Oregon State Waters Multibeam Mapping Project: A Progress Report

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1.0: Project Overview

For Oregon, as for most coastal states, the sea represents both a valuable resource and a potential threat. The sea provides many Oregonians with a livelihood, food, and recreation, and it attracts visitors to our coastal communities. The sea also represents a significant threat in the form of an inevitable earthquake-generated tsunami, akin to the recent one in Indonesia. Understanding the nature of Oregon’s Territorial Sea is critical to sustaining sport and commercial fisheries, coastal tourism, wave power, and a broad range of other ocean derived ecosystem services valued by Oregonians, in addition to addressing the threat posed by a major tsunami. Presently, we have detailed bottom mapping of only about 5% of the area of the Oregon Territorial Sea, which extends 3 nautical miles from the coast and comprises approximately 950 square nautical miles. Effective decisions concerning the management and conservation of ocean resources in accordance with Department of State Lands Strategic and Asset Management Plans depend upon better knowledge of nearshore waters. To address this problem the Oregon Department of State Lands proposes to initiate a seafloor mapping program within Oregon’s Territorial Sea. This in part comes from recognition by the State, and by other States, that no Federal entity is charged with or has intentions to map State waters in the United States.

Given the renewed and diverse interests in activities within Oregon’s Territorial Sea (outlined above) the Multibeam Mapping Project advances the agencies mission and responsibility to manage state owned lands, offshore lands and coastal estuarine tidelands, as well as submerged and submersible lands of the navigable waterways within the state. A comprehensive mapping of these state lands provides the fundamental unit (map) from which all aspects of management are developed. Goals 1 and 2 of the 2006-2010 Strategic Plan are directly supported through this program by providing a product that enables waters of the state to be spatially managed for the greatest benefits in conservation, restoration, and protection. More generally, this program supports the Asset Management Plan (AMP) by enabling a valuation of core real estate assets in the territorial sea. This valuation of Territorial Sea assets can be used with the policy direction and management principles set forth in the AMP to guide both short and long-term management of Common School Fund lands for greatest benefit. Overall, this project begins a transition toward informed science-based or information-based management of the nearshore environment.

The State of Oregon has jurisdiction and management responsibilities for the seafloor out to 3 miles from the nearest point of land. To date however, no map of the Territorial Seafloor has been made. High resolution mapping of the Oregon Territorial Seafloor is designed to address multiple issues. Numerous activities in the nearshore waters of Oregon, existing and proposed, impact the nearshore environment, and fall within the management authority of the Department of State Lands. At our present level of knowledge, we do not have the capacity to assess projects such as marine reserves, wave energy and other future activities without basic information on the depth, seafloor geology and biology.
Seafloor mapping provides the information needed. For wave energy, surface and subsurface information is needed to properly site anchors, to model currents, and to assess the local environmental impacts within a geobiological context for proposed sites. For marine reserves or any conservation activity, seafloor mapping provides the basis for mapping of biological habitats, their diversity, and their distribution along the Oregon coast. This basic information presently does not exist, and is an integral part of the proposed project. With respect to Geohazards, seafloor mapping addresses both the tsunami hazard issue and coastal erosion by providing accurate modern bathymetry that is used directly to model tsunami and storm waves and predict their impacts. Presently, without such data, this type of modeling is not possible to the accuracy needed for the future.

The mapping program underway and discussed in this report is the outgrowth of a Seafloor Mapping Task Force formed at Oregon State University in 2006. This group met on numerous occasions through 2007 and 2008 to discuss the needs for nearshore mapping with state legislators, biologists, geologists and members of coastal communities to develop the proposal. Presentations were made to the Joint Committee on Emergency Preparedness and Ocean Policy on four occasions, and to the State Land Board. Further discussions were held with the Department of Land Conservation and Development, DOGAMI, ODFW and others about the needs and application to the missions of these agencies. Discussion and questions about tsunami modeling, wave energy siting, and marine reserves and the needs for basic seafloor data were addressed at these meetings. Subsequently, this topic was discussed extensively at OPAC meetings, meetings of the Marine Reserves Working Group (MRWG), and the Science and Technology Advisory Committee (STAC), charged with advising the OPAC on Marine Reserves and other ocean management issues. There has been unanimous support for the seafloor mapping project, with no negative opinions or impacts. Members of the public and in particular the fishing communities were present at many of these meetings, and expressed the strong sentiment that little could be achieved in management of the coastal ocean without the basic seafloor data that are now being collected under this project.

**Implementation**

One of the goals of this project is to begin a transition to science based management of the nearshore environment to provide sustainable fisheries. The work requires considerable at sea time on nearshore vessels, and thus one of the first elements of the plan calls for use of under utilized crews and fishing vessels along the Oregon coast as the mapping platforms for this project. Fishing closures have impacted coastal communities, therefore use of impacted crews and fishing vessels is a way to complete the project cost-effectively while providing some relief these communities. A locally based plan also gives the opportunity for scientists and fishers to work together to develop a better seafloor map based on the experiential knowledge with in the fleet. This plan offers a long term opportunity for such collaboration. The second element of the plan as outlined by the Task Force is to utilize the scientific capacity within the State University system to complete the project. Oregon State University has a well
established expert group of marine scientists with ~ 100 years of collective seafloor mapping experience ranging from small skiff based estuarine surveys to global class research vessels in the deep ocean and the arctic. A University based team using a professional team leader and student participation can accomplish the project in a cost effective manner. The plan includes establishing a training program in seafloor mapping, and training students in the acquisition, processing, and interpretation of marine multibeam data. This strengthens Oregon’s Universities as leaders in marine sciences, as well as training new professionals in the field and completing the project cost effectively. An additional benefit is the development of the science linked to seafloor mapping is that the science applications are integral with the mapping itself, forming strong links and a short path between the data and the directly related science.

1.1: Project Structure

In parallel with the decision to support this project by the Oregon Legislature, the NOAA Office of Coast Survey (OCS) was has awarded ~ $30M through the ARRA stimulus package. This expenditure was intended to help OCS with their mission of nautical charting, which had developed into a 12 year backlog over time. Given the short timeframe of the ARRA funds, OCS sought regions that both fell within their overall mission of nautical charting, and had “shovel ready” plans and priorities set that could be addressed without an extensive planning effort. Both Oregon and California met these criteria. California had a State Waters mapping effort already underway. Oregon had previously held a planning workshop, had a “grass roots” effort underway, and the Legislature was poised to support a mapping plan internally, demonstrating the perceived need for this work. As a result, OCS leadership decided to support ~ 5M in funding for mapping State Waters in Oregon. Oregon is one of 34 coastal states and territories, and thus the decision to support mapping work here was significant for the State. The NOAA decision to work in Oregon came partly because we were one state of several that had a well developed plan in place, defined through recent workshops, and also because the state has a long term commitment to seafloor mapping and nearshore management.

The Oregon funds from the New Carissa (1.3M) settlement play a key role in mapping the Oregon Territorial Sea and for ocean sciences in the Oregon nearshore. The State funds initially leveraged the NOAA ARRA supported work, increased the total coverage possible to a more meaningful level, and ensured that high priority areas will be completed.

As the funding plans developed, the OSU group and hydrographic contractor David Evans and Associates (DEA) developed a collaborative plan to merge the State and NOAA supported projects to take advantage of reduced costs of mobilization, the respective expertise of the two groups, and a shared interest in supporting the goal of supporting Oregonians and fishing vessels though this work. The NOAA supported work, awarded to DEA in July of 2009, is in support of the OCS nautical charting mission, but does not extend to developing habitat maps or other products derived from multibeam bathymetric and sidescan data. OSU has long experience in this area. The
DEA/OSU operational plan is to have DEA primarily focused on acquisition of the data and processing of these data for NOAA to nautical charting standards. Priority areas (discussed below) awarded to DEA by NOAA are being mapped in a joint effort initially led by DEA, with shared mobilization of the vessel and purchase and construction of some needed hardware (mounting hardware, high precision GPS navigation systems etc.). During this period, OSU graduate students and technicians have jointed with DEA hydrographers to fill out the crew roster. The students are trainees in the art of multibeam mapping and data processing, and gained extensive sea time in 2009. Following completion of the NOAA supported areas, OSU will continue acquisition of additional State waters priorities, and then conduct the ground truthing efforts (underwater vehicle surveys, bottom sampling etc.) and development of habitat maps. In addition to the NOAA/DEA/OSU efforts, NOAA OCS also awarded ~ 1.7 M to Fugro International, the hydrographic contractor conducting the California surveys. These funds are directed to complete State Waters mapping of southern most Oregon from the California Border to Crook Point.

**Selection of Priority Areas**

In March 2008, the general themes relevant to the State of Oregon were identified at a two day Seafloor Mapping Workshop held at OSU. This workshop report as well as abstracts and powerpoint presentations are available online at: [http://geohab.coas.oregonstate.edu/index.php?option=com_content&view=section&id=3&Itemid=13](http://geohab.coas.oregonstate.edu/index.php?option=com_content&view=section&id=3&Itemid=13). The themes include but are not limited to, habitat and ecosystem science, wave energy, tsunami modeling and mitigation, coastal erosion and sea level rise, safety of navigation, and sediment management. Similar themes have been identified as those of regional importance by the Action Teams of the West Coast Governors Agreement on Ocean Health (WCGA). [http://westcoastoceans.gov/](http://westcoastoceans.gov/). In April 2009, a second brief workshop was held to implement priorities into a specific plan tied to funds supplied to the NOAA Office of Coast Survey (OCS) under the [American Recovery and Reinvestment Act of 2009](http://www.recovery.gov/), and by the Oregon Department of State Lands. To that end, each State Agency participant supplied maps or text describing priorities, rationale, and rankings of multiple choices where appropriate. We have tried to reconcile these, taking advantage of overlaps, abutting areas, and cumulative priority from the received input. We included a qualitative assessment of the efficacy of high resolution seafloor mapping to address each of the relevant issues in addition to the rankings of priority supplied by the agencies. In other words, how much does high resolution bathymetric and backscatter data help resolve each issue? This completely subjective assessment used the following, ranking efficacy or efficiency on a score of 1-10, with 10 being perfect efficiency:

- Safety of navigation = 10
- Habitat science = 6-8 (more data are required)
- Wave Energy = 3 (more data are required)
- Tsunami modeling and mitigation = 3-5 (depending on vulnerability and local conditions)
- Coastal Erosion = 2-5 (depending on vulnerability and local conditions)
Sediment management = 2 (for a single survey, 7-9 for repeat surveys over time)
Sea level rise = 2 (for a single offshore survey, 8-10 for bays and estuaries coupled with LIDAR).

We assumed that the funding level would be ~ 5.3 M (The actual total funding levels is now 7M) and that the hydrographic contractor day rate would be $15,000 per square nautical mile, a typical average value. These rough assumptions allow for mapping of ~ 30% of State waters under this package. The actual coverage could be higher or lower with weather, fuel prices and other factors involved.

Remaining within an estimated 30% coverage, this proposed plan includes:
1) All marine reserve sites moved forward by OPAC (All agencies, OSU and TNC)
2) The highest priority sites for tsunami and coastal erosion (DOGAMI)
3) All Very high and High priorities from ODFW
4) Highest priority sites from DSL (Marine Reserves, two wave sites and Cape Arago area)
5) Several ODFW second priority areas where contiguous with the above
6) High Priority from DLCD (two wave sites marine reserves, and other rocky reefs).

In general, there was good convergence of priorities focused on the marine reserve sites, other rocky reefs, and the two wave energy sites farthest along in their process, along with the highest priority for tsunami and erosion.

**Final Mapping plan and Coverage**

The final work plan is shown in **Figure 1**, including mapping areas tasked to Fugro, DEA/OSU, and to OSU. The overall work plan is designed to complete all areas shown in Figure 1 within the project period, ending with FY 2011. The total area covered is ~ 44% of the Oregon Territorial Sea.

**Operational Plan**
The final work plan integrates the Department of State Lands (New Carissa) funds with NOAA funds to form a single project with effectively $6.3M in State-Federal support. NOAA has awarded two contracts to hydrographic contractors to perform the NOAA side of the project. David Evans and Associates of Portland has been awarded a contract to map the State Priority Areas from Cape Perpetua northward. A second contract has gone to Fugro Inc. to map State waters from the California border to Crook Point along the southern coast. The effectively has added ~ $1.7M to the overall State Waters Mapping project, and now covers all of the highest priority areas. Total funding for all phases of this project stands at ~ $7M.

OSU has explored various models for efficiently conducting this project, and found that a
Figure 1. State waters mapping priorities, 2009. Areas are ranked according to priority with numbers from 1-10. The areas tasked to DEA/OSU are those north of Yachats. These are mostly completed as of late 2009. Areas tasked to Fugro include the white polygon from the California border to Crook Point (Original state priority polygons are overlain). The areas from Crook Point to Coos Bay are the OSU priorities for State Waters for 2010, and include Cape Arago, Orford/Blanco Reef, and Rogue Reef (N to S). The NSF supported OOI sites mapped in 2009 are shown off Newport as white polygons.
model closely integrated with David Evans and Associates is by far the most cost effective. This plan integrates student training, use of fishing vessels, and efficient use of sonar equipment and sampling gear to achieve maximum coverage of State Waters. The following sections outline the work plan in detail coordinated with David Evans and Associates (DEA).

**Mapping/Science Team**

OSU is supporting four full time MS students for the project over two years. Each will also be engaged in an MS program related to Hydrography and or habitat mapping, and all four will focus on Marine Reserves. Students act as watchstanders/surveyors for field operations, with two students onboard each leg (more were onboard the initial legs for training during July-August, 2009), and will process the data to be used at later stage for their thesis projects. Students augmented the crew on NOAA contracted legs, and have made up the majority of staffing non-NOAA legs. Students will participate in ~ 2 weeks of training at DEA in Vancouver, and work with DEA as practicable. Student workstations with CARIS, Fledermaus, Arc 9.3 and Geocoder have been set up at OSU, drawing on the well developed high-speed IT infrastructure that exists within the College of Oceanic and Atmospheric Sciences.

DEA staffed the mapping vessel with an Electronics Engineer and 2-3 Hydrographers for all legs during 2009. The two students (one per watch) will complete the 6 person (3 per watch) OSU/NOAA survey team. OSU is supporting one full time senior research assistant (Chris Romsos) who is supervising the students, participating in MOB/DEMOB, and seagoing operations. Chris is managing data handling, backups, and the processing scheme at OSU. The OSU science team is be managed by Chris Goldfinger who will oversee students, technicians and the overall project, and participate in seagoing legs as needed. The DEA team is managed by Jon Dasler.

**1.2: Project Startup**

The project officially began on July 1, 2009. Given the relatively short timeline to completion by the end of FY 2011, the OSU/DEA group worked to rapidly mobilize the mapping vessel, acquire needed equipment, increase staffing levels, and bring on the new students and OSU and additional staff at DEA. Hardware required for sonar mounting was constructed quickly and the vessel deployed on its first mapping leg on 25 July, 2009.

**1.3: Mobilization**

*Mapping and Groundtruth Vessels*
Prior to the official project start, a search was conducted to locate a Mapping Vessel suitable for the intensive two-year mapping effort. The basic requirements for this vessel were as follows:

**Vessel Size:** 60-80’ or greater due to the needs outlined below, although there may be some limited need for a smaller vessel as well.

Science party: We'll need a vessel that can support a minimum of 6 scientists in addition to enough crew and a cook (3-4) to operate 24hrs/day for at least a week at a time without refueling or reprovisioning at 6-7 knots survey speed.

**Lab space:** A lab space, or something that can be quickly converted into a lab space is required for 3-4 people to operate the sonar gear and process data on a 24 hour basis. This would ideally be on the main deck, and be a minimum of 100 sq ft (10x10’ (any shape) of floor space to set up the sonar equipment and computers etc for long term operations. This space needs 110 v and 12 v power.

**Navigation:** The vessel needs good solid radars, modern WAAS or better GPS navigation and coupled autopilot and nav display capability such as Nobeltec nav software.

**Electrical:** Vessel must have two generator sets in good condition with as "clean" spike free power as possible. Total power draw will be under 2 kw, but the source needs to be a clean source.

**Documentation/Safety:** Vessel must have all relevant Coast Guard inspections/certifications and safety equipment required (and beyond) up to date and have insurance and licensing appropriate for the crew size. For the NOAA survey legs, NOAA requires subchapter T inspection and TWO licensed mate or higher people on board.

**Work season:** Vessel must commit to as much as 60 sea days between ~June 15 and ~September 30 2009. This may not be consecutive days.

To conduct efficient 24 hour mapping operations, the number of sleeping berths available proved to be the key factor. After publicizing our requirements to the fishing community, four bids were received. Unfortunately, many of the fishing vessels examined for this project had 4-5 berths total, when our requirement was for a total of 10 berths (4 vessel crew, 6 mapping team). We only found one vessel that could meet these requirements, and meet our budgetary limits. This vessel is the Pacific Storm, a former fishing vessel donated to and now operated by the Marine Mammal Institute at Oregon State University (Figure 2). This vessel had previously been modified by removing the trawling gear and fish holds, and constructing an enclosed lab space on the main deck, and accommodations for an additional 6 persons below.

Subsequently, a second search was conducted for a Ground Truth vessel. The requirements for this vessel were much simpler, requiring only the safety and documentation items as required for the Mapping Vessel, and the addition of a suitable winch system for bottom sampling. Many fleet fishing vessels were suitable for this task, and of the bids received, the work was awarded to Carleton Fisheries LLC, operators of the 65’ crabber Michele Ann.
**Outfitting the Vessels**

Outfitting the Pacific storm required several operations: 1) construction of an over the side pole installation for the sonar head; 2) Installation of the sonar processor, motion reference unit, and acquisition and processing computers in the lab area; 3) Installation of the Moving Vessel Profiler (MVP); and 4) installation and routing of cabling and antennas for multiple high-precision GPS units.

Yaquina Boat of Toledo Oregon was contracted to construct the sonar pole, the mounting system for the MVP, and antenna mountings for the GPS units. The sonar pole, 20’ in length and constructed of stainless steel was built and installed in the starboard side of the vessel amidships. The pole was jointly designed by OSU and DEA, with some structural analysis performed by DEA engineers regarding pole flexing under water loads at cruising speed. The pole is 8” in diameter, and pivots from the 01 deck, providing a 10 extension below the waterline, placing the sonar head approximately 10’ below the surface, and even with the keel of the vessel (Figure 3). The sonar head placement was kept as deep as practicable in order to reduce the effects of surface disturbance and hydrodynamic noise from the vessels hull, allowing operations in moderately heavy seas. The pole pivots aft, and is lifted to the stowed position by a davit arrangement constructed by Yaquina Boat. The sonar head mounts to the end of the pole, with cabling led up the inside of the pole, along with a safety line attached to the sonar head. The pole is latched to a permanently mounted plate on the side of the vessel near the waterline. This plate is provided with shear bolts in the event of the pole striking a large object underway.

The Brooke Ocean Technologies Moving Vessel Profiler (MVP) provides underway measurements of water velocity used in the calculation of the bathymetry. This function is normally provided by stopping the vessel, and lowering a CTD device to acquire a velocity profile of the water column. In inshore waters, this is generally needed every hour, and often less in areas of strong currents. The MVP performs this function underway at cruising speed by reeling out a sensor from a freewheeling drum, and stopping it a few meters above the seafloor. The data is fed directly into the processing computers, greatly improving efficiency of operations. Yaquina Boat constructed the mounting and routed power and data cables from the MVP into the lab space.

Yaquina Boat also constructed antenna mounts on the main mast for the Applanix PosMV 320 vessel attitude system, and the Starfire high-precision GPS system which were subsequently installed in the Yaquina Boat dock.

Computers were installed during July 10-23, and the vessel conducted sea-trials in Yaquina Bay with all systems operating on July 25 and 26, 2009. The vessel was provisioned on July 25 and 26, and departed for sea on the evening of July 26.

**2.0: Data collection and processing**
2.1: Overview

Bathymetric swath sonars measure the oblique slant range from the sonar head to the seafloor by using several beams oriented both vertically and obliquely. Typically these beams are 1° - 2° in both fore-aft and athwartship directions, and are much narrower than the 5-40° beams employed by single beam systems. Thus multibeam sonars are capable of resolving targets that are much smaller than those detected by single beam sonars. Because the beam footprint geometry is a function of the total water depth, water depth is the primary control on the ability of the sonar to resolve seabed targets (Hughes Clarke et al., 1998). Multibeam sonar systems are typically based on a Mills cross fan beam geometry generated by two transducer arrays mounted at right angles to each other (de Moustier, 1988). Each array produces a beam which is narrow in the direction of its short axis, and the intersection of the two results in a narrow beam pattern footprint defined by the narrow dimensions of the beams.

In practice, the arrays are made up of a number of identical transducer elements that are equally spaced. The beams are either generated by discrete transducer elements, or “formed” electronically by the elements. In the transmit array, these element are placed parallel to the ship’s keel and project a vertical fan beam, that is narrow in the along track direction and broad in the across track direction (Farr, 1980). The typical beamwidth for a transmit array is 1° to 3° in the along track direction and up to 150° in the across track direction. The receive array consists of a series of hydrophones mounted orthogonally to ship’s keel. The receive array receives beams that are in planes parallel to the ship’s keel. Typically, the receive beamwidths are 1° to 3° in the across track direction, and 20° in the along track direction. The large width of the receive beam in the along-track direction ensures that the receive array will be oriented properly to detected the return signal regardless is the ship’s motion.

Because of the finite beam width, the acoustic footprint from an oblique beam ensonifies an area of the seafloor whose size is a function of the beam angle, and the slant range distance along to the seafloor. In non stabilized systems, it is also a function of vessel roll and pitch to some degree. In order to calculate the range to the seafloor, the best possible estimate of the true travel time though the water is required. This best estimate of time arrival is determined by the beam angle relative to the vessel, and the bottom detect algorithm being employed by the system. The output for each acoustic ping, is a coordinate pair for each beam, which provides the depth and the horizontal distance from the ship along a line perpendicular to the ships heading, from which a swath bathymetric map can be generated.

Most conventional echo sounders determine the travel time of the acoustic pulse by detecting the position first arrival of the returned echo. From this, the two-way travel time, and depth are calculated. With a multibeam sonar, the angle of incidence for the beams oblique to the ship reduces the sharpness of the retuned echo, making the accurate determination of travel time difficult. The solution is to use phase detection, an
Figure 2. R/V Pacific Storm.

Figure 3. Aft deck of the Pacific Storm. Sonar pole and Reson 8101 sonar are shown above the rail in the stowed position at left. High school students taking a tour of the vessel and mapping operations were onboard during a port visit shown here.
The interferometric principle, to determine the range to the seafloor for these oblique beams. This is accomplished by generating two beams pointing in the same direction through beamforming, and measuring the phase difference between these beams over the duration of the return echo envelope. The point at which there is no phase difference is equivalent to the first arrival, and determines the two-way travel time for that beam (Yang and Taxt, 1997). The multibeam system can then perform both amplitude and phase detection on each beam and select the best detection method for each beam.

2.2: Reson Seabat 8101 Multibeam

The Reson Seabat 8101 (Figure 3) multibeam operates at 240 kHz, and generates 101 beams per ping, covering an angular sector of up to 150° (Malik and Mayer, 2007). The usable angular sector derived from internal quality flags generated by the sonar typically is limited 125° -130°. The quality of the beams may be influenced by vessel motion, surface noise, bottom hardness and roughness and other factors. The maximum ping rate for the 8101 system is 30 pings per second. The beam widths in both the fore-aft direction and the port-starboard direction are 1.5°, and are of equal angular size regardless of whether they are nadir or outer beams. This is because the design of the Seabat 8101 utilizes a curved array, and unlike a flat array, does not require the use of beam steering to generate the non-nadir beams, except in the outermost beams. The curved array allows the system to generate beams that are orthogonal to the transducer face at all orientations. The 8101 is capable of both amplitude and phase detection methods for depth to the seafloor determinations. Typically, for the inner beams, the amplitude detection method is used, while the outer beams utilize phase detection to determine travel time and slant range distance. The 8101 is an unstabilized system, that is, beam steering to keep the fan array directed downward in all vessel attitudes is not performed, as is true of most shallow water systems. In practice this means that vessel rolling can adversely affect swath width, and make the vessel somewhat more sensitive to sea conditions than with a stabilized system. This is a common tradeoff for shallow water systems as compared to large vessel stabilized systems.

2.3: Moving Vessel Profiler, Navigation and Vessel Motion Sensors

The watercolumn sound speed profile was regularly monitored with a Brooke-Ocean-Technology, Moving-Vessel Profiler (http://www.brooke-ocean.com/mvp_main.html). Sound casts could be taken at any time without stopping the survey or slowing the vessel. This system reliably provided soundspeed data when required, and was typically deployed every 15-30 minutes during survey operations, with somewhat longer intervals used in deeper water. This high frequency of sound speed profiling is highly beneficial to the ultimate quality of this nearshore survey, and in itself provides a secondary dataset of water velocity in the survey areas. The MVP was backed up by a Seabird SBE 19 CTD used when the MVP was down for maintenance. Continuous ‘real-time” sound speed measurements were made with a sound-speed probe at the Reson 8101 transducer head, a
particularly important place to measure sound speed due to the physics of forming multiple sonar beams.

Vessel motion was measured by an Applanix POS/MV 320 inertial measurement unit during all surveys. This system uses multiple GPS antenna arrayed on the vessel and an inertial system to produce Inertially-Aided Real-Time Kinematic (IARTK) attitude and position data utilizing \textit{L1 and L2 carrier phase measurements}. The system is used for ships position, heading, and to determine roll, pitch, yaw attitude as well as heave. Additional positioning information is being collected with a NavCom StarFire SF 3050 GPS system. This system is a commercial satellite based differential system known as GSBAS (Global Satellite Based Augmentation System). Access to the system is though a subscription service. This system provides positioning accuracy of \(\sim 10\) cm horizontal, and \(15\) cm vertical worldwide, and eliminates the need for land based base stations, or location dependant differential signals such as the Coast Guard differential beacon system. The system is used as a backup positioning system, as well as providing high precision vertical control.

\textbf{Datums}

Final bathymetric sounding data will be reduced to a tidal datum referenced to Mean Lower Low Water as specified by the NOAA 2009 Specification and Deliverables document available online at \url{http://www.nauticalcharts.noaa.gov/hsd/specs/specs.html}. This reduction is accomplished by using verified tidal observations (a NOAA product) from, at minimum, three nearby tide gauges to “correct” depth soundings by accounting for varying tidal stage or varying tidal magnitude during the survey.

Bathymetric data from all surveys are being processed using CARIS \url{http://www.caris.com/products/software.cfm/prodID/1} HIPS/SIPS v. 6.5 (soon to upgrade to version 7.0) data processing software in order to produce tide-, motion- and sound-speed-corrected, geo-referenced bathymetry and backscatter imagery. Backscatter mosaics are being generated with IVS Geocoder software to additionally produce backscatter mosaics that incorporate geometric and beam pattern corrections, as well as removing artifacts of gain changes and topography during the survey (Fonseca and Calder, 2005; Fonseca and Mayer, 2007). The data are being collected using standard hydrographic protocols (NOAA Hydrographic Manual, 1976; NOAA 2009 Specification and Deliverables, 2009).

The surveys are being conducted at speeds of 7-8 knots, depending on weather conditions and other factors such as proximity to the coast, visibility, and density of crab pots. During sea-trials it was determined that vessel speed had little or no effect on data quality, validating the construction of a massive and deeply placed sonar pole for this project. Standard squat tables were constructed for the changes in vessel pitch at various speeds, and are applied during processing.

Weather data was provided in real time either through Satellite based web access, or through a Garmin 496 Aviation/Marine GPS system with XM satellite weather overlays.
3.0: Progress to date

Mapping operations began on July 26, 2009. The first leg consisted of a shakedown in Yaquina Bay and off Newport for system testing and calibration. Mapping was then begun to an area off Newport. Two sites off Newport were surveyed during Leg 1, supported by the National Science Foundation Ocean Observing Initiative project. This cabled observatory project was also begun in July of 2009, and required multibeam surveys of proposed instrument and mooring sites. Surveying these sites under OOI funding allowed a long shakedown of our systems, and generated unplanned extra data within and adjacent to the State Waters project. The areas surveyed for the OOI project are shown in Figures 4 and 5.

On August 2, survey operations began with DEA and OSU operating the Pacific Storm in State waters. Survey continued almost continuously until weather forced a shutdown for the season on October 15. A total of ~ 76 sea days were used on Pacific Storm in 2009. To date, ~ 95% of the objectives of outlined in Figure 1 between Yachats and Tillamook head have been completed. Remaining areas to be completed include some of the inshore areas that were not surveyed during the course of normal operations due to high density of crab pots, poor visibility, wave action and shallow water depths. Some areas may also require additional data collection by DEA to meet the sounding density requirement imposed by NOAA. These areas will be completed by DEA in 2010, most likely using a small launch. Figures 4 and 5 show the multibeam mapping progress to date.

Few significant problems were encountered during the 2009 season. The weather was perhaps the most favorable stretch of flat weather Oregon has had in many years, making it possible to survey almost continuously through the summer season, with only a few down days for weather. Typically a figure of 20% or more weather days can be expected. There were also few mechanical difficulties that impacted the survey work. On two occasions the vessel hit objects in the water hard enough the break the shear bolts on the sonar head. On the second occasion, the sonar head cowling was damaged, necessitating a port call and repair work. On several occasions the MVP sensor was snagged on underwater objects, causing operations to cease while a new line was spliced. Overall, downtime due to all factors was well below 5%.

Selected sample images from the 2009 mapping effort are shown in Figures 6-11.

The ground truth vessel Michele Ann utilized 12 sea days in 2009. The ground truth effort was late in starting, but these 12 days enabled collection of ~420 bottom samples using a Shipek grab sampler and winch system. One technician and one student staffed the Michelle Ann with three ships crew. Sample locations were selected using two methods. NOAA requirements for bottom samples for nautical charting require samples to be collected on a 2 km sampling grid regardless of topography or substrate. OSU collected these samples, along with a large number of other samples selected from the backscatter/bathymetry grid. These samples were chosen in locations to best sample the geologic units represented on the backscatter/bathymetric data, given the existence of the 2km gridded data and other existing data and observations. The data density was tuned to
Figure 5. Progress map for 2009 surveys
the need for developing habitat maps from the data. Sample collection for the areas shown in Figures 5 and 6 was completed by October 30, utilizing a brief weather window that opened up after the first few winter storms had moved through the area.

3.1: Data Processing and Habitat Mapping

As of this writing, the data collected in 2009 are being processed at David Evans and Associates and at OSU. NOAA requirements for data handling include extensive quality control procedures for data integrity in the nautical charting application (NOAA Hydrographic Manual, 1976; 2009 Specification and Deliverables). Careful processing and consideration of vertical datums and data quality are of utmost importance, and these steps require considerable time and effort. The data processing for the bathymetric data is expected to extend through the winter of 2010. Backscatter data processing, integration of other existing data, and development of habitat maps mostly must wait until the bathymetric processing is complete, and thus the habitat map development has not begun as of this writing. The habitat maps will be constructed using the new data, and integrating the new multibeam, backscatter, and sample data with all existing data using the methods of Romsos et al. (2007). As of this writing, preliminary backscatter mosaics were created for the ground truth sample selections, and these are being used to develop plans for further groundtruth work to be conducted in the 2010 field season.

3.2: Timeline for Project Completion

We anticipate that the OSU lab can begin work on the habitat map development in Spring of 2010. The students engaged in this process are currently taking their first year classes at OSU, and thus the timing works quite well to focus on coursework during the winter when the data are not ready for interpretation. In Spring 2010, we will re-mobilize the Pacific Storm and Michele Ann for the second field season of data collection. During the 2010 season we will complete data acquisition for the southern areas shown inside the green box in Figure 1, including Cape Arago, Cape Blanco, Redfish Rocks (extension to the POORT survey), and Rogue Reef. There may also be an area off Reedsport that we map with support from the Oregon Wave Energy Trust (OWET). The groundtruth vessel will collect a high-density grid of physical samples as we did in 2009. If resources allow, we will also collect as much imagery data of the Marine Reserve sites as possible, utilizing the SeaBed AUV operated by the NOAA NWFSC, or alternatively in collaboration with ODFW. Discussions regarding collaborative opportunities for this groundtruth work are underway as of this writing.

Presently, a new habitat map has been created for the Redfish Rocks Pilot Site, based on multibeam data collected by Jim Golden and the POORT initiative. This work was completed in the OSU lab under separate funding, and is the subject of the MS thesis work of Amolo Rizaller. The other pilot reserve site at Otter Rock is problematic in terms of mapping because of its location far inshore, and its close proximity to awash rocks. In may not be possible to map this site with multibeam sonar.
During the remainder of 2010 and the winter of 2011, the OSU lab will continue to generate habitat maps for all of the regions shown in Figure 1, focusing first on the marine reserve sites to provide timely data to that process. These data will be made publicly available as each site is completed. The data will be made available through the PaCOOS Habitat Server, an interactive web-based query server which can be found at: http://pacoos.coas.oregonstate.edu/

The Oregon State waters mapping data will be integrated with the regional West Coast habitat maps that have been developed under the NOAA Essential Fish Habitat Initiative, and the West Coast Governors Agreement on Ocean Health.

4.0: References Cited

Ocean Mapping Group, Department of Geodesy and Geomatics Engineering, University of New Brunswick, pp. 6


Figure 6. Cape Perpetua area shaded relief bathymetry
Figure 8. Perspective shaded relief view of the Cape Perpetua area.
Figure 9. Perspective shaded view of Haystack Rock area bathymetry
Figure 10. Shaded relief bathymetry of Newport, OR. ( Acquisition supported by the National Science Foundation, Ocean Observing Initiative.)
Figure 11. Shaded relief bathymetry of Redfish Rocks, OR. (Acquisition supported by the POORT group).