surveys we should compare the cost, accuracy, and resolution of green LIDAR with the combination of small footprint infrared LIDAR acquired at low tide and small boat acoustic mapping at high tide. The infrared-acoustic combination would provide greater accuracy and resolution and may be cheaper.

## US Geological Survey Nearshore Mapping in Puget Sound

Eric E. Grossman

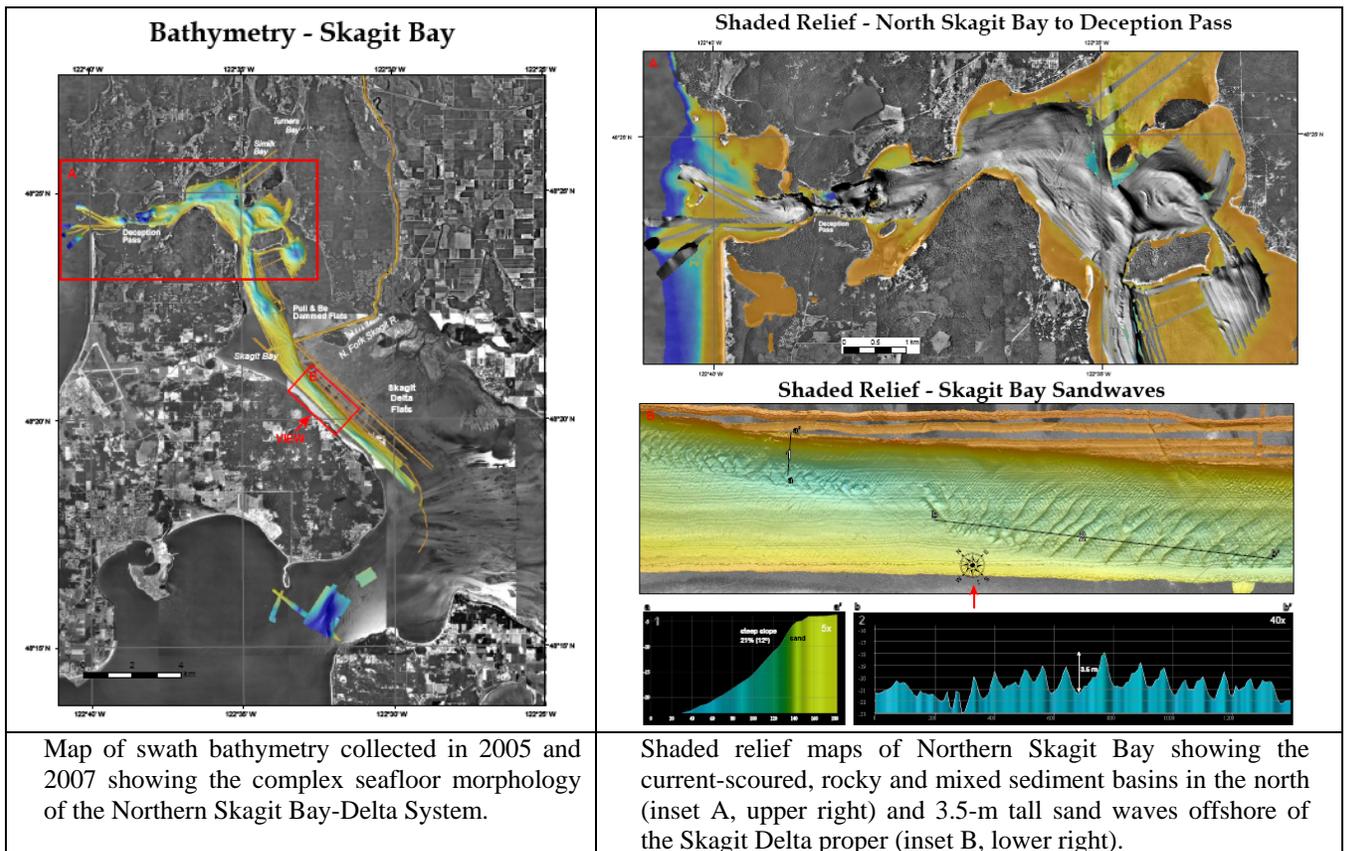
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To address the scientific needs identified by the Puget Sound Nearshore Partnership to recover ecosystem function in Puget Sound, the US Geological Survey's Coastal Habitats in Puget Sound (CHIPS) Project conducts extensive nearshore mapping. High-resolution multibeam and single beam echosounder bathymetry, seismic reflection profiling, roving and stationary Acoustic Doppler Current Profiling (ADCP), acoustic cameras, bottom video, sediment sampling, electrical resistivity, and radiochemistry are used to map nearshore seafloor and water column properties that influence habitat structure and availability. Recent efforts have focused on *simultaneously* mapping benthic habitats, circulation, and the fish/invertebrates/macrofauna that use the habitat in order to better understand the geomorphic, hydrodynamic and environmental factors that contribute to habitat structure and use. Partnering in the WA Department of Natural Resources Eelgrass Stressor-Response Project, CHIPS scientists generated high resolution maps of the bathymetry, morphology, circulation and substrate/sediment properties of Westcott Bay, San Juan Islands to examine possible causes for the recent die-off of *Z. marina* there (and many other embayments in northern Puget Sound) and the potential for its recovery.



The CHIPS Large River Deltas Project has been mapping the seafloor, substrate type, and sub-bottom geologic framework, including distribution and thickness of sediments

throughout the Skagit Delta-Whidbey Basin to characterize the fate and impact of sediment discharged by the heavily channelized Skagit River. These efforts reveal the complex morphology and substrate character of the seafloor of the Northern Skagit Bay-Delta System that is scoured by strong currents to depths of 50m near Deception Pass. The mapping combined with analyses of core samples indicates that the central Skagit Delta tide flats now comprised of medium to coarse sands experienced a significant and abrupt change in depositional environment beginning in the 1850s, when they were dominated by mudflats. The Skagit mapping results also show that a significant fraction of fine sediment discharged by the heavily channelized Skagit River is being exported out of the basin by strong tidally-driven currents, likely impacting nearshore habitats and habitat availability for diverse taxa across extensive areas of Northern Puget Sound.



Similar mapping efforts are underway to characterize substrate-hydrodynamic-vegetation-contaminant linkages of eelgrass, forage fish and salmonid use of habitats as part of the CHIPS Urban Impacts Project and a brief description of recent submerged vegetation and submarine groundwater discharge (SGD) mapping will be presented. Novel applications of electrical resistivity and radiochemistry are being employed to map SGD. These studies reveal that although SGD likely plays an important role in conditioning nearshore salinity gradients for migrating juvenile Chinook salmon, it is a conduit for high-nutrient loads to many coastal areas in Puget Sound that are already threatened by eutrophication.

## Modern Processing Techniques

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Modern processing of high-density swath mapping systems has the two-fold goal of (1) producing the most accurate representation of the sea floor possible, and (2) generating this product at a rate that is less than the time necessary to collect the data. Furthermore, it is no longer sufficient to produce just a bathymetric map; it is increasingly necessary to produce a suite of electronic products ranging from navigation charts to high-resolution acoustic imagery. The data volumes generated by modern mapping systems present processing challenges, but the increased data density introduces redundancy, which can be used to estimate measurement uncertainty.

The sonar post-processing pipeline begins with a measurement of time and backscatter intensity. These data are combined with ancillary information about the position and orientation of the vessel as well as environmental data to produce a total sounding solution. The soundings are then subjected to quality control and calibration and then stored in a database. Finally, bathymetry, imagery, sea floor properties and other derivative products are produced.

As recently as the late 1990s, only rudimentary filtering procedures were in place for automating the processing pipeline. It could take days of manual editing for each day of ship time and it was difficult or impossible to estimate uncertainty. Today, however, advanced statistical models of every aspect of the sonar system (and to a lesser extent the surrounding environment) can be used to automatically process the data and produce estimates of uncertainty in the measurements at the same time. Our understanding of underwater acoustic propagation has also increased substantially, so that the processing of acoustic imagery is becoming much more quantitative. We can use acoustics as a remote-sensing tool to tell us a lot about sea floor characteristics and that leads directly to useful maps of environmental state that would not be available from the bathymetry alone.

## **A Groundtruthing Method for Sea Floor Mapping**

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Interpretation of sonar data requires some groundtruthing information to verify basic substrate types visually. We use bottom-video and the usSEABED sea-floor sampling database for groundtruthing. For video-groundtruthing we use a camera sled system designed by the USGS and methodology developed through a joint NOAA Fisheries and USGS postdoctoral study. The camera sled has downward and oblique-forward digital video cameras, a downward digital still camera, depth-pressure transducer, altimeter, and dual lasers. The altitude is maintained by changing the tether length with a winch. We have found camera sleds to be more cost-effective for groundtruthing transects. ROVs require a pilot who must keep the ROV within tether range of the ship to avoid kiting off the bottom. Submersibles require a team of technicians and a pilot, and require more time for deployment and maintenance. ROVs and submersibles are better than a camera sled for detailed observations in a small area. During a video transect observations are tabulated every minute that describe a 10 second window of observation. Primary substrate, secondary substrate, abiotic complexity, slope, biotic coverage, and biotic relief are estimated. Additional observations of key species and geologic features are made when they are present. The key species list is generated through consultation with local fisheries managers and biologists. The observations are recorded as a point feature with a geographic location of the camera at the 5 second mark during the 10 second window. We use points rather than dynamic line segments because changes in substrate are often subtle gradational changes that are not easily segmented.

We use the video observations to supervise a maximum likelihood classification of the sea-floor sonar data into substrate classes. Tracking systems, or layback corrections, do not provide sled navigation as accurate as the shipboard navigation applied to the sonar data. This problem requires that the small polygonal areas, used to generate multivariate statistics for the classification be hand drawn with an estimated position-error in mind. The numerical classification produces a grid that has as a minimum of three classes that correspond to the Greene classification attributes of induration and complexity; Soft-flat (thick deposits of fine sediment), mixed-flat (flat hard areas of coarse sediment or rock), and hard-rugose (rock reef areas). Additional classes, such as ripple-scour depressions

are classified as well, when they are observed and if they can be differentiated using our supervised classification technique. After the numerical classification the resulting grid is further subdivided into bathymetric zones, slope zones, and topographic position index zones, that add value to the grid for fisheries management and research purposes. The classified grid preserves the gradational change information because each pixel is classified. The classified grid can also be used as a starting point for the production of a generalized polygon-based geology or habitat layer, so that each zone has boundary and an area. The polygons support the multiple attributes in the Greene classification scheme including a geologic unit.

## Classification and Mapping of Potential Sea Floor Habitats

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*“A potential marine benthic habitat describes the physical, geological, chemical and biological conditions at the seafloor that are associated with the species or population of interest. These conditions consist of, but are not limited to, depth temperature, light or turbidity, salinity, nutrients, currents, substrate type, geomorphology, and structure-forming organisms.”* (Greene et al., 2007).

Many different types of habitat classification schemes have been developed to describe and map these conditions for coastal and marine environments. These schemes range from site or topic-specific types to broad approaches that cover large geographic regions. Many investigators tailored classification schemes to support their specific interest at the time of their studies. However, comparison of (cross-walking of) habitat types from one study or from one region to another is generally not possible because of the incompatibilities of these schemes. Today with the intense effort of seafloor mapping and the support of Geographical Information Systems (GIS), coordination of marine benthic habitat classification is necessary if habitats are to be evaluated on a regional or national basis.

Often mapping efforts are focused solely on the collection of the bathymetric data and little or no attention is paid to the “added value” aspect needed for the construction of an end product. End users are generally impressed with the pretty pictures that can be constructed from digital multibeam bathymetry, but are often perplexed in how to use the data for management or planning purposes. It is critical, therefore, that any mapping effort undertaken should have an objective, in contrast to mapping just for mapping sake, and that an interpretive process be included as a major part of the exercise so that usable maps can be produced. Adoption of a marine benthic habitat-mapping scheme is necessary to advance this goal.

In the evaluation of a classification and mapping scheme it is critical in determining how user friendly and adaptable a scheme is and if it can be used to evaluate all of the parameters considered critical for management purposes. Although many of the parameters needed to identify a habitat may not be easily included in a scheme, it may be possible to use seafloor conditions and other parameters as surrogates or proxies for particular habitat types. In this context the term “habitat” as applied to such schemes needs to be defined, as the word means different things to different investigators, thus “potential habitats” has been introduced as the descriptor for mapped seafloor conditions such as depth, temperature, light, salinity, nutrients, currents, substrate type, geomorphology, and structure-forming organisms (Greene et al., 2005).

Of critical importance to mapping habitat types is the flexibility of a user to mix and match or add and subtract attribute types to produce a map that specifically addresses the objective(s) of the mapping exercise and future unknown needs. This is often accomplished by using a hierarchical or nested scheme. Mapping requires the clear, unambiguous definition of classes that will allow consistent mapping. The minimum mapping unit (smallest mapped area) must also be stated, and often varies with the level in an hierarchical classification. The lowest detectable amount must also be stated. The deep-water marine benthic habitat-mapping scheme used in the past 15 years to map the west coast of North America allows for such mixing of attributes that can be easily queried in a GIS (Greene et al., 1999, 2007). Although it is recognized that there is no perfect habitat-mapping scheme that meets all users expectations, this scheme allows for the archival of detailed interpretations that can be accessed in the future when the biological and ecological information become available. It can be applied in shallow water as well as in deep water. However, a standard for mapping such attributes needs to be agreed upon, which has been the effort of NOAA (Allee et al., 2000) in its drafting of the Coastal and Marine Ecological Classification Standard (CMECS), with the second version recently developed by NatureServe (Madden et al., 2005, 2007).

Presently there are about 12 different marine benthic habitat schemes available for use in characterizing habitat types (Lund and Wilbur, 2007), some of which address west coast habitats as follows:

Allee et al. (2000) – “Marine and Estuarine Ecosystem and Habitat Classification.” A comprehensive coastal and marine scheme for the entire US.

Cowardin et al., 1979 – “Classification of Wetlands and Deepwater Habitats of the United States.” A nested-hierarchical classification scheme for wetland and deepwater habitats. Provides the basis for schemes developed by Dethier (1992), Greene et al. (1999), Allee et al. (2000), Kutcher et al. (2005), and Greene et al. (2007). Mostly focused on wetlands.

Dethier (1992) – “A Marine Estuarine Habitat Classification System for Washington State.” Extends Cowardin (1979) to cover high-energy environments such as open coasts.

Of the twelve classification schemes Lund and Wilbur (2007) reviewed, only four appeared to be adaptable to mapping as follows:

Greene et al. (2007) – “Construction of Digital Potential Marine Benthic Habitat Maps Using a Coded Classification Scheme and Their Application.”

Kutcher et al. (2005) – “A Recommendation for a Comprehensive Habitat and Land Use Classification System for the National Estuarine Research Reserve System (NERRS).”

Madden et al. (2004) – “Coastal and Marine Systems of North America – Framework for an Ecological Classification Standard: Version II.”

Valentine et al. (2005) – “Classification of Marine Sublittoral Habitats, with Application to the Northeastern North America Region.”

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## **Habitat Mapping: The Canadian Perspective**

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For the past five years the Geological Survey of Canada in conjunction with the Canadian Hydrographic Service and fisheries scientists of the Department of Fisheries and Oceans have undertaken a Geoscience for Ocean Management Program in the two major basins of the Pacific margin of British Columbia. The primary data set consists of contiguous multibeam swath bathymetric coverage of the Strait of Georgia, Juan de Fuca Strait and the inter island waterways that separate the two straits, and targeted surveys within the Queen Charlotte Basin region of the Pacific North Coast. The seafloor regions were imaged at a grid resolution between 2 m, using a Simrad 3002 300 kHz system, and 5 m, using a Simrad 1002 95 kHz system. The specific objectives of the program are to map the distribution of different seafloor types, predict sub-seabed geotechnical conditions through an understanding of Quaternary processes, determine the seafloor expression of earthquakes (neotectonics), establish the geologic controls on geohazards, and map key and critical habitats. The need for a planned program comes from the potential for renewed oil and gas exploration and large scale engineering development, such as offshore wind farms, that will inevitably be in conflict with traditional and new fisheries (Sinclair et al., 2005) and occur in areas that contain globally significant ecological habitat (e.g. sponge reefs (Conway et. al, 1991; Kruatter et al., 2001; Conway et al., 2005; Cook, 2005)).

The southern Strait of Georgia is Canada's most economically important coastal area, hosting the largest coastal communities in Canada, which are dependent on the adjacent marine areas for transportation, power transmission and resource infrastructure, tourism and other economic and cultural reasons. In this transboundary region between Canada and the United States multibeam bathymetry and backscatter data has been collected in the San Juan Islands, southern Gulf Islands and the southern Strait of Georgia area as part of a program with the Center for Habitat Studies (Moss Landing Marine Laboratories). The collection of this imagery has provided for the interpretation of habitats, surficial geology and geohazards that cross the international boundary. Emphases were placed on rockfish (*Sebastes* spp.) habitats because of declining populations of inshore species. Geological structures, including faults (some active) and folds, glaciated bedrock, and extensive sediment waves and dune fields were imaged. Geological interpretations of these images suggest that active tectonics has shaped the seafloor and islands into steep walls and cliffs that have since been modified by glaciation. In addition, strong tidal currents have winnowed most of the glacially deposited sediments into coarse-grained lag pavements, boulder/cobble/pebble fields and very large mobile sandwaves. The past and present active physical processes have created a variety of fish habitats, such as steep, near vertical rock walls, stacked boulders (e.g., moraines and rockfalls), which offer habitat for juvenile and adult rockfish, sandwaves that shelter sand lances and other organisms that may provide foraging habitat for bottom fish, and raised glacial deposits that allow for the formation of small sponge reefs that provide critical habitat

for juvenile rockfish. These new data are now being used to evaluate the effectiveness of MPAs in the San Juan Islands and for the Rockfish Conversation Areas within the southern Gulf Islands and Strait of Georgia region.

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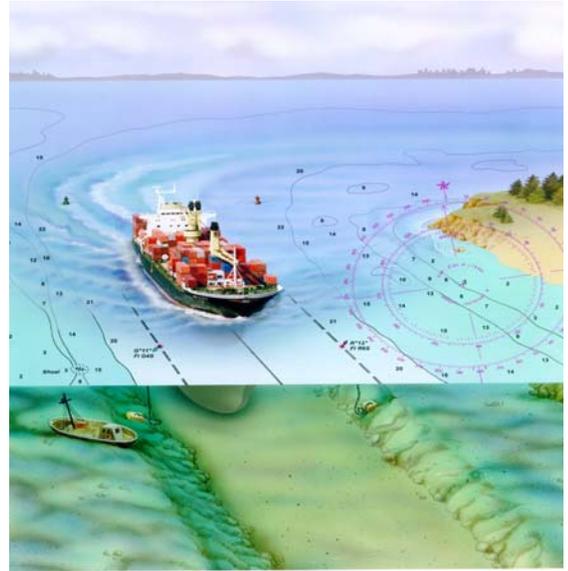
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## NOAA's Hydrographic Survey Program Northwest Region Update

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The statutory mandate of the National Oceanic and Atmospheric Administration (NOAA) authorizes NOAA to provide nautical charts and related hydrographic information for the safe navigation of maritime commerce as well as provide basic data for engineering, scientific and other commercial and industrial activities. This mandate covers all U.S. territorial waters and the U.S. Exclusive Economic Zone (EEZ), a combined area of 3.4 million square nautical miles (SNM) which extends 200 nautical miles offshore from the nation's coastline. The production of high-quality navigation charts to support the safety of marine transportation depends on the availability of up-to-date, reliable hydrographic survey data.



Hydrography is the science which deals with the measurement and description of the physical features of bodies of water and their littoral land areas. Special emphasis is placed on the elements that affect safe navigation and the publication of such information in a suitable form for use in navigation. A hydrographic survey may be conducted to support a variety of activities: nautical charting, port and harbor maintenance (dredging), coastal engineering (beach erosion and replenishment studies), coastal zone management, and offshore resource management and development. The primary use of NOAA hydrographic surveys is for nautical charting. Depending upon the geographic area and environment, Shallow Water Multibeam Sonar (SWMB) or Side Scan Sonar (SSS) are now standard equipment utilized to facilitate acquisition of high resolution hydrographic data. This data undergoes rigorous Quality Assurance procedures before being applied to the chart and made available to the general public. The requirements for data acquisition and application to the nautical chart are based upon detailed NOAA technical specifications.

The Pacific Hydrographic Branch (PHB) is one of two data processing branches under the National Ocean Service, Hydrographic Surveys Division. Hydrographic survey data acquired by NOAA field parties and contractors along the west coast and Alaska are

submitted to PHB for final processing, certification and cartographic compilation to NOAA nautical charts. Raw and final processed data are archived offsite, and made available for public dissemination at NOAA's National Geophysical Data Center: <http://www.ngdc.noaa.gov>

To identify and prioritize the areas within NOAA's scope of navigation safety responsibilities that are in greatest need of hydrographic surveys, NOAA developed the "National Survey Plan" (NSP) in November 2000 (now entitled "NOAA Hydrographic Survey Priorities" (NHSP)). Prioritization of the nation's survey requirements is revised periodically due to the dynamic nature of the trends in waterborne commerce, the increasing size and draft of commercial vessels, sea-floor changes due to natural and man-made processes, and the need for more highly detailed hydrographic survey coverage utilizing modern technologies. NOAA's Navigation Managers, the Office of Coast Survey's representatives in the field, help focus future hydrographic survey activities based upon ongoing interaction and communication with various maritime constituents including the U.S. Coast Guard, U.S. Navy, Columbia River Pilots, Puget Sound Pilots, Port Authorities, local constituents and other Federal and State agencies. With the assistance from Regional Navigation Managers, NOAA reviews the priority assignments within the NHSP and publishes new editions annually. The 2007 edition of the NHSP can be viewed at: <http://nauticalcharts.noaa.gov/>

Over the last several years, NOAA has routinely conducted SWMB and SSS surveys in the Northwest Region, including Puget Sound, Strait of Juan de Fuca, along the Oregon and Washington Coasts, and the Columbia River. These hydrographic surveys are usually limited to opportunities during the spring and fall, prior to and after NOAA Ship RAINIER's deployment to Alaska (RAINIER's homeport is Seattle, WA). Surveys are also conducted by NOAA's Navigation Response Team 3, which is based in the Pacific Northwest. These hydrographic surveys are usually limited to a specific geographic area, based upon prioritization within the NHSP. Over the past year, NOAA has conducted hydrographic survey operations within Southern Puget Sound, Northern Puget Sound and the San Juan Islands, Strait of Juan de Fuca, Columbia River and Coos Bay. Future operations will include additional efforts in these areas and along the Oregon and Washington Coast and the Columbia River between Astoria and Portland.

## Seafloor Habitat Survey Effort in Olympic Coast National Marine Sanctuary

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The shelf and canyon habitats of the Olympic Coast National Marine Sanctuary (OCNMS or sanctuary) off the coast of Washington are areas of high primary productivity and biodiversity. They also support extensive groundfish fisheries, including commercial, tribal and recreational. Some of these areas have been identified as essential fish habitat (NOAA Fisheries 2006), however, only limited information is available on seafloor habitats within the sanctuary. And recent information has also shown that some hard bottom sites hosts an array of associated fauna, including deep-sea coral and sponge communities (Brancato et al. 2007). These combined resource questions point to a critical need for seafloor surveys to eventually produce high resolution habitat maps.

Classification of habitats and the general characterization of the seabed are critical for supporting management, research, monitoring, and education programs within the National Marine Sanctuary Program. More detailed site assessments are needed to better prioritize mapping efforts and outline an overall joint strategy (NOAA NMSP 2003; Draft Action Plan 2007). Since OCNMS was designated in 1994, the site has prioritized and conducted seafloor survey efforts as frequently as budgets and vessels allowed. However since the sanctuary covers over 3,300 square miles of continental shelf and three submarine canyons, this has been a daunting task. The continental shelf in the sanctuary extends from 8 to 40 miles from the shore (Fig. 1). Three submarine canyons cut into the shelf and slope within the sanctuary boundary.

To accomplish seafloor surveys from the nearshore to deep water areas, the sanctuary and its partners have used different methodologies. The majority of survey effort has included acoustic seafloor surveys, using both side-scan sonar surveys and high resolution multibeam bathymetry (Intelmann 2006). And a pilot project to use LIDAR to map nearshore bathymetry and the intertidal zone was flown in 2005.

Acoustic surveys have occurred off the sanctuary's R/V *Tatoosh* for nearshore areas, and off of various NOAA ships (e.g., *McArthur*, *McArthur II*, and *Rainier*) and charters for deeper sites. To date roughly 25% of the sanctuary has been surveyed sufficiently to produce high resolution maps (Fig. 2). To ground truth the acoustically derived data and to characterize the habitats following Greene et al. (1999), the sanctuary and its partners have been using combinations of bottom grabs, videography from ROVs or subs, and drop cameras. Just as the initial acoustic survey effort, this is an expensive and time-consuming operation.

At the current rate of effort with ship time allocation and budgets, it has been projected that the entire sanctuary would not be 100% mapped for up to tens of years (Intelmann

2006). For time critical management decisions, increased effort is necessary, specifically additional funding and leveraging of other partnerships for ship time and equipment.

Additional information on the sanctuary's seafloor mapping efforts can be found on the OCNMS web site. <http://olympiccoast.noaa.gov/research/mapping/welcome.html>. Additional OCNMS seafloor publications are located on the Marine Conservation Series web site <http://www.sanctuaries.noaa.gov/science/conservation/welcome.html>.



Figure 1. Bathymetric features and boundary of the Olympic Coast National Marine Sanctuary

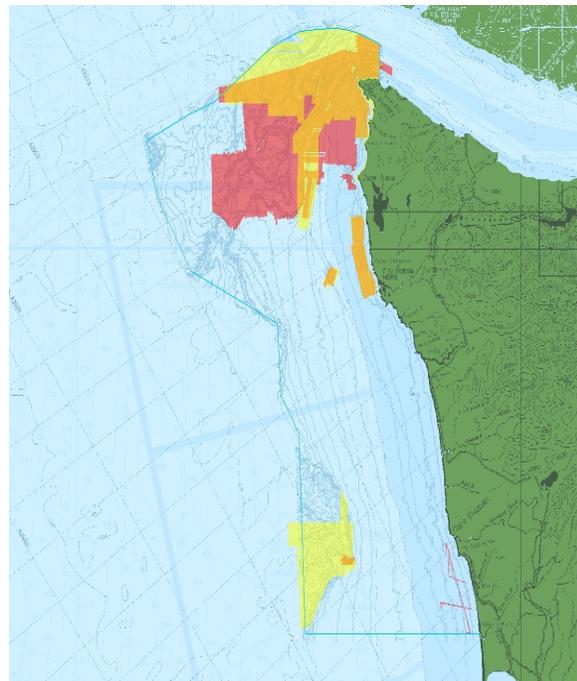


Figure 2. Acoustic survey effort to date. Red = side scan, yellow = multibeam, and orange = dual coverage

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## Mapping the Sea Floor Around the San Juan Islands

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For the past seven years extensive sea floor mapping using Simrad 1002 (95kHz), Simrad 3002 (300 kHz), and Reason 8101 (240 kHz) multibeam bathymetric mapping systems were used to map the inland seas of the San Juan Islands under a joint cooperative agreement between the Canadian Geological Survey and the Center for Habitat Studies, Moss Landing Marine Labs. The initial objective of this mapping exercise was to image the sea floor in as much detail as possible in order to identify and map marine benthic habitats of adult rockfish (*Sebastes* spp.). However, as the mapping progressed it became apparent that many other benthic habitats could be identified and mapped in great detail. For example, the discovery of high concentrations of Pacific sand lance (*Ammodytes hexapterus*) in deep water (60-80 m) within a dynamic sand wave field has focused much of our mapping efforts to locating and classifying the various dynamic bedforms that exist in the region with the intent to identify potential habitats of the sand lance (Blaine, 2006; Lopez, 2007). Since sand lances are preyed upon by many other marine species it appears important to identify and map these foraging habitats.

To date all of the deep water areas and much of the shallow water areas have been mapped within the San Juan Archipelago. We are continuing to map the shallow water sea floor areas up to 3-5 m water depth using the Canadian Coast Guard Vessel *Otter Bay* outfitted with a Simrad 3002, a task that will take several more years to accomplish. In addition to collecting multibeam swath bathymetry and backscatter data, we are now in the process of collecting 3.5 kHz sub-bottom seismic reflection profiles that are being used to determine thickness of unconsolidated sediments as well as to identify faults. Many recent faults have been observed to offset what appears to be late Pleistocene to Holocene sediments within the Lopez Fault Zone beneath the bays and inlets of Southern Lopez Island. In addition, we are initiating a “groundtruthing” phase of our mapping project to document the substrate and habitat types interpreted from the multibeam and geophysical data sets. The habitat maps are based on the mapping scheme and attributing code of Greene et al. (1999, 2007) and are displayed for inspection at this workshop.

To date we are completing a 12 sheet, 1:20,000 scale habitat map set that was interpreted at a scale of 1:5,000 (Fig. 1). Two 1:50,000 scale map sheets produced from combining

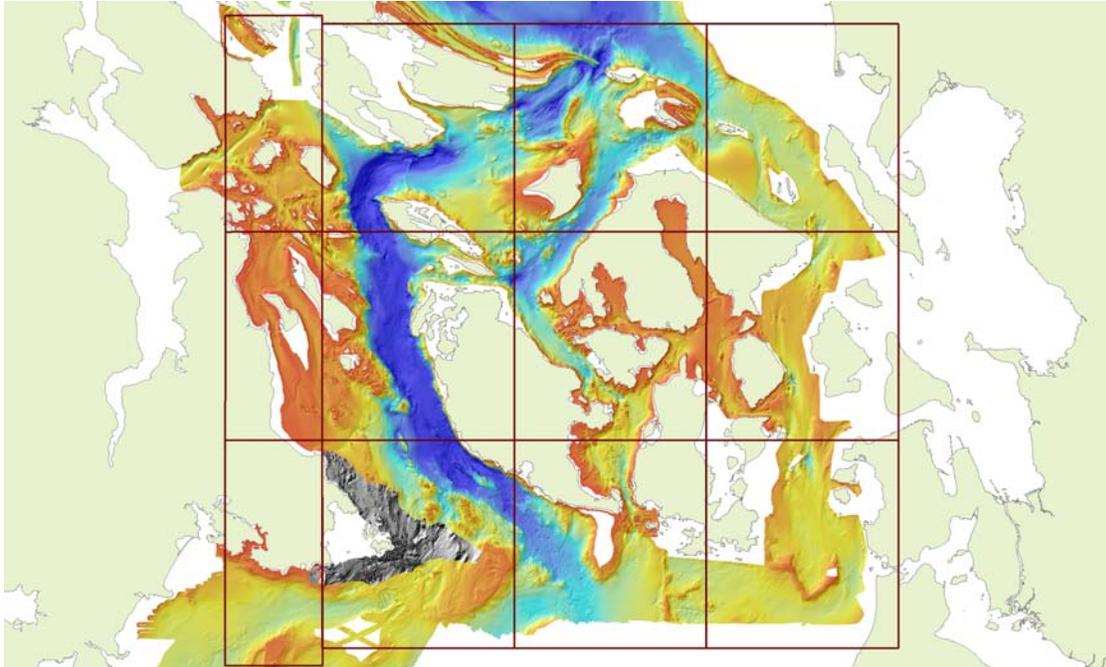


Figure 1 – Outline of the twelve 1:20,000 scale map sheets being produced from the multibeam bathymetry and backscatter data jointly being collected by the Canadians and Americans. Blue color represents deep water and red color represents shallow water. Scale approximately 1:200,000.

the 12 maps will be published in the Canadian Marine Geologic Map Series. Work has begun on the construction of the marine geologic and geohazards maps for the region, which will display faults, landslide deposits, and geologic units. Anticipated future mapping effort is to extend the maps to the south into the Strait of Juan de Fuca and east into Skagit County.

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## **U.S. Geological Survey Cooperative Mapping Projects within Puget Sound, WA**

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Sea floor maps including depth and acoustic backscatter are important base map information for many marine geological studies and help guide coastal management decisions. These data are crucial when modeling sediment processes, pollution transport pathways, deciphering tectonics, defining benthic habitats, and assessing anthropogenic impacts. The U.S. Geological Survey is involved in a number of cooperative mapping projects within Puget Sound, WA using two types of acoustic sonars; multibeam echosounders and bathymetric sidescan sonars. While these systems use different technologies they both map depth and acoustic backscatter of the sea floor in relatively high resolution.

Recent projects have mapped in Skagit Bay and off the Elwha River in support of coastal sediment transport and benthic habitat studies. Also, three major deltas within Puget Sound were mapped to better understand any submarine failures after the February 28, 2001 6.8 magnitude earthquake in southern Puget Sound. While these surveys did not show any conclusive evidence of failures from the earthquake they did map previously known and unknown failures as well as anthropogenic impacts in great detail. These high-resolution mapping tools and new processing techniques display the sea floor and water-column features as well as enable interpretive maps to be disseminated with ground-truth information in an intuitive and interactive fashion.

**Swath Mapping in Greater Puget Sound by the University of Washington's R/V  
*Thomas G. Thompson* using the Atlas Hydrosweep DS and the Kongsberg-Simrad  
EM300 Systems**

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The present R/V *Thomas G. Thompson* entered service in 1991. *Thompson* is operated for UNOLS by the University of Washington, under a contract with the U.S. Navy. An agreement with the State provides support for up to 45 days a year to be devoted to graduate and undergraduate training and research aboard *Thompson*. Use of this ship time is spread out over a given calendar year in such a way that these educational cruises do not interfere with UNOLS-scheduled operations. Some of this time is spent in greater Puget Sound in support of various academic courses (~3-4 cruises/year) and the PRISM (Puget Sound Regional Synthesis Model) program (~2 cruises/year). Many students in the Marine Geology and Geophysics option have made use of *Thompson's* swath mapping systems in carrying out their thesis research. These cruises have provided opportunities to incrementally map portions of Puget Sound and Hood Canal, sometimes with only single-track coverage but also frequently with full multi-track coverage of a study area.

When delivered, *Thompson* was equipped with an Atlas Hydrosweep DS (Deep Sea) swath mapping system. Hydrosweep operates at ~15 kHz with a 90° swath width (twice water depth). The system measures depths using 59 discrete beams with each ping. This system was used on several cruises to map areas in central Puget Sound (1993-TN018), part of Possession Sound (1998-TN077), and the region south of Possession Point (1999-TN089). As the "DS" indicates, Hydrosweep is primarily a deep water system, and its use in the shallow (>300 m) waters of Puget Sound limited swath widths to less than ~500 m and more usually less than ~100 m. Nevertheless, data collected using this system permitted our students for the first time to obtain quasi-real-time contour maps of a large (relatively) area of sea floor.

In March 2002 a Kongsberg-Simrad EM300 swath mapping system was installed on *Thompson*, and it was almost immediately put to use in Puget Sound during a student cruise in April of that year. The Hydrosweep transducers were retained, thereby providing the vessel with two swath mapping systems, each with their own strengths and weaknesses. The EM300 obtains data from 135 discrete 30 kHz beams over a 135° swath (3-4 times water depth) and is therefore a much more useful mapping tool in the relatively shallow waters of Puget Sound and Hood Canal. The system was used in 2002 (cruises TN-142 and 146) to map northern Puget Sound (Edmonds-Kingston to Whidbey Island) and central and southern Admiralty Inlet. Cruise TN-175 in 2004 mapped portions of Bellingham Bay and north-central Puget Sound from Meadow Point to Point Wells. In 2005 (cruises TN-177 and 178) mapping was carried out in Hood Canal, central Admiralty Inlet, and west-central Puget Sound from Skiff Point to Yeomalt Point.

The most recent surveying was carried out in southern Hood Canal in the spring of 2007 (cruise TN-203). As might be expected the data produced during these cruises, particularly those on which the EM300 system was used, provided for a more detailed examination of previously known features and also disclosed many unexpected (and to date unexplained) morphologic structures.

Plans are being formulated to coordinate future collection of EM300 swath imagery data in greater Puget Sound during student and PRISM cruises in such a way that continuous mosaics can be gradually built up. Intra-station transits will be designed in such a way that duplicate tracks are avoided whenever possible. If the cruise operations permit, blocks of survey time will be devoted to obtaining continuous coverage of specific areas of interest.

## Sea Floor Mapping Products and Applications

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Sea floor maps are in increasing demand by coastal zone managers for science-based decision making and are considered a high priority in the West Coast Governor's Agreement. Important applications of such maps include (but are not limited to) the following: (1) Safe navigation and commerce; (2) Characterization of benthic habitats; (3) Fisheries management and designation of marine protected areas; (4) Baselines for monitoring environmental changes associated with varied phenomena such as major storms, sea-level rise or dam removal; (5) Documentation of nearshore sediment distribution and processes to understand sediment and contaminant budgets and transport; (6) Developing and evaluating regional sediment management plans, including identification of offshore sand resources; (7) Siting and (or) evaluating potential impacts of nearshore and offshore infrastructure such as energy facilities, pipelines and cables, and aquaculture farms; (8) Locating and characterizing offshore faults and submarine landslides, providing essential input to earthquake and tsunami hazard assessments; (9) Providing high-resolution bathymetric grids for local to regional circulation and sediment transport modeling, and for modeling tsunami and storm inundation of coastal zones; and (10) Understanding geologic history, change, and thresholds.

Development of different seafloor map products (types, standards, scales) was considered at the California Statewide Marine Mapping Workshop held 12/05 in Seaside, CA (56 participants from 38 institutions), and was the principle theme of the Coastal Map Development Workshop held 5/07 in Menlo Park, Ca (60 participants from 25 institutions). These workshops featured vigorous discussion between map developers and map users, contributing to development of the map folio concept. One example of a comprehensive seafloor map folio, recently developed as a mock up by the California State Waters Mapping Consortium, was presented to and well received by the California Ocean Protection Council (10/07). This folio will be displayed at the Washington State

Sea Floor Mapping Workshop and consists of the following eleven map sheets covering an area near Half Moon Bay, CA:

- (1) High resolution multibeam echosounder color bathymetry (1:24,000)
- (2) High resolution multibeam echosounder gray-scale bathymetry (1:24,000)
- (3) Perspective views of the high-resolution bathymetry
- (4) Gray-scale multibeam echosounder backscatter (1:24,000)
- (5) Gray-scale backscatter draped on bathymetry (1:24,000)
- (6) Groundtruthing map and imagery
- (7) Seafloor character map ("Tier 2.5," 1:24,000)
- (8) Habitat map ("Tier 3," 1:24,000)
- (9) Subbottom seismic-reflection trackline map (1:50,000) and selected seismic profiles
- (10) Holocene isopach map and Depth to base of Holocene map (1:50,000); Geologic structure map (1,50,000) and Regional structure and seismicity map (1:150,000)
- (11) Onshore-offshore geologic map (1,24,000)

Development of the interpretive map products (maps 5 to 11 on above list) have variable dependencies. For example, the seafloor character and habitat maps rely on high-resolution bathymetry, backscatter, and groundtruthing (bottom video and sediment sampling) data. The geologic maps (maps 10 and 11) rely on the same information, but also greatly benefit from sub-bottom data collected in seismic reflection surveys. Such comprehensive map coverage may not be possible everywhere, but should be considered as the ideal mapping goal of the California, Washington, and Oregon State Waters Mapping Programs.

## b. Status of West Coast Mapping

### California's Seafloor Mapping Program: A Successful Model for the Design, Support and Launch of Comprehensive Regional Mapping Campaigns

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**Problem:** We cannot manage what we do not understand, and we cannot understand what we do not know. Such is the case for California's state waters. The entire surface of Mars has been mapped in greater detail than the narrow strip of seafloor within California's 3-mile state waters boundary. Yet over 85% of California's Gross State Product (the 7<sup>th</sup> largest economy in the world) and 75% of its population are based in the coastal market sectors that border and rely on these highly productive waters. The continued success of this robust coastal economy is dependent upon the health and sustainable management of California's coastal ocean ecosystem and resources. Despite having the ability to create the needed high-resolution base maps for these dynamic and critically important hidden landscapes, the only information available for managing the sustainable use and protection of more than 66% of California's seafloor habitats is in the form of nautical charts: tools never intended and inadequate for the tasks at hand. This lack of high-resolution seafloor maps has limited and profoundly compromised our ability to address a variety of critical marine and coastal management issues including:

- **Coastal Erosion**, sediment transport and beach loss
- Baseline data for environmental change detection and **Coastal Ocean Monitoring**
- Development and implementation of true **Ecosystem Based Management**
- Restoration of **Degraded Habitats, Depleted Fish Stocks** and **Endangered Species**
- Identification, classification and protection of **Essential Fish Habitats**
- Effective design and monitoring of **Marine Protected Areas**
- Discovery, assessment and monitoring of **Earthquake** and **Tsunami Hazards**
- Placement and maintenance of **Oil, Gas** and **Telecommunication Facilities**
- Location and removal of **Seafloor Debris** and **Derelict Fishing Gear**
- Identification and protection of **Submerged Archaeological Sites**
- Managing offshore **Sand** and **Aggregate Mining**
- Maintaining **Shipping Channels** and **Harbor Entrances**
- Surveillance for submerged threats to **Homeland Security**

**Solution:** The California State Coastal Conservancy (SCC), Ocean Protection Council (OPC), Department of Fish and Game (DFG), and the NOAA National Marine Sanctuary Program (NSP) have launched the first phase of a comprehensive state waters mapping program for California. The ultimate goal is the creation of a high-resolution 1:24,000 scale geologic and habitat base map series covering all of California's 14,500 km<sup>2</sup> state waters out to the 3 mile limit. This statewide project requires, involves and leverages expertise from industry, resource management agencies and academia. The first phase of the program is the North Central Coast Mapping Project. This phase has served as the proof-of-concept model demonstrating the viability, efficiency and value of this approach in support of the state's Marine Life Protection Act Initiative (MLPA) goal to create a statewide network of Marine Protected Areas (MPAs). The tiered mapping campaign involves the use of state-of-the-art sonar, LIDAR (aerial laser) and

video seafloor mapping technologies; computer aided classification and visualization; expert geologic and habitat interpretations codified into strip maps spanning California's land/sea boundary; and the creation of an online, publicly accessible data repository for the dissemination of all mapping products. Because the project involves and trains many university students, it is helping to meet the rapidly growing demand for professionals in the public and private sectors skilled in the applications of these geospatial technologies.

Here we describe the steps leading up to the launch of California's historic state waters mapping campaign, the approach and technologies being employed, progress and products to date, lessons learned, applications of the results, and plans for completing the statewide enterprise.

### ***Laying the foundation – Strategic Planning Workshop***

The SCC funded a Statewide Marine Mapping Planning Workshop held at CSU Monterey Bay, December 12-13, 2005 (<http://seafloor.csUMB.edu/StrategicMappingWorkshop.htm>). The purpose of the workshop was to create a strategic plan for completing the mapping of all seafloor habitats within California State Waters (shoreline out to 3 nm). The approach was to involve key stakeholders in a gap analysis of existing data coverage, identification and ranking of current mapping information needs, the prioritization of areas for new field data acquisition, and the definition of minimum survey and analysis specification required to support these needs.

The sponsors also requested a separate ranking of mapping priorities within the proposed pilot project area that was subsequently funded as the North Central Coast Mapping Project (NCCMP) (Fig. 1). The two-day workshop attracted 56 invited participants representing 38 institutions including regional, state and federal resource management agencies, universities, research institutions, NGO's and private industry. A surprising degree of overlap was discovered among the participants regarding their need for mapping data products including:

- MPA mapping in support of the MLPA process
- Environmental monitoring and change detection
- Sediment transport dynamics (erosion, deposition and beach nourishment)
- Geologic hazards (faults and landslides capable of producing tsunamis)
- Habitat maps for fisheries management, stock assessment and identification of biological hot spots
- Safe navigation in shallows, bays, harbors and estuaries
- Economical sources of sand
- Data to support wave, current, sediment transport and oil spill prediction models
- Location of shipwrecks with potential for oil leaks
- Location of derelict fishing gear
- Tsunami run-up modelling

Identification and ranking by the participants of areas for future mapping within state waters was conducted through a voting process making use of the existing 10' CDFG commercial fishing block designations (Fig. 1). Recommendations for data acquisition and final products were obtained during group and breakout sessions regarding critical elements key to the success of a statewide mapping effort. These elements included: data acquisition, level of interpretation, metadata, and dissemination. There was consensus that the minimum universal seafloor mapping

information should cover all “lands” from the shore strand line (MHHW) out to the 3 nm state water limit and include:

- Seabed geomorphology (relief via xyz digital elevation models - DEM)
- Texture (substrate type via backscatter mosaics).
- Ground truthing (via video or physical samples)
- Subsurface structure, sediment thickness and stratigraphy via subbottom profiles & coring
- Meet or exceed International Hydrographic Organization (IHO) Order 1 standards, and be carried out at the maximum resolution obtainable using state-of-the-industry tools.
- Best available geodetic positioning technology (vertical and horizontal)

All present acknowledged the ultimate need for and great value in full geologic and habitat interpretation of collected mapping data. The recommended approach was to consider map product generation as a 3 tiered process, with each tier being constructed from the previous. The first tier consists of the basic survey data (xyz grids [bathymetry] and backscatter [substrate] mosaics). These first tier data sets can be efficiently converted into second tier products in GIS at little additional cost using automated numerical derivatives including autoclassification of substrates and surface models based on parameters (slope, aspect, rugosity, contours, relief, etc.). Second tier products are GIS-ready and are often of high value to management agencies because many of the patterns they are interested in (e.g. rocky versus soft bottom habitats, bed forms, and depth zones) are easily discernable at this intermediate level of data analysis. The third product tier (fully interpreted, classified and attributed geologic and habitat maps), enables consideration of a variety of different types of data of varying scales and so represents considerable “value added” when there are several different data sets to be considered.

Finally, all acknowledged the critical importance of having all data meet FGDC metadata standards. For archiving and dissemination, the recommendation was for a tiered system of accessible databases (ftp with links, http download sites, website images of data that link to data sources, internet GIS map servers).

Central Coast RFP Priority Blocks  
2005

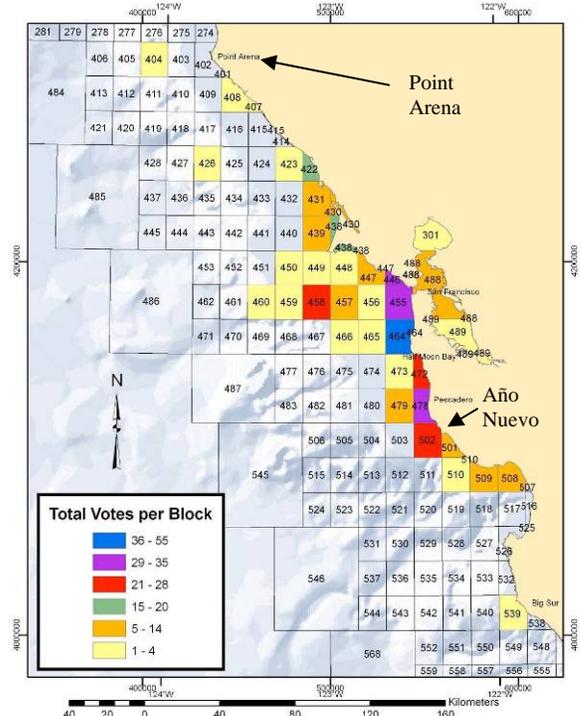


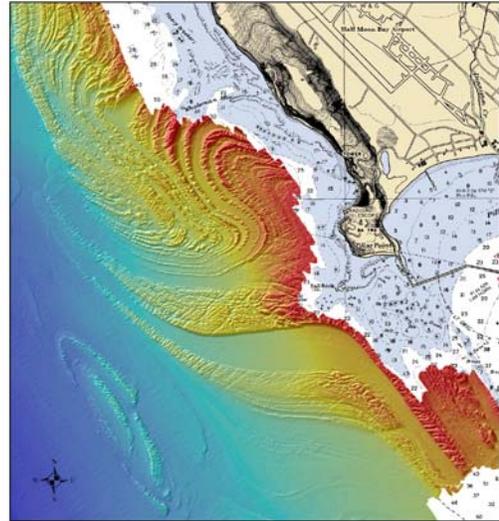
Figure 1. Spatial distribution of number of votes cast per block for the NCCMP priority mapping needs during the 2005 Statewide Marine Mapping Planning Workshop

## **Initiating Phase I Pilot Project - North Central Coast Mapping Project**

The first phase of the anticipated statewide mapping program commenced in November 2006 with support from the OPC, SCC, DFG and NMS. The NCCMP mission is to map the state waters between Ano Nuevo and Point Arena (Fig. 1). The team conducting this work is a uniquely qualified partnership between academia, industry and resource management. Members include the Seafloor Mapping Lab at California State University Monterey Bay, US Geological Survey National Seafloor Mapping and Benthic Habitat Studies Group, Fugro Pelagos Inc. and the Center for Habitat Studies at Moss Landing Marine Labs.

Acquisition of mapping data involves bathymetric LIDAR and multibeam echo sounders (MBES) to obtain bathymetry data, acoustic backscatter and reflectance imagery, as well as acoustic sub-bottom profiling data. The surveys and the information created will comply with the recommended requirements for statewide seafloor mapping as specified in the Workshop Report, including:

- Seabed geomorphology (relief via xyz digital elevation models - DEM)
- Texture (substrate type via acoustic backscatter and reflectance mosaics)
- Ground-truthing (via video or physical samples)
- Surveys designed to meet or exceed IHO Order 1 standards, and to be carried out at the maximum resolution obtainable using state-of-the-industry tools
- Best available geodetic positioning technology (vertical and horizontal)



**Figure 2.** Mavericks, Half Moon Bay, California. Preliminary Tier 2 results from NCCMP. High-resolution multibeam sonar map showing spectacularly faulted and deformed seafloor geology, in shaded relief and colored by depth, overlain on the NOAA 18682 nautical chart (depth soundings in feet). This level of detail is needed, but not available for 66% of California state waters. (Source: California OPC North Central Coast Mapping Project).

The Tier 1 and Tier 2 products specified as requirements in the RFP include the following ESRI compatible Data layers with FGDC compliant metadata files:

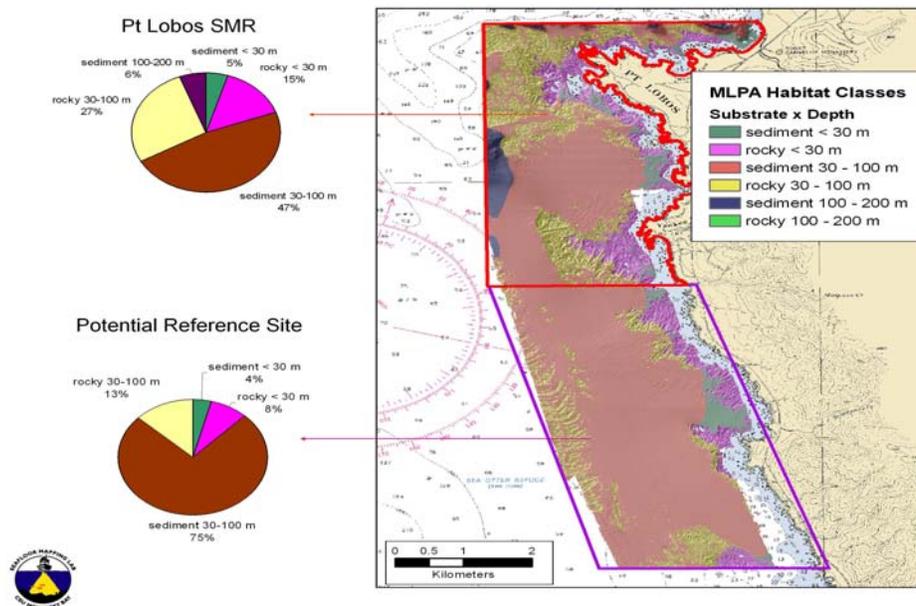
- Sediment sample point features with grain size attributes
- Video observation point features with geologic and biologic attributes
- Geologic structure with motion attributes
- bathymetric ESRI grid and ASCII xyz file
- bathymetry in shaded relief as georeferenced tiff image (colored by depth and in grey scale)
- backscatter intensity as georeferenced tiff image
- bathymetric contour feature layer at 5 meter intervals
- A seafloor texture grid derived from unsupervised clustering of derivatives of the bathymetry and backscatter intensity

- A surficial geologic ESRI grid produced using video-supervised classification of derivatives of the bathymetric and backscatter data

Two Tier 3 interpretation example products are also being created: 1) an updated 1:100,000 Essential Fish Habitat (EFH) interpretation map, and 2) a 1:24,000 quad map set composed of:

- Color coded bathymetry draped over shaded relief bathymetry overlain with bathymetric contours
- Backscatter intensity draped over shaded relief bathymetry
- Color coded seafloor texture draped over shaded relief bathymetry
- Color coded Geologic units draped over shaded relief bathymetry overlain with structure
- Color coded benthic habitat draped over shaded relief bathymetry

Habitat Abundance: Pt Lobos SMR vs Potential Reference Site



**Figure 3.** Auto-classified habitat map of the Point Lobos State Marine Reserve created from high-resolution, hyper-clean multibeam sonar data to aid in MPA monitoring program design for the MLPA initiative.

### ***Hydrographic charting versus habitat mapping***

Data collection and processing for habitat mapping must be held to the highest standards of precision and accuracy across a wide depth range. At times, this may exceed the standards set for hydrographic charting. The difference is because the current status for auto-classification or even the visual interpretation of seafloor habitat types (e.g. Fig. 3) is such that hyper-clean data is required for the processes to be accurate. Even small artifacts or erroneous data points projecting no more than 10-20 cm above or below what is actually a smooth seafloor will appear and be classified as rough and therefore rocky habitat. Future improvements in data collection standards and techniques coupled with future improvements in the auto-classification tools will both be required to yield the highest accuracy possible.

## Washington State Sea Floor Mapping Workshop

### Seafloor Mapping of the Oregon Continental Margin: Progress, Activities and Opportunities

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Mapping activities along the Oregon continental margin in recent years have largely built on the original EEZ mapping which was released for Oregon in the early 1990's. Recent surveys have included several EM 300 surveys in slope areas off central Oregon, Astoria Canyon, and the major submarine shelf banks surveyed by OSU, NOAA, and MBARI and which are now ~ 80% complete at a resolution of ~ 10 m or better. However ~ 75% of the area of the shelf and upper slope shallower than the ~ 700 m upper limit of the EEZ multibeam surveys remains unmapped. In the Oregon Territorial Sea, only about 5% has been mapped, all by ODFW with a rocky reef focus. A compilation habitat maps, evolved from the 2005 EFH/EIS mapping with NOAA support, is in continuing development, and incorporates these recent and historical surveys.

A recent initiative of academic and agency partners is currently proposing complete mapping of the Oregon Territorial Sea. This concept is gaining momentum in the State Legislature for 2009 and is finding support among coastal communities for habitat science, marine reserves, tsunami inundation mapping, and wave energy.

([http://activetectonics.coas.oregonstate.edu/index\\_files/Consensus\\_Statement\\_Final.pdf](http://activetectonics.coas.oregonstate.edu/index_files/Consensus_Statement_Final.pdf)).

A spinoff of this effort has been the formation of an Oregon Marine Mapping Group (OMMG). The State of Oregon is participating in the Governors Tri-State Agreement that promotes a wide variety of Ocean policy issues. The State is currently putting into motion a plan to establish marine reserves within the Territorial Sea, with nomination for reserve sites slated to begin this spring. A coalition of Oregon State University, the Oregon Department of Land Conservation and Development, NOAA NWFSC (Portland and Seattle offices), and the Oregon Department of Fish and Wildlife are constructing new habitat maps and a GIS of related marine and economic data for use in the nomination and selection process. The new habitat maps are interim products created in advance of full multibeam coverage. These maps are quite detailed and have been developed using a previously untapped source of bottom sample data. The GIS compilation will be used in conjunction with the PaCOOS Habitat Server (<http://nwioos.coas.oregonstate.edu/>) acting as a decision support tool during the Marine Reserves evaluation process (see Clarke et al, this session).

Upcoming mapping activities currently include three cruises in 2008 focused on mapping within the Territorial Sea. One will take advantage of MacArthur II shiptime granted to the South Slough Estuarine Reserve. A second will involve collaboration with OSU and USGS, and a potential third will be done by ODFW as part of their continuing high-resolution mapping efforts. An Oregon Marine Mapping Workshop is being organized for early March, 2008.

### **c. Data Distribution**

#### **Interactive Habitat Database for Pacific Coast Ocean Observing System (PACOOS)**

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Recognizing the need to develop an ocean observing system covering the entire California Current Ecosystem (CCE), NOAA and its partners are establishing PaCOOS as a west coast observing ecosystem “backbone” for the U.S. Integrated Ocean Observing System (IOOS). PaCOOS’ long-term objective is to develop and maintain an integrated distributed data access, transport, and analysis system serving data and products and meeting research and management needs for multiple users in the CCE. Building on databases assembled for the development of an Essential Fish Habitat Environmental Impact Statement for west coast groundfish, we have developed a data portal that links several remote servers and delivers a variety of habitat relevant data including benthic, biological and oceanographic data, and allows multilayer query and reporting and query comparisons (<http://pacoos.coas.oregonstate.edu/>). The data portal provides for data-discovery, direct client access to data, custom/interactive view environments, as well as developing integrated decision support tools for Ecosystem Based Management. Our long-term goal is to bring the 2-D geospatial world and the 4-D oceanographic world closer to seamless exploration by examining interoperability between these two inherently different data structures.

## Washington Coastal Atlas

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The Washington Coastal Atlas

[http://www.ecy.wa.gov/programs/sea/sma/atlas\\_home.html](http://www.ecy.wa.gov/programs/sea/sma/atlas_home.html) provides geographically linked information to support coastal zone management and has been significantly improved in the past year. It now includes information on:

- habitat features such as wetlands and eelgrass,
- physical features such as drift cells and slope stability,
- regulated features such as rivers and streams regulated by the Shoreline Management Act,
- shoreline modifications such as piers and docks, and
- jurisdictional delineations such as cities and watersheds.

The Washington Coastal Atlas also offers:

- downloadable current and historic oblique aerial photography of Washington shorelines;
- land cover information for 1991, 1996, and 2001; and
- reports showing the amount of change in forest canopy cover and impervious surface cover between these years at a county, watershed and subbasin scale.

The Washington Coastal Atlas is easily used by local government planners and resource managers. Other groups using the coastal atlas include Tribal governments, state and federal land and resource managers, researchers, consultants, and interested citizens. The improved Washington Coastal Atlas is the result of a cooperative effort between Washington Department of Ecology, Puget Sound Action Team (now Puget Sound Partnership), and Washington Department of Natural Resources. Current work is directed towards forming an interagency group to collaborate on future development of the Washington Coastal Atlas and to determine additional data layers that would be appropriate to add to the Atlas.

Coastal Atlases have been used successfully, within the United States and in other countries, to improve data accessibility for environmental and resource management (O’Dea and others 2007) and efforts are currently underway to find ways to achieve interoperability among Coastal Atlases (Wright and others 2007). Plans for the future of the Washington Coastal Atlas include adding information on public access to the marine shorelines of Washington (White and others 2007). In addition, the Department of Ecology has submitted a proposal for a project which, if funded, would allow further development of the Washington Coastal Atlas to display information on Puget Sound shoreline erosion (Shipman and Taylor 2007). The Washington Coastal Atlas is an important tool providing information valuable for Coastal Zone Management and should be considered as an option for making sea floor mapping data available.

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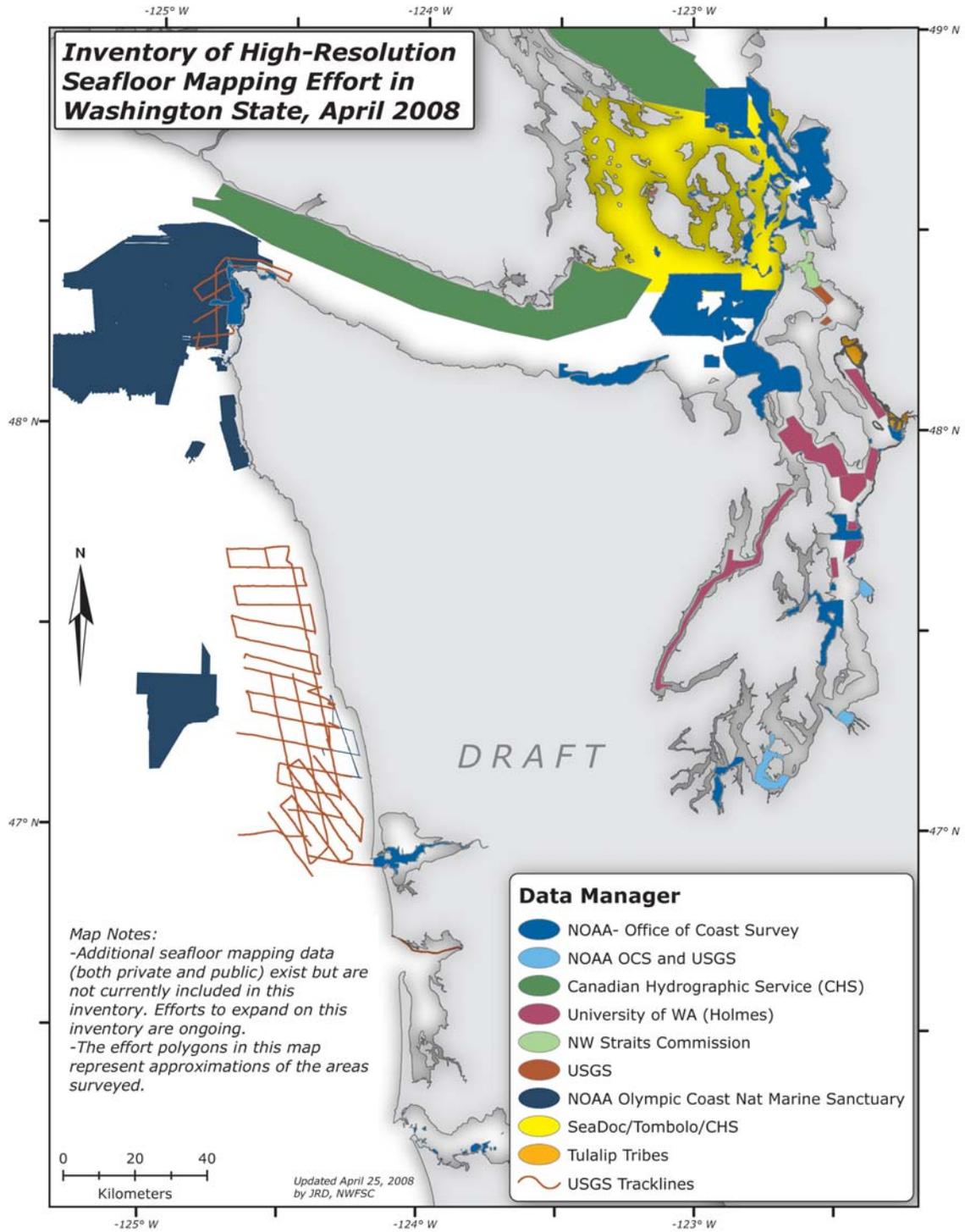
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## VII. Inventory of mapping effort



## VIII. Conclusion

The workshop was well attended and contributions by the participants were excellent. Most all participants, if not all, indicated an interest in staying involved in future efforts to organize and implement seafloor mapping in Washington and felt that such an effort was timely. As pointed out in the break out sessions it is apparent that in the long term *“It is more expensive not to do the mapping than to do the mapping.”* However, it was concluded that many things must be accomplished before a comprehensive mapping effort for the State of Washington could be initiated, even though the workshop was a good start. In conclusion the workshop participants suggested the following major actions be undertaken:

- Develop a strategic and business plan for mapping Washington’s State waters.
- Identify data gaps.
- Complete inventory of available data useful in mapping state waters including type, quality and location (holder) of data.
- Establish standards for mapping and product development.
- Select a habitat classification scheme to be uniformly used in any state mapping effort.
- Investigate potential partners for both the contribution of expertise and financial support for the State’s mapping effort.
- Develop products that can be used to inform and solicit cooperation and funding.
- Establish partners.
- Form a consortium of mapping scientists, managers and policy makers representing state and federal government agencies, non-government organizations, fishers, tribes and other interested contributors that can address and implement the above action items

## IX. Posters

In addition to the oral presentations many participants responded to an invitation to display posters of their work. Those posters and the presenting author are listed below:

Presenter	Title
Ed Bowlby	Seafloor Habitat Mapping Effort in the Olympic Coast National Marine Sanctuary
Chris Chamberlin	Development of high-resolution coastal digital elevation models for the US: seamlessly integrating bathymetric and topographic data to support tsunami forecasting and modeling efforts
Peter Dartnell	Geologic and Geomorphic Interpretations from NOAA Multibeam Bathymetry Data, Admiralty Inlet WA (6 sheets)
Mercedes Erdey	ArcGIS Mapping Tools: A Seafloor Characterization Toolbox for Benthic Habitat Investigations
James L. Galloway	Coastal BC High Resolution Multibeam Bathymetry
Gary Greene	Potential Marine Benthic Habitat Types of the Inland Seas of the San Juan Archipelago – A joint US/Canadian Sea Floor Mapping Effort (10 sheets)
Gary Greene	Habitat Maps of the Central California Coast – Examples from the California North Central Coast State Waters Mapping Project (6 sheets)
Sam Johnson	Folio Maps of the Californian Coast – Examples of Map Products Being Developed from the California North Central Coast State Waters Mapping Project (25 sheets)
Jeff June	Application of Sidescan Sonar for Delineation of Eelgrass Distribution and Derelict Crab Pots in Similk Bay, Washington
Rikk Kvitek	California North Central Coast State Waters Mapping Project
Lisa Lacko	Benthic Terrain Model Methodology, A GIS Tool

Pat McCrory	Combining multibeam, sidescan sonar & seismic reflection profiles to map Quaternary structures: An example from the NW Washington shelf
Kim Picard	Marine Habitat Mapping in the Transboundary Region (US\Canada)
Dirk Rosen	Remote operated vehicles
Bert Rubish	New High-Resolution Images of Bellingham Bay, North Puget Sound
Suzanne Shull	Mapping the Distribution of Submerged Aquatic Vegetation and Saltmarsh in the Padilla Bay, WA
Taylor, L.A.	Development of high-resolution coastal digital elevation models for the U.S.: seamlessly integrating bathymetric and topographic data to support tsunami forecasting and modeling efforts

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