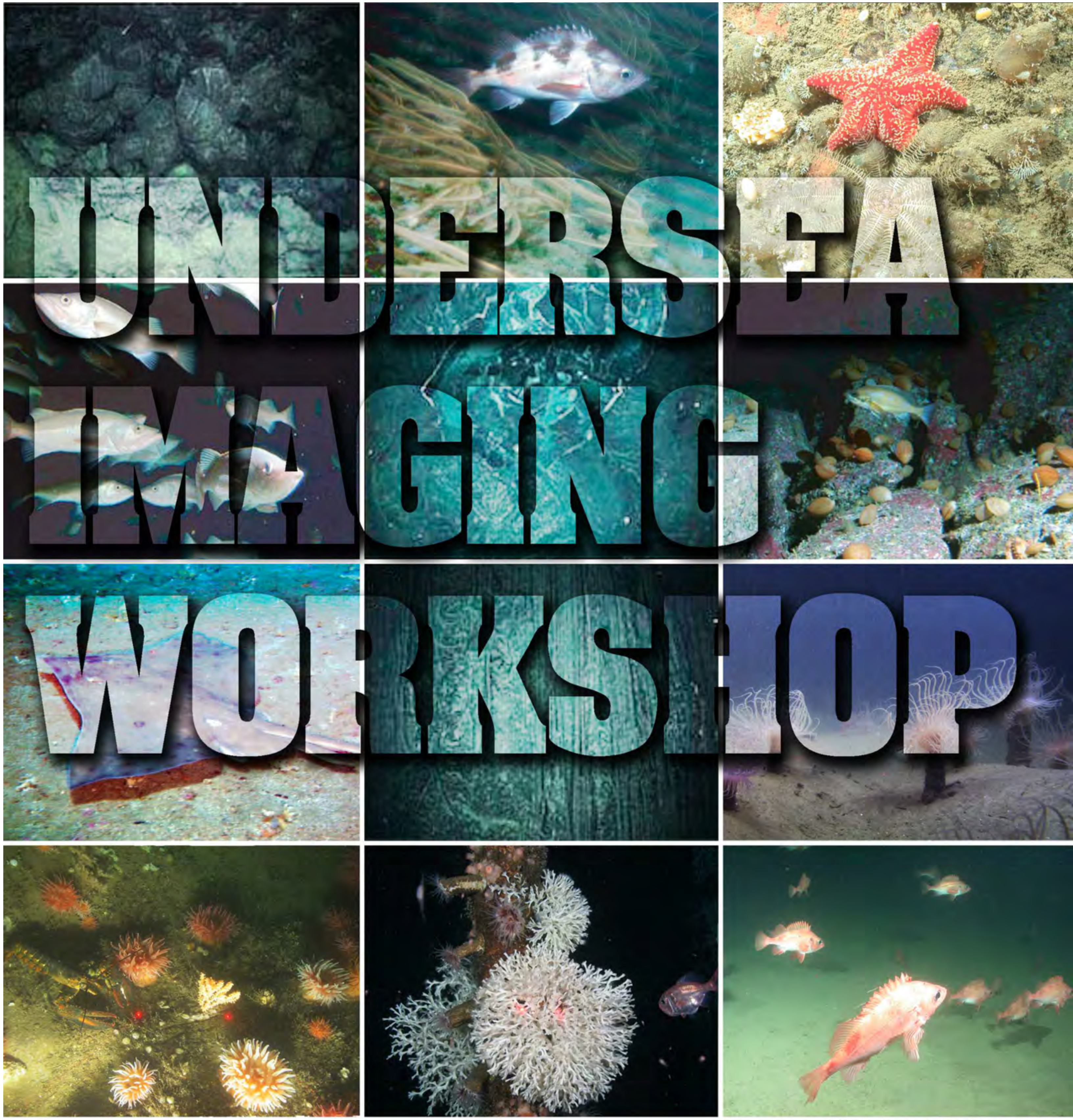
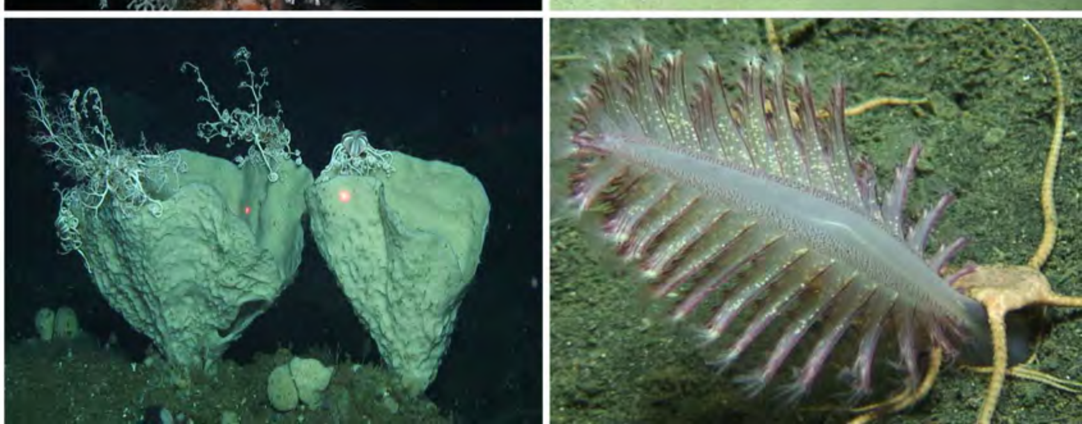
UNDERSEA IMAGING WORKSHOP



Red Bank, NJ
January 14-15, 2014

WORKSHOP REPORT



EXECUTIVE SUMMARY and WORKSHOP RECOMMENDATIONS

A workshop on undersea imaging, hosted by the New Jersey Sea Grant Consortium (NJSGC) and the NOAA Fisheries James J. Howard Marine Science Laboratory on Sandy Hook, evaluated the strengths and limits of photographic, videographic and direct observations, as well as associated platforms, for seafloor imaging as part of a benthic monitoring strategy. The workshop brought together government and academic scientists and engineers to discuss the need for cost effective and comprehensive characterization of offshore macrobenthic and demersal communities and habitats in the Northeast Large Marine Ecosystem. Three topical workshop sessions focused on: 1) describing the different subsea imaging systems used by workshop participants; 2) strengths and weaknesses of these systems, as well as issues related to work flow of imagery; 3) future directions of imaging technologies and products.

Discussion and recommendations by the workshop participants included:

- Recognition of an increased utilization of the seafloor for multiple purposes and the need to monitor associated changes, particularly as they relate to fisheries, offshore energy development and climate change.
- Acknowledgement that there is a need to develop a systematic and comprehensive approach to monitoring seafloor communities across the continental shelf though the establishment of a series of sentinel sites, which could be initially developed in coordination with the impending explosive growth in offshore energy development.
- Given the variety of imaging systems currently being used to characterize seafloor communities, and the potential survey biases each system introduces, a process for intercalibration is needed to compare and contrast existing and future data sets. A series of calibration sites should be established to compare image products and resulting data from different systems. This would be somewhat akin to determining trawl efficiency for different gear types and configurations.
- There is a clear distinction between the abilities of human vision and machine vision with regard to producing data from imagery. While machine vision has made great strides in rapid segmentation and object identification, further advancements are necessary to improve detection, identification, and measurements of organisms in complex and biologically diverse seafloor communities. In the short term, however, work flow needs to be optimized utilizing both machine vision and human-based object identification of imagery. With increasing pixel density, machine vision will become an increasingly powerful analytical tool and allow for greater automation and interpretation of data.
- In contrast to the era of film, the ability to collect orders of magnitude more imagery in digital form can produce bottlenecks in work flow and data management, requiring closer collaboration between environmental and bioinformatics researchers.
- Because of the growing need for characterization of seabed communities, it is time to reconsider the nation's investments in undersea imaging systems and platforms that not only span the technological spectrum but could also be available to the broader scientific community.
- Models for covering the cost of a nationally available network of optical imaging technology include the concept of the National Ocean Endowment, or the Small Business Innovative Research or the Small Business Technology Transfer programs.
- Baseline data, for evaluating environmental change, are generally lacking over all habitats and spatial and temporal scales of impact. There is a need to assess the scope of needed baselines and to develop undersea imaging technology that would provide a comprehensive evaluation of change at the scale of Large Marine Ecosystems or subunits.

Richard Langton, Ph. D., NEFSC and Peter Rowe, Ph.D., NJSGC, Editors

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Sea Grant
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Cover Photos - Peter Auster, Mary Yoklavich, Dan Fornari and Tim Shank

INTRODUCTION

The study of seafloor communities in offshore US waters is experiencing a renaissance because of the growing interest in offshore energy development, the impact of climate change on the distribution of benthic organisms, and the implementation of ecosystem-based management principles for fisheries and resource management. In the Northeast, for example, fish populations have been monitored annually for fifty years and recent studies have clearly shown a northern shift in the epicenter of the distribution for a number of different fish species and modeling efforts have projected even greater changes to come. Although virtually unstudied, it is logical to conclude that these population shifts will be mirrored by many of the prey species and the benthic organisms that serve as physical habitat for demersal fish. Additionally, offshore wind energy areas (WEAs) have been designated for development, and BOEM (Bureau of Ocean Energy Management) is collaborating with NOAA Fisheries to develop the baseline benthic characterization for all the US East Coast sites. The interplay between the need for spatially comprehensive seafloor data and for understanding spatial changes driven by climate change makes it essential to develop and deploy technologies that will allow for documentation of the benthic communities over both space and time. Such an effort must include not only mapping to define physical seafloor features, but also to the integration of physical and biological data into the definition of habitat and communities. This need for detailed seafloor community information requires evaluation of the best and most efficient methods to collect the necessary data over all habitat types.

> *The interplay between the need for spatially comprehensive seafloor data and for understanding spatial changes driven by climate change makes it essential to develop and deploy technologies that will allow for documentation of the benthic communities over both space and time.*

Digital photography/videography is certainly becoming the technology of choice to document macrofaunal seafloor communities. The ability to record and inspect a large number of images while still in the field has made image sampling much more efficient, and allowed significantly larger sample sizes, when compared to the days of film. In addition, traditional sampling, using quantitative grabs and/or dredges, is still necessary to ground truth images with actual specimens, and sediment samples, but can be based on near real time inspection of imagery. In short, traditional grab sampling, by itself, is conducted on too small a scale, and requires too much extrapolation, to adequately characterize benthic communities and habitats on the scale that would reflect climate change or even on the scale required for the proposed WEA development. Admittedly, visual imagery has its technical limitations, but the numbers of photographs, and consequently the amount of quantitative data that can be generated on a single cruise, far exceeds that of grab or dredge based sampling. Indeed, one of the major issues facing the use of visual imagery for sampling is how best to deal with the terabytes of available information. Although machine vision promises to automate the assessment of visual images, and is achieving success for single species such as scallops, the techniques are still rudimentary and have limited utility for a comprehensive survey of diverse seafloor communities.

Looking forward, it is clear that nondestructive survey technologies will augment if not totally replace extensive capture surveys for fish and invertebrate stock assessments. It is, for example, not difficult to imagine a fleet of Autonomous Underwater Vehicles (AUVs) constantly monitoring the offshore environment. However, AUVs are currently expensive to purchase, have limited range, and are not totally ‘bug free’ regarding their operations. Rough bottom topography can, for example, make the use of AUVs difficult and dangerous for the equipment. It is also difficult using AUVs to detect and identify fishes living in highly complex rocky habitats. In other words, for now they are more of a research-and-development tool than a routine survey tool for diverse seafloor communities. Until AUVs are perfected to the point where they can be routinely deployed and their data downloaded remotely, less sophisticated technologies will continue to be used for seafloor investigations worldwide. For Example, on the US East Coast, the Northeast Fisheries Science Center (NEFSC) is in the process of replacing scallop dredge surveys (except for the collection of biological samples) with integrated benthic surveys utilizing the Habitat Mapping Camera System (HabCam). HabCam is a towed camera system that documents scallop populations with a series of overlapping stereo images that can then be used to enumerate the numbers of scallops, and other macrofaunal organisms, per unit area. Complementary to this towed system is a drop camera system, developed by scientists at U. Mass Dartmouth, which also takes a series of photographs for enumerating scallop densities and evaluating benthic conditions. Both scallop survey systems have successfully been used to assess east coast scallops and are currently being utilized, side by side, to evaluate the macrobenthic communities in offshore wind energy areas, as well as characterize black sea bass/soft coral habitat that occurs in one of the WEAs.

There are other camera systems that have been developed by a number of academic institutions and government agencies, such as the University of Connecticut, Woods Hole Oceanographic Institution and the U.S Geological Survey, which have advantages for sampling particular environments (e.g., topographically complex habitats such as boulder ledges, steep escarpments in submarine canyons). Employing such systems in concert with the above technologies might generate a more comprehensive understanding of the benthic communities and habitats across the shelf and continental margin, leading to the better understanding of natural variability and climate driven changes on the scale that is important to sustainable fishing and energy development. To address the question of cost effectiveness and comprehensive sampling methodology for characterizing seafloor communities, the NJ Sea Grant Consortium (NJSGC) and NOAA Fisheries James J. Howard Marine Science Laboratory on Sandy Hook, NJ, hosted a workshop that focused on the imaging systems used to evaluate the benthos. The objectives of this workshop were to document the advantages and limitations of these various systems, and consider future needs regarding imaging systems.

THE WORSKHOP AGENDA

The workshop was, by design, an informal gathering of twenty-four people all of whom have experience with optical imaging of the sea floor, primarily in the Northeast. The experience of the workshop participants reflects the spectrum of undersea imaging systems that are in use by the region's marine science community.

The workshop itself was a one and one half day event that was divided into three sessions. The session themes are listed below.

Session 1: How your system was developed and how it has developed to meet your needs?

There were 13 different imaging systems represented at the workshop, and participants made brief (15minute) presentations addressing the above question.

Session 2: What would you do differently?

Having heard about, and briefly discussed, the various camera systems and their purpose, background and evolution, participants discussed what should have been done differently. This was either specific to their own system, or as a question directed at other systems described at the meeting.

The second part of Session 2 focused on handling, viewing, producing data, and archiving of data, but not analysis and results. Although scientific results per se were not discussed as part of the workshop, there are work flow issues related to processing imagery once back in the laboratory.

Session 3: Lessons learned and future needs and directions?

If participants were to leave this workshop and go out to build the next generation underwater imaging system, what would be done to make the system work seamlessly through to the processing of images in the laboratory? This also involved conversations about what capabilities the idealized imaging system, or systems, should include and how to achieve this.

Workshop Presentations

The full presentations are not appended to this report. Instead, a summary of each talk is included, a webpage is listed if it is available, the presenters and collaborators are identified and, in some cases, a listing of scientific papers that pertain to the different imaging systems is included. In the event that more detail is required, an attendee's list is appended to the report that includes an e-mail address for all the participants and their collaborators.

PRESENTATION SUMMARIES

SEABOSS, or the Seabed Observation and Sampling System

Presenters: Valentine, Blackwood and Guida

The SEABed Observation and Sampling System (SEABOSS) was designed by the U.S. Geological Survey to rapidly, inexpensively and effectively collect seabed images and sediment samples in coastal and continental shelf regions up to approximately 200 meters water depth. The SEABOSS is a drift system which incorporates two video cameras, a still camera, a depth sensor, light sources and a modified Van Veen grab sampler. There are two SEABOSS systems. The large system (4 x 4 ft footprint) is deployed through a ship's A-frame, using a dedicated winch and conducting cable. The small system (3 x 3 ft footprint) is designed for shallow water coastal use and is deployed using a ship's winch and lifting cable, and a hand-deployed conducting cable. The SEABOSS frame has a stabilizing fin capable of orienting the system while it drifts with a forward-looking video that documents the terrain and enables the winch operator to avoid obstacles. The down-looking video is used to document the seabed, to choose sites for still photos, and to select sampling locations for the Van Veen grab which is gently lowered to the seabed to collect undisturbed sediment samples. The data generated, in conjunction with geophysical mapping, is used to provide a comprehensive interpretation of seabed character.

http://woodshole.er.usgs.gov/operations/sfmapping/seaboss.htm

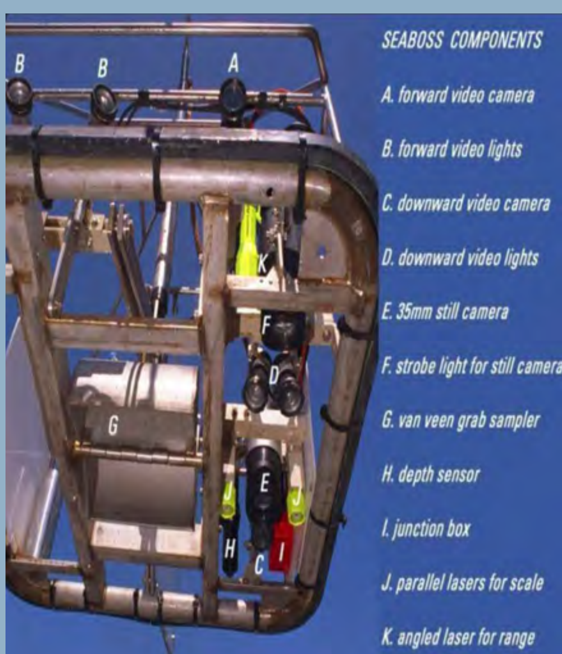

Figure 1. The large SEABOSS, on the left, is suitable for both coastal and continental shelf water depths. The smaller SEABOSS, on the right, is suitable for coastal water depths.

Video Survey Pyramid System

Presenter: Stokesbury

The US sea scallop fishery is managed under an area rotation system requiring spatially-specific information on scallop density and size. The SMAST–Industry cooperative video survey provides this type of information with high levels of accuracy and precision. Since 1999, SMAST has completed >150 video cruises surveying Georges Bank and the Mid-Atlantic (>1000 days at sea, Figure 2), with support from the commercial sea scallop industry, the Massachusetts Division of Marine Fisheries (MADMF), and the sea scallop RSA program (NOAA grants). This unique database covers the entire scallop resource (~70,000 km^2) from 2003 through 2012. Further, it includes numerous video surveys on a finer scale focusing on scallop aggregations primarily in closed areas of Georges Bank and the Mid-Atlantic.

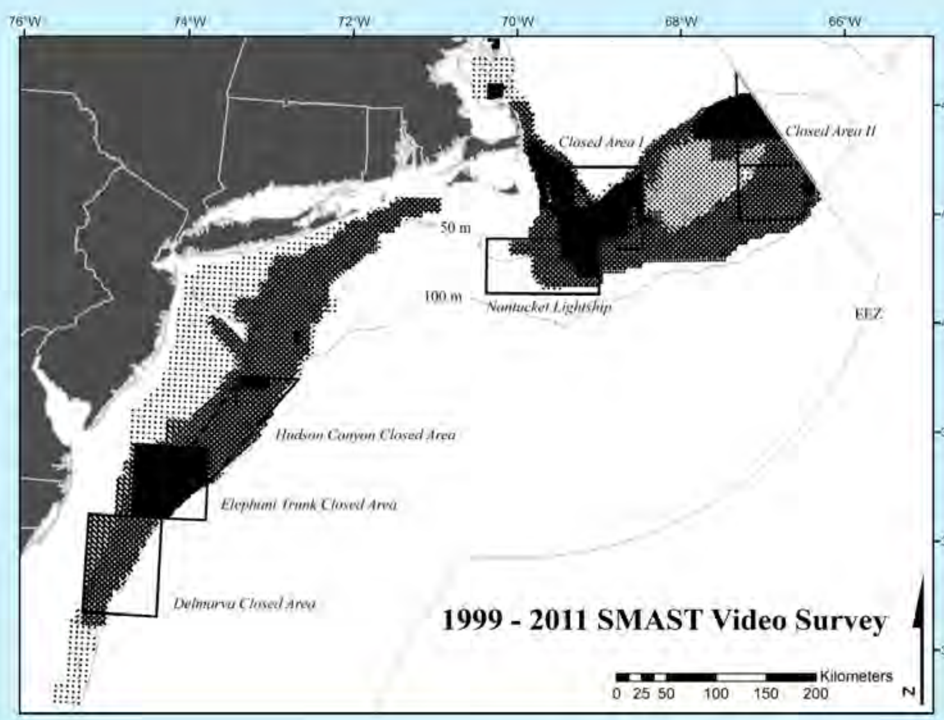

Figure 2. The Industry-SMAST video survey of the Mid Atlantic and Georges Bank sea scallop resource surveyed from 1999 to 2011. The annual continental shelf-scale survey stations (5.6 km^2 grid), and the high resolution survey stations (1.6 and 2.2 km^2 grids) appear in black areas. At each station the SMAST video pyramid is set on the sea floor four times.

Our goal is to provide fishery resource managers, marine scientists and fishing communities with 1) an assessment of the spatial and temporal size specific distribution of sea scallops, 2) an estimate of the absolute density (individuals m^{-2}) and biomass of sea scallops in closed and open areas of Georges Bank and the Mid-Atlantic, and 3) the spatial structure of substrate characteristics, seabed disturbance and the abundances and densities, or presence/absence of

Video Survey Pyramid System (cont'd)

macrobenthos in the video survey sampling domain. We employ a multistage centric systematic sampling design, using a 5.6 km grid with four replicate quadrats at each station. Each year we sample approximately 1800 stations requiring 9 research cruises (8 days each) equaling 72 days at sea. We collect samples of size specific sea scallop density and produce a series of maps of the sea floor detailing the distribution of substrate, depth, live and dead scallops and megafauna (sponges, starfish, filamentous fauna). To identify areas of recruitment, we employ a 10.1 megapixel digital still camera coupled with the 3 video cameras (Figure 3). The scallop counts, density and size estimates, abundance and exploitable biomass are collected, quantified, quality controlled and submitted to the New England Fisheries Management Council Scallop Plan and Development Team and National Marine Fisheries Survey, on 1 August of each year.

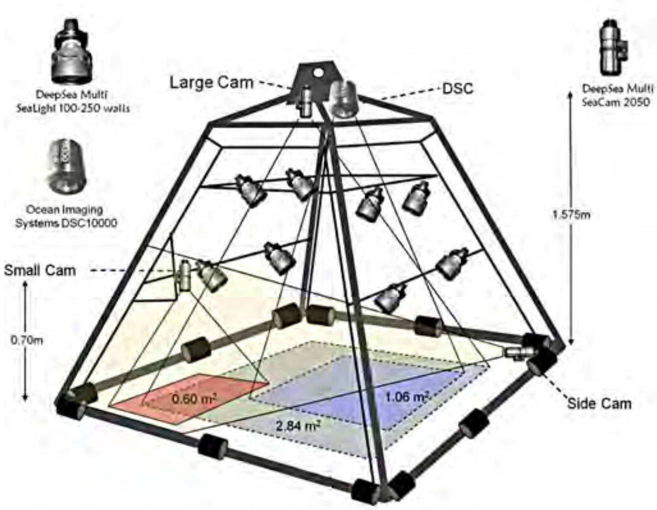

Figure 3. SMAST Video survey pyramid including 8 lights, 3 DeepSea video cameras, a 10.1 megapixel digital still camera and the area of each quadrat.

To ensure that we are conducting research that is "the best available science" we have published the protocols and analyses from our survey. The survey design, including precision between stations on 0.85 NM and 3 NM, quadrat size and protocols, are published in Stokesbury 2002 and Stokesbury et al 2004. Further examination of accuracy on different spatial scales and geostatistics on scallop aggregation structure are published in Adams et al 2008, 2010. The high resolution substrate map of Georges Bank, was using geostatics, was published in Harris and Stokesbury 2010. The accuracy and precision of measuring scallop shell height by video was questioned in one of the SARC's. In response, with NMFS scientists, we conducted a series of experiments on video large camera and NMFS protocols published in Jacobson et al 2010. We added a high resolution digital still that increased our accuracy and precision by an order of magnitude, this sample protocol and resulting data were published in Carey et al. 2011. Descriptions of the sea scallop stock and biological interactions include Stokesbury et al 2011, Stokesbury 2012 and Carey and Stokesbury 2013. Using the survey to examine distributions of species other than scallops includes sea stars (Marino et al. 2007 and 2009) and the skate complex with an estimate of selectivity (MacDonald et al 2010). The first of a series of fishing impact papers unique in that it looks at the entire effect of the fishery on the marine habitat was published in Stokesbury and Harris 2006. In all the SMAST–Industry cooperative video survey was reviewed and accepted in the 50th SAW and has been published in 26 peer-reviewed articles. These publications build a solid peer-review of our survey procedures and data analysis reflecting our commitment to the producing the "best available science."

Video Survey Pyramid System (cont'd)

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Low-cost underwater video Towed Camera Sled and Fixed Trap Monitoring Systems

Presenter: Stevens, in collaboration with Cullen

Introduction

Fishery species (e.g. fish or crabs) that live among heterogeneous or deep habitats are notoriously difficult to assess. NOAA stock assessment cruises that use trawls cannot sample such habitats, and therefore miss important components of the stocks. Underwater video allows observation of animals in such habitats without interference from divers, and videos can be viewed and analyzed by multiple observers or methods. We evaluated use of two different types of systems for different purposes. Design/operation criteria for both systems were:

- Relatively low cost (<$10,000 per system)
- Portable and usable from small (<40 ft) vessels of opportunity by 1-2 people.
- Uses simple, off-the-shelf (OTS) technology that is easily operated and replaceable
- Useable in the open ocean to a depth of 50-100 m

System # 1: Stationary video observation system

Goal: Assess fish abundance and behavior in heterogeneous habitats with stationary gear.

System: Remote underwater fish assessment system (RUFAS) is a stand-alone unbaited underwater video system (Fig. 4). Two types were evaluated for their utility in assessing abundance and behavior of black sea bass (*Centropristis striata*) on reefs in the Maryland coastal zone. Initial system consisted of 5 Go-Pro cameras attached to a frame built over a commercial BSB fish trap. Second system consisted of a separate frame with Go-Pros and a Canon digital handi-cam in a diver housing. Total cost was < $5,000.

Pro/con: Go-Pro cameras are cheap and easy to use, and provide high quality video. Higher cost Canon in housing was not a great improvement. Neither system was usable at dusk or night, but addition of lights was marginally helpful due to backscatter.

Conclusion: Go-Pro cameras on a simple frame are effective and easy to use, and can provide valuable information on fish presence, abundance, and behavior (Cullen and Stevens, in review).

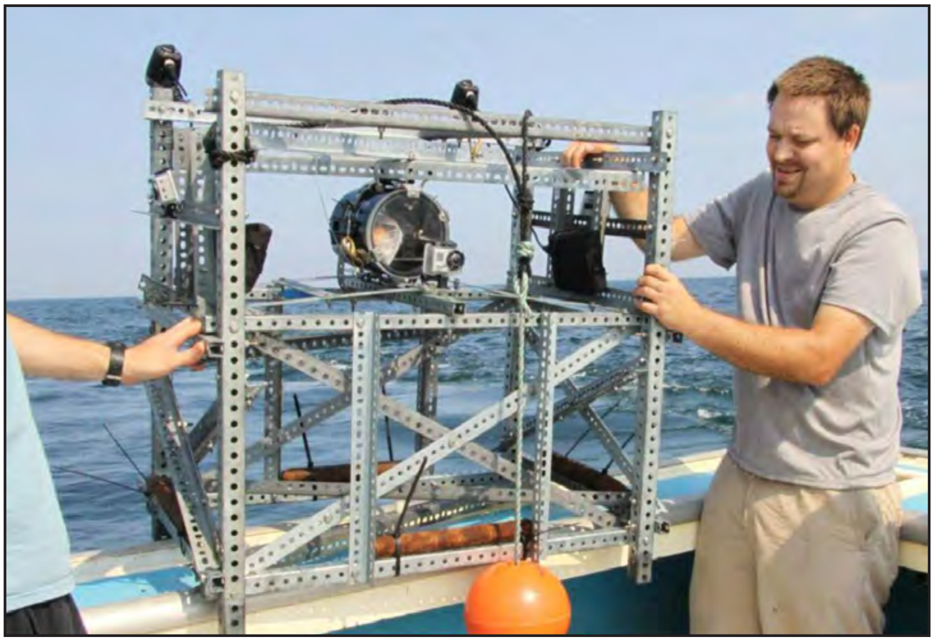

Figure 4. Graduate student Dan Cullen with RUFAS video system

Low-cost underwater video Towed Camera Sled and Fixed Trap Monitoring Systems (cont'd)

System #2: Towed video camera sled

Goal: Assess epibenthic faunal communities and habitats for wind power installation sites.
System: The benthic resource assessment device No. 6 (BRAD-6) is a towed sled with low-light video cameras (Fig. 5). This consisted of a small (2 x 4 ft) steel frame with a DSPL low-light B/W "Wide-I seacam" that transmitted video to the surface over a coax cable, battery powered lights, and 3 Go-Pro cameras. This system evolved from larger predecessors used for deep-sea crab research, but which required much larger vessels (Stevens, 2003, 2004). Total cost was <$10,000 including recorder and monitor. System was towed from a 42 ft lobster/trap boat using the power block.
Pro/con: Heavy sled stays on bottom with fixed field of view, but at 45 degree-angle. DSPL camera did not have enough resolution for identifying organisms, so was mainly used to monitor sled performance. Go-Pro's provided much better video, and 3 of them allowed wider view of seafloor. Video images were blurred due to slow shutter speed. Cumbersome tether system limited the depth of use; it could be improved with a tether reel but that would defeat the goal of low-cost and easy use.
Conclusion: The video system was too slow for this application. It could be greatly improved by use of a high-speed frame-capture machine view camera with synchronized strobe lights. We are now building such a system.

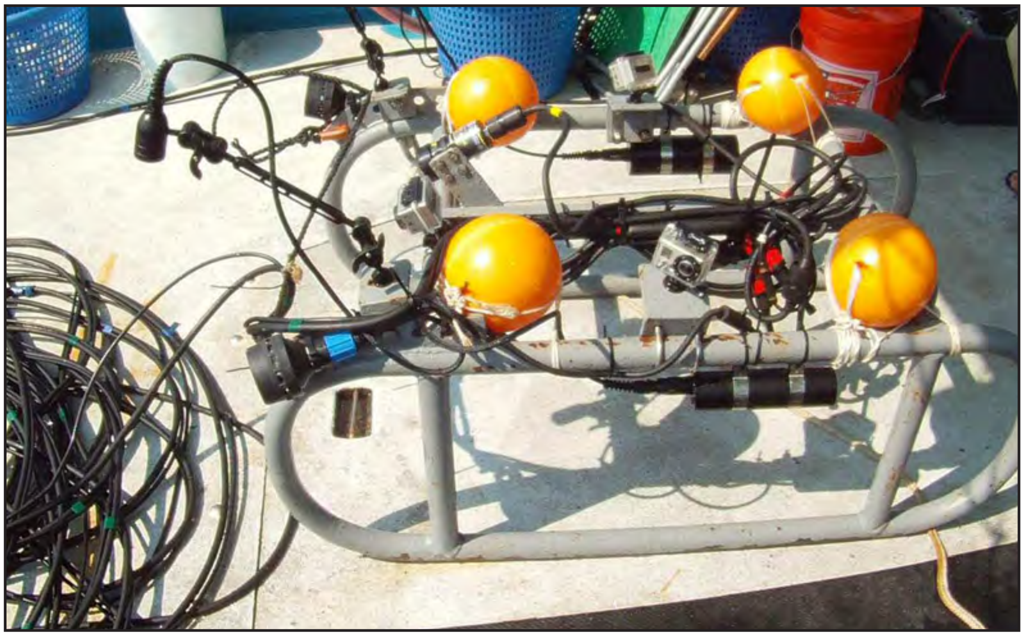

Figure 5. Towed video camera sled BRAD-6. Note coils of tether system at left.

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Video Lander: A drop camera system developed for sampling rocky reef habitat by the Oregon Department of Fish and Wildlife

Presenter: Wakefield, in collaboration with Hannah and Blume

Introduction

Deepwater rocky reefs are environments that are very challenging to sample, as they often include many areas that cannot be effectively sampled with survey trawls. Visual surveys of deep water rocky reefs on the U.S. west coast have typically been conducted with remotely operated or human-occupied vehicles (ROVs, HOVs). Recently, less expensive video landers have been developed and tested as an alternative survey tool for these habitats (Hannah and Blume 2012, Easton 2013). The Oregon Department of Fish and Wildlife (ODFW) has developed and evaluated a stereo-video equipped video lander as a survey tool for marine demersal reef fishes in Oregon waters (Figure 6-7). The lander has the following design features:

- Protective frame
- Designed with breakaway attachment points that cause the lander to tilt and rotate to free itself from rocky habitat
- Uses a breakaway, sacrificial mild steel base, which is sometimes lost
- Current version incorporates a calibrated stereo-video that can be used to estimate fish lengths, range and dimensions of habitat features
- Utilizes high-definition Canon camcorders set to “progressive scan” (24P) in underwater housings
- Separate UW housing holds batteries and a micro-controller board that send LANC signals to the camcorders
- ODFW has deployed landers into rocky habitat over 3,000 times (2009-2013) without camera system damage or loss

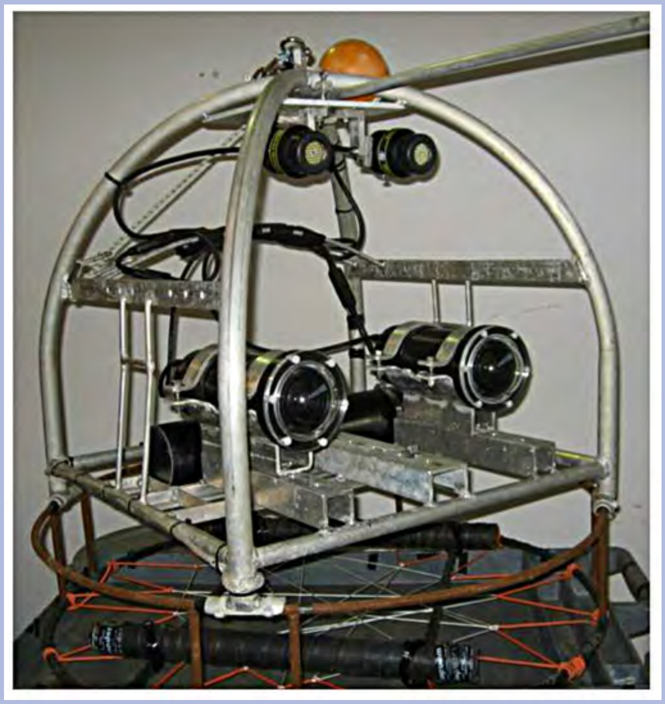

Figure 6. ODFW stereo-video lander system, showing paired stereo-calibrated high-definition Canon Vixia® HFS21 video cameras, and two DSPL Sealite Spheres® (3000 lm, 6000 K) (photo - R. W. Hannah, Oregon Department of Fish and Wildlife).

Video Lander: A drop camera system developed for sampling rocky reef habitat by the Oregon Department of Fish and Wildlife (cont'd)

The video lander system has advantages over other systems traditionally employed in visual surveys of fishes and their habitats. The system has demonstrated efficacy for surveying marine habitats that are risky for larger ROVs (remotely occupied vehicles) or HOVs (human occupied vehicles) due to shallow depth, extreme topography or strong currents. The smaller vessels that can deploy the video lander, along with its simplicity and portability, make mobilizing a survey quick and inexpensive in comparison with most ROVs and HOVs. This could facilitate visual surveys of rocky habitat across a wider range of marine conditions increasing the likelihood of encountering favorable conditions and completing a survey in the near shore environment. The ease of deployment also makes the video lander an excellent choice for very broad-scale surveys of demersal fish distribution, benthic habitat types or species-habitat associations: situations in which broad spatial coverage may be more important than viewing a large amount of seafloor in a single deployment, as is more typical for ROVs and HOVs. The inclusion of a calibrated stereo-video (e.g., Williams et al. 2010, Hannah and Blume in preparation) supports length and distance estimates for fish and other targets. The addition of bait during deployments reduces the mean distance at which acceptable estimates of demersal fish length and distance can be obtained for some species.

Figure 7. Stereo video lander during deployment – note configuration of bait bag (upper right).

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WHOI-MISO TowCam System

Presenters: Fornari, Shank

Introduction

WHOI's Multidisciplinary Instrumentation in Support of Oceanography (MISO) Facility provides deep-sea digital imaging capabilities for seafloor experiments and surveys, and related equipment to academic oceanographers in the US and internationally. MISO is a NSF-supported cost-center at WHOI managed by Dr. Dan Fornari (Sr. Scientist in the Geology & Geophysics Dept.) to facilitate cost-effective and scientifically relevant access to deep-sea imaging and related equipment for oceanographic research in a wide range of seafloor environments.

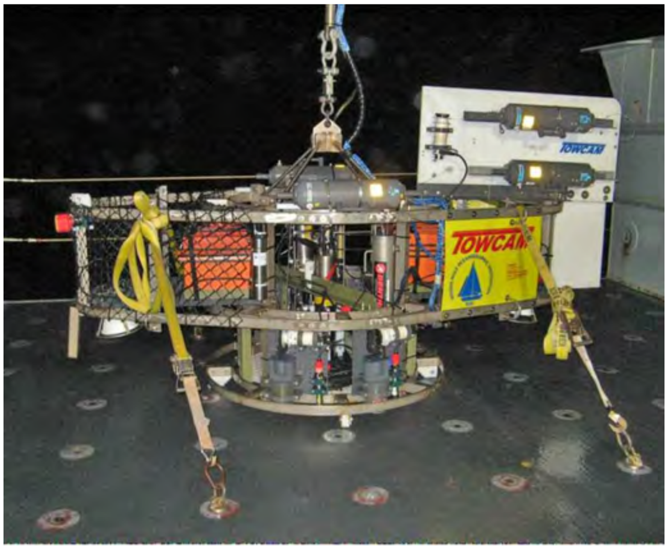
The website where descriptions of various types of equipment can be found is at:
http://www.whoi.edu/website/miso/miso-instrumentation

Scientists requesting to utilize MISO equipment, including the TowCam deep-sea imaging system, include budgets to mobilize and operate the system for their field programs in their proposals to federal and private agencies.

Brief Description of the WHOI-MISO TowCam

The WHOI *TowCams* (Figures 8-11) within the MISO Facility are currently the only routinely available US systems for towed deep-sea digital imaging and short-term time-lapse imaging. The MISO TowCam is an internally recording digital deep-sea camera system (16 megapixel OIS camera) that also permits acquisition of volcanic glass samples using up to eight (8) rock core winches, and triggering of six (6) 5.0 liter Niskin bottles, in conjunction with CTD (SBE25) water properties data. The TowCam is towed at ~1/4-1/2 knots on a standard UNOLS 0.322" coaxial CTD sea cable while taking photographs every 10 sec. The strobe system used is a Benthos 383 600 watt/sec, 2-headed strobe with separation of ~3 m between strobe heads. The camera is mid-way between the strobes. Real-time acquisition of digital depth and altitude data, and from either green or red lasers spaced 20 cm apart, can be used to help quantify objects in the digital images and make near-bottom profiles. Obstacle avoidance is done using a forward-looking altimeter. The use of the conducting sea cable and CTD system also permits real-time triggering of any of eight rock core units and six Niskin bottles on the frame so that discrete samples of volcanic glass and seawater can be collected from specific areas during a lowering. In addition, we have developed a high-speed 'Data Link' system that permits real time transmission of the low-resolution video signal from the camera up the CTD cable in order to allow real-time observations of the seafloor during each bottom traverse and to help guide sampling.

WHOI-MISO TowCam System (cont'd)



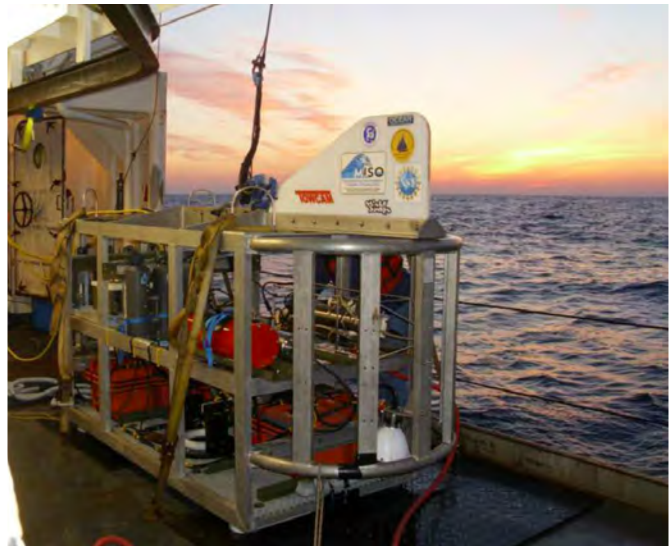


Figure 8. WHOI-MISO TowCam system rigged with water sampling and rock coring capability in 2006 (left) and with DataLink and suction system for Bigelow East Coast Canyons cruise in June 2013 (right)

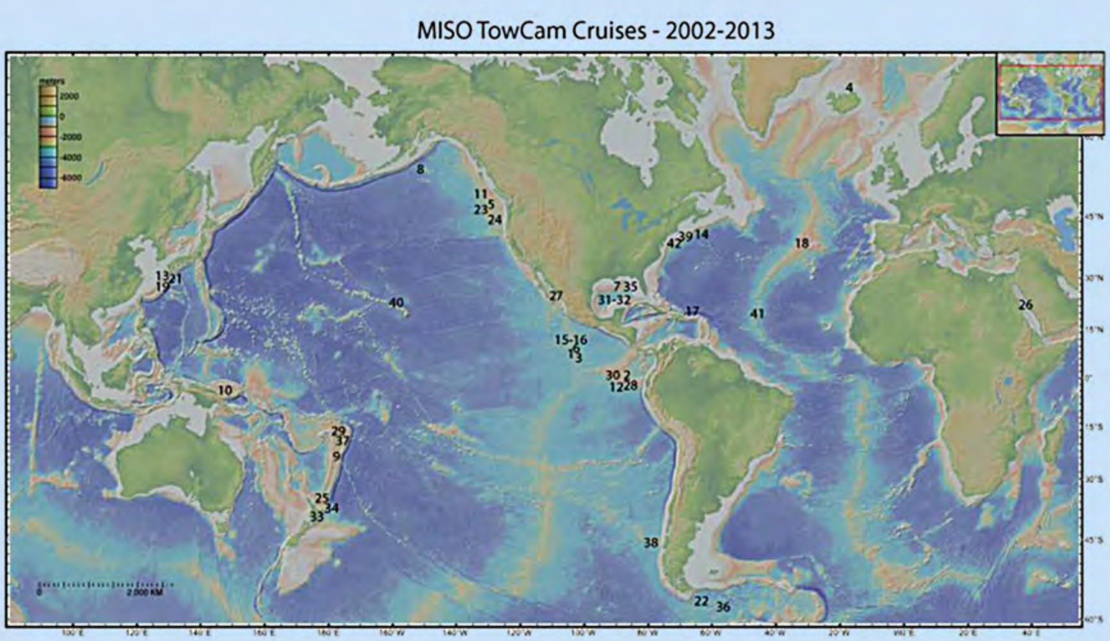


Figure 9. TowCam cruises supported by the MISO Facility for US and foreign science programs from 2002-2013. Map from LDEO-MGDS-GeoMapApp global bathymetric dataset.

WHOI-MISO TowCam System (cont'd)

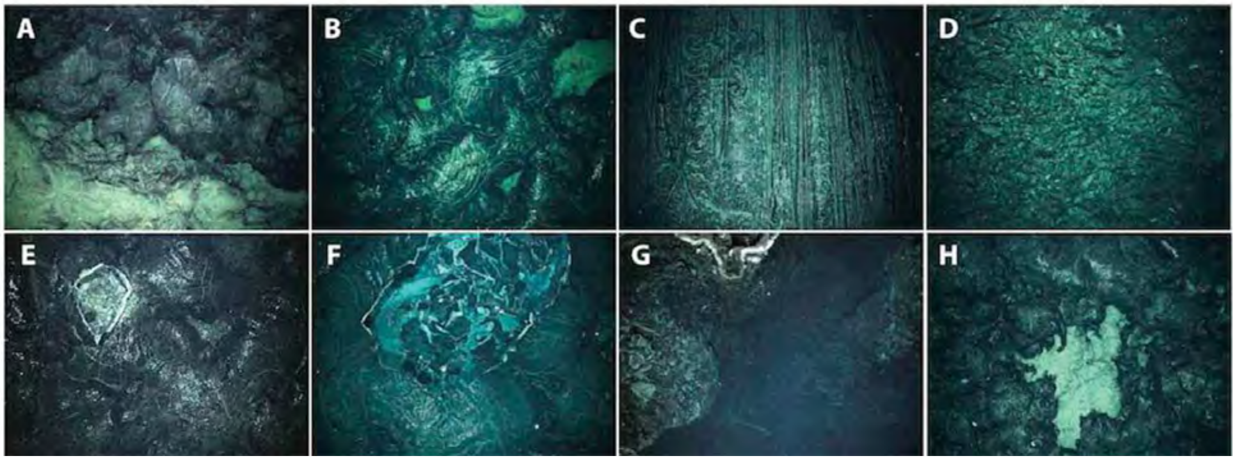


Figure 10. Examples of classification scheme employed for the TowCam images used to map the 2005-06 East Pacific Rise lava flows. A-D shows the four morphology types: (A) pillow, (B) lobate, (C) sheet and (D) hackly. E-G show the three collapse types: (E) lobate blisters, (F) skylight collapse and (G) lava pond collapse. (H) Shows an example of a kipuka, an area of exposed flow older than the 2005-06 flow and completely surrounded by the 2005-06 flow.

Normal *TowCam* operations require a trained operator that sails as part of the scientific complement on a cruise – cost for that engineer is included in the per tow use fee. Additional costs are budgeted depending on the mobilization and vessel characteristics. At times, two engineers may be required to mobilize for a cruise in port, with one engineer supporting the field operations and maintenance of the equipment at sea. Scientists participating on cruises where *TowCam* is used

Figure 11. Example of a 16 megapixel image from a Bigelow East Coast Canyons cruise TowCam lowering (Nizinski and Shank) (note green and red laser dots spaced 20 cm apart in upper middle of image).

WHOI-MISO TowCam System (cont'd)

normally supply 2-3 watch-standers to assist with real time data acquisition. All data are delivered to the science party after each tow on high-speed hard drives (Firewire or USB2). Data include full resolution images in time/date stamped files that can be correlated to navigation data, CTD data that are also time stamped and co-registered with image data, and water and rock samples when those are also collected.

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Habitat Mapping Camera System (HabCam)

Presenters: Gallager, Nordal, Godlewski

The HabCam imaging system (Fig. 12) (Howland et al. 2006; Taylor et al. 2008; York et al. 2008) is “flown” 1.5 to 2.5 meters above the seafloor at 5 to 6 knots (~2.5 – 3 m/sec), thus a track approximately 100-120 nautical miles is imaged each 24 hours of operations. Optical imagery is collected at a width of approximately 0.75 to 1.25 meters (total ~170,000 - 260,000 square meters/day) and at a rate of 5-6 images per second, providing about 50% overlap to aid in mosaicing continuous strips. The most recent system upgrade, NOAA stereo HabCamV4, includes side by side stereo pair images that are fused into a single image at the time of acquisition allowing precise stereo referencing with metadata such as latitude, longitude, temperature, salinity, chlorophyll, wavelength-specific light absorption, dissolved oxygen, and other environmental data.

What distinguishes the HabCam series from other imaging systems is digital imaging and the ability to handle, process, and store huge amounts of data as a camera is being towed from a ship. Another aspect of HabCam that sets it apart is the use of high speed xenon strobes, which are synchronized with the cameras to provide a very short (~10 µs) exposures to eliminate motion blur even when towing at 6 knots (~3 m/s). HabCam was designed to take advantage of the ever growing and advancing fields of fiber optic communications, high speed image processing, real-time extraction of information from images coming in at 20 MB/s, and machine vision interpretation of image informatics for understanding and classifying targets, organisms, and substrate. Using an image annotation tool, we are currently able to manually identify over 450 taxonomic categories and classify substrate to 51 categories.

In 2012 the HabCamV4 vehicle and imaging system (Fig. 13) was constructed. The redesign objectives of this project were to expand the current capabilities by adding the following: 1) Stereo cameras for imaging in 3D to allow for accurate measurements of scallops and ground fish regardless of their orientation, 2) Addition of an integrated Benthos C3D side scan sonar system for acoustically imaging 50 m or more out to either side of the vehicle, 3) A software database for storing metadata and a 45 TB sea going server for storing images in real-time while towing at sea for 6 to 7 days, 4) A web-enabled human annotation GUI to allow for annotation of images from anywhere on the network or while at sea, 5) Sensors for measuring chlorophyll, turbidity, CDOM, wavelength-specific light attenuation, dissolved oxygen, pH, and plankton using a high resolution imaging system, 6) Additional ports for serial and Ethernet devices to be added at a later date, and 7) Automated classification of sea scallop and substrate. While we will undoubtedly be working on item 7 for many years to come, items 1-6 have been implemented and are fully operational on the NOAA NEFSC annual sea scallop survey conducted each spring with the HabCamV4 system.

Applications: While the HabCamV4 system will be used for years to come in the annual scallop survey, several other applications have been identified and implemented. In August 2013, the Habitat Group at the NOAA Sandy Hook Lab used HabCamV4 to survey for sea bass habitat while surveying for likely locations to deploy wind farm towers in the Maryland BOEM wind farm area. Another application that has become evident while completing routine towing of HabCamV4 along the seafloor is water column profiling. Water column processes are central to delivery of food and energy to the benthos and in many ways are responsible for structuring benthic communities, particularly at hot spots such as at the base of persistent fronts. Profiling the imaging system actually provides more and better (higher spatial resolution) information than an on-board CTD. We have adopted the plan of profiling the water column every hour at a minimum on every survey conducted since June 2013 and will continue to do so in future surveys. Water column data along the entire shelf may then be gridded at 5 m depth intervals to provide localization of critical process that would otherwise go unnoticed.

One additional application is the utilization HabCam data for Habitat Suitability Index (HSI) modeling. Using the high resolution spatial data obtained from HabCamV4 and output from the on-board side scan sonar for collecting data on bathymetry, geomorphology (slope, gradient, rugosity, etc.), substrate type, epifauna coverage (% cover), and water column process (temperature, salinity, chlorophyll, pH, DO, etc) coupled with remote sensing (AVHRR, SS color, etc.) information to produce multiple raster layers at a defined scale, which we call predictor layers. The presence and

Habitat Mapping Camera System (HabCam) (cont'd)

absence information obtained from the imaging system provides data on the presence and distribution of a variety of targets from scallops to ground fish. By combining all of the predictor layers into a statistical model with the presence and absence data for specific targets, we can predict the probability of finding that target at locations that were either sampled poorly or not at all. Such HSI modeling can be very powerful by providing information on habitat that may be used to directly improve stock assessment through optimization of sampling design such as stratifying on critical habitat for the species in question. Finally, the output from HSI models may be used in "what if" projection scenarios given climate change and ocean acidification to assess how species and communities may change in light of these forcing functions.

Acknowledgements: We would like to thank HabCam Group members- Richard Taylor, Norman Vine, Karen Bolles, and the crew of the F/V Kathy Marie, the NOAA Team members- Victor Nordahl, Joseph Godlewski, Rob Johnston, Dvora Hart, Burton Shank, Paul Rago, Russ Brown, Nicole Charriere, Jon Duquette, Geoff Shook, Richard Langton, Vince Guida, and Jennifer Sampson, and WHOI Team members Amber York, Jon Howland, Jared Schwartz, Glenn McDonald, Lane Abrams, Hugh Popenoe and the R/V Hugh R. Sharp Crew and Officers for their commitment to the development and application of the HabCam system and their continuing support.

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Habitat Mapping Camera System (HabCam) (cont'd)

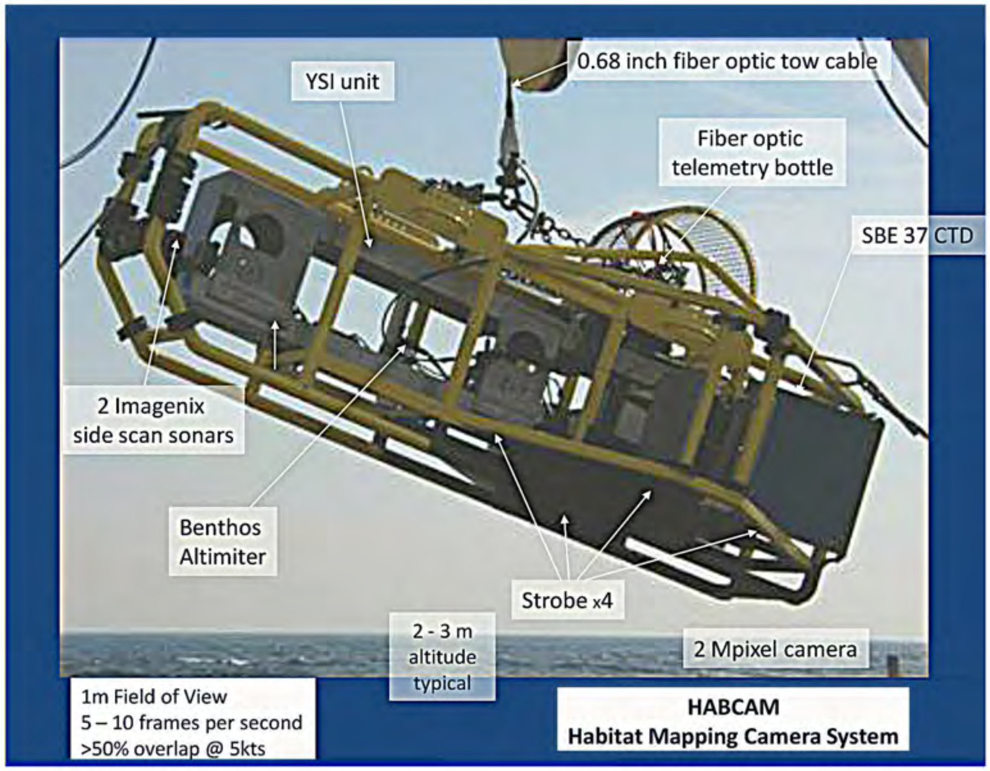


Figure 12. HabCamV2 ready for deployment. This system has a single machine vision 16 bit Bayer color camera, CTD, and an Imagenix 881a sector scanning sonar on the nose of the vehicle.

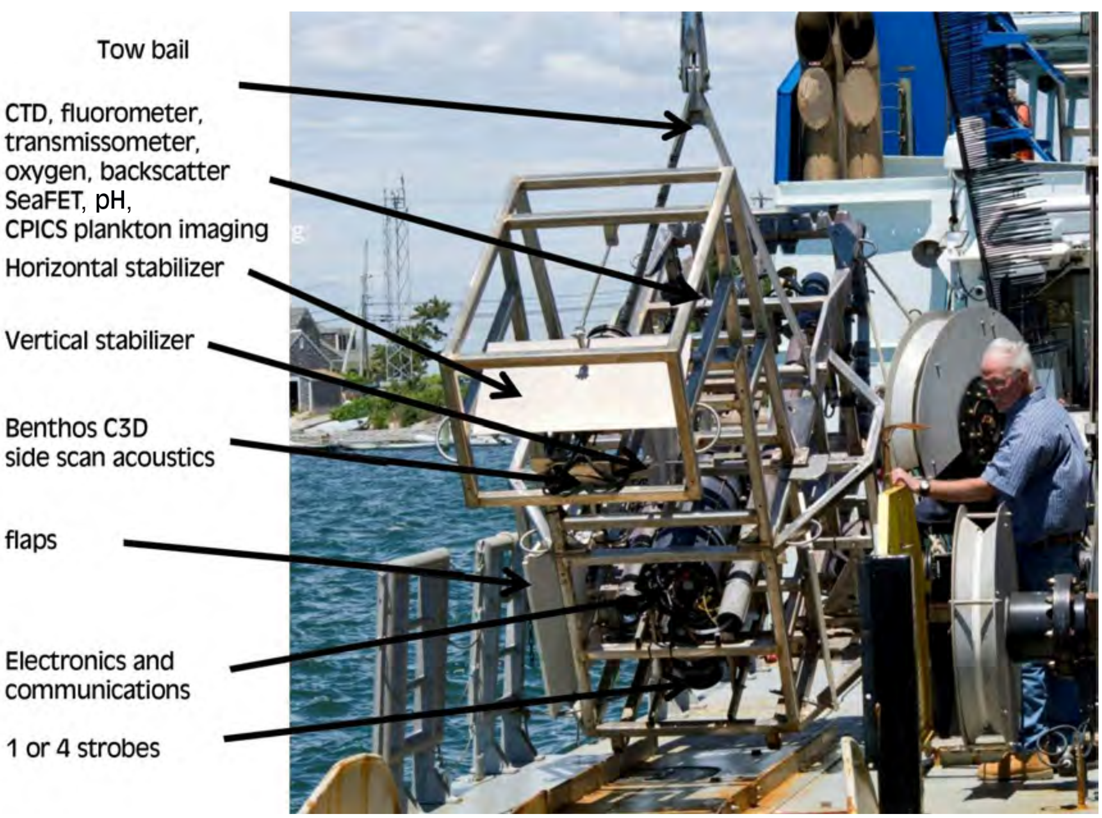


Figure 13. The NOAA NEFSC HabCamV4 imaging system. Stereo cameras, integrated sidescan acoustics, plankton camera, light attenuation, Dissolved Oxygen, and pH sensors have been added to provide a complete a picture of habitat as possible.

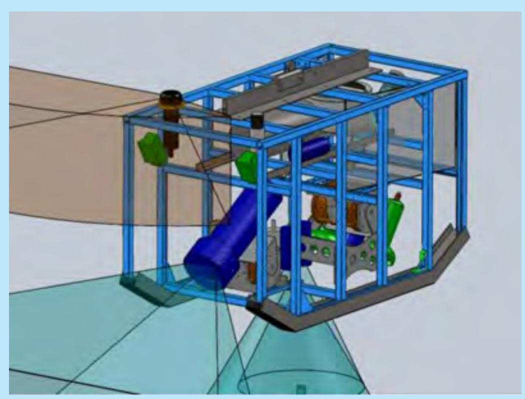
Kraken II ROV and ISIS Towed Camera Sled

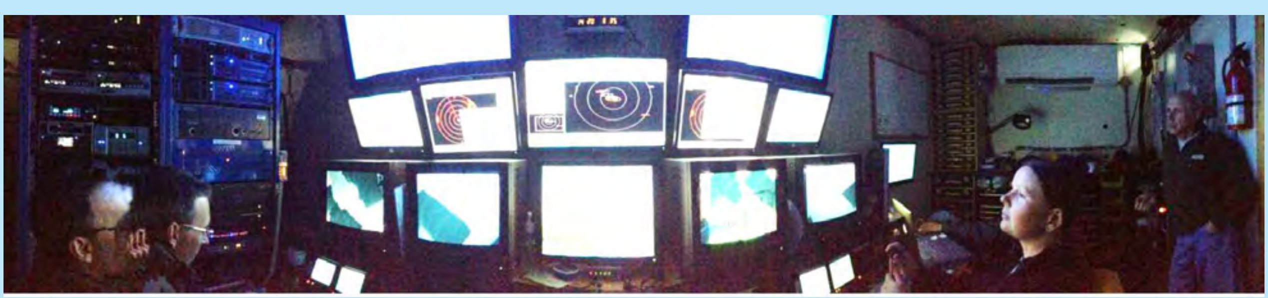
Presenters: Babb, Auster

ISIS Towed Camera Sled

The Instrumented Seafloor Imaging System (ISIS2) was developed as an exploratory tool and "smart" camera sled to collect high resolution seafloor imagery (video and digital still) in steep topographic settings (e.g., where corals occur in the northern Gulf of Maine and along canyon walls) (Fig 14). The 1000 meter system is operated via an electro-optic cable to support high definition and standard definition video cameras, movable lights on pan-tilt units, a digital still camera with electronic flash, sector scanning sonar, and altimeter. Space for CTD and other sensors have been included within the framework and telemetry and power can be accommodated via a pressure balanced oil filled junction box. The operational objective is a "flyable" vehicle providing the pilot with real-time imagery with which to control the depth off bottom via a winch (z-axis movement) in combination with dynamic positioning of the surface support vessel (x & y axis movement along the seafloor) to conduct near bottom transects in precipitous topography. The vehicle-winch configuration allows rapid launch and retrieval to occupy more stations per unit time than could be achieved with a two vehicle ROV-depressor-winch configuration that requires greater launch/recovery time at the surface. The ISIS2 sacrifices significant maneuverability and station-keeping and the ability to collect physical samples for the capability to occupy many stations.

Figure 14. The ISIS 2 vehicle during launch (left). Optical and acoustic imaging details in concept drawing (right). View of control van (below).





Kraken II ROV and ISIS Towed Camera Sled (cont'd)

Kraken 2 ROV

The Kraken2 (K2) vehicle is a purpose-built "science class" ROV (remotely operated vehicle) capable of operating to depths of up to 1000 meters (Fig 15). The K2 platform uses a dual tether, down-weight system, comprised of a main Kevlar reinforced electro-optic cable spooled on an oceanographic winch that is coupled to a secondary 45 meter electro-optic flying tether. A variable weight depressor frame, configured between 500-1000 pounds, provides a junction point for the transition between tethers as well as isolation between the vehicle's movements and those of the support vessel above. A modified 20' ISO shipping container provides the primary operations center incorporating all power, control, navigation, and data recording equipment associated with the K2 platform. Along with providing accommodations for the ROV pilot, navigator, and two science personnel, this space also doubles as the primary workshop from which all routine vehicle maintenance is performed.

The K2 platform can support up to two simultaneous hi-definition (HD-SDI) and four standard definition (NTSC) video feeds and up to nine independent video and digital still cameras (HD and SD) configured on the vehicle. Vehicle design allows flexible configuration of multiple, simultaneous camera systems for qualitative and quantitative imaging and recording on multiple formats; e.g. Hi-definition video for documentary or oblique view transect imagery, down-looking video cameras for quantitative orthogonal imagery during transects, manipulator camera for imaging in hard to reach spaces, sampling cameras, and digital still imaging. The vehicle can also contact closure to support 35 mm still or digital triggered devices. Two sets of independently switched parallel laser pairs can be used for size scaling and image calibration (20 cm typical). Up to four individually switched lighting circuits (1 to 2 lights per circuit) offering a flexible combination of lighting systems and configurations. A heavy duty center-positioned pan/tilt unit with potentiometer feedback can accommodate various imaging, lighting, and scaling systems that require movement during dives. The pan/tilt includes logged and user-selectable "home" pan & tilt settings that return the camera to a known angle for conducting repeatable transects.

Beyond imaging, the K2 supports multiple acoustic systems (sector scanning sonar and altimeter sonar) and tools for physical sampling. The vehicle provides independently switched electrical power supply ports in both DC (5, 12, 24 V) and AC (120 V) to support a range of user supplied subsea sampling tools and sensors as well as independent serial data ports (RS-232, RS-485, & RS-422) to accommodate a range of data transmission and control requirements (independent Ethernet ports are available as an expansion capability). A 6-funtion hydraulic manipulator with various claw and wrist attachments (i.e. coral cutter, scoop tool, camera mount, etc.) supports physical and biological sample collection, device deployment, component recovery, and other manipulative functions. A secondary 6-function hydraulic valve pack (+/- 2400 PSI) can support additional science sampling applications and devices. Configurable specialized sampling tools and containers can accommodate physical, chemical and biological sampling requirements; including 1) a 12"w X 36"l X 10"h insulated polypropylene "biobox" mounted to a hydraulic extensible sample tray, designed to keep specimens at ambient water temperatures; 2) an integrated suction sampling system incorporating a high power, variable speed, bi-directional suction pump and eight-bucket suction sample rotisserie allowing for independent sample collection; 3) 4"x4" mechanically (manipulator) closed stainless steel boxcores; 4) various diameter & length tube/punch cores and quivers; 5) opening/closing detritus samplers; and 6) an 18 quiver carousel for isolating small specimen samples (e.g., corals).

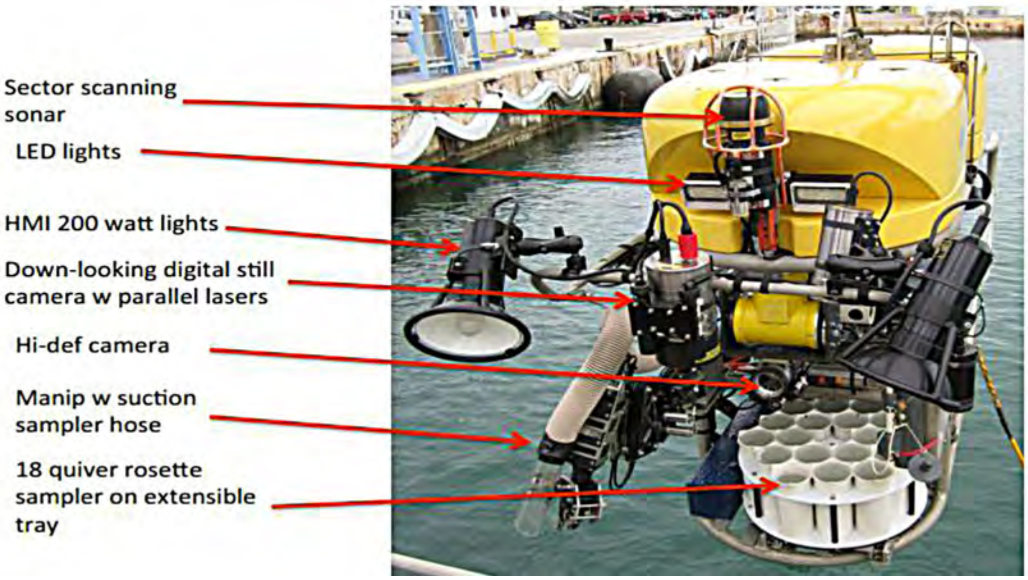


Figure 15. Configuration of the K2 ROV for coral collections.

Canadian Remotely Operated Platform for Ocean Science (ROPOS)

Presenter: Wakefield, in collaboration with Shepherd, Morgan, Proskurowski, Kelley

The ROPOS (Remotely Operated Platform for Ocean Sciences) vehicle is a science/work-class ROV (Remotely Operated Vehicle) designed to support a broad range of scientific and engineering missions, including fisheries surveys; ocean exploration across a broad range of disciplines; development, installation and maintenance of cabled ocean observatories; and remotely operated cable laying (Figure 16, Table 1). Over the history of its development and operations, the ROPOS ROV has gone through three generations: 1986, 1996, and 2005. It is most accurate to consider ROPOS as a series of sub-systems that provide mission-specific flexibility through five systems with multiple arrangements: the vehicle, control, power, launch & recovery, and support systems. Each system is configured to best suit the operational goals, the support platform, and the budget of its users. The ROPOS vehicle has three general configurations employing three interchangeable foam packs which provide buoyancy to the vehicle:

1. Shallow configuration – Vehicle is "free-flying", using a synthetic tether supporting operations to 1000 meters. In this configuration, its small footprint, "light" weight, and neutral tether make it an ideal configuration on small vessels and for coastal operations.
2. 3000-meter configuration – Vehicle is free-flying, using an armored umbilical, and is deployed through a crane-based Launch and Recovery System (LARS) (Figure 16). In this configuration, ROPOS can be deployed without an A-frame or ship's crane and work in more severe weather conditions, up to sea state 6.
3. 5000-meter configuration - In its deepest configuration, ROPOS used a cage tether management system (TMS). The cage could be lowered down to 5000 meters using a ship's A-frame and ROPOS' deep winch and armored umbilical. This configuration was decommissioned, and currently, there is a refit plan in place for this deep configuration.

Table 1. Technical Overview.

ROPOS	The Remotely Operated Vehicle for Ocean Sciences (ROPOS) is a 40 hp Science/Work Class Remotely Operated Vehicle (ROV) capable of opersating at depths of up to 5000 m
Size and Weight	3.05 m (length), 1.64 m (width) and 2.17 m (height), 3393 kg
Speed	2.5 knot (forward max), 1.0 knot (typical transect), 1.0 knot (lateral), and 1.5 knot (vertical)
Sea State	Sea State 6 (Using LARS heave compensation system)
Video	Two HD Cameras, Six pilot and tooling cameras, 12.1 megapixel digital still camera and over 3700 watts of lighting
Manipulators	2 x Kraft Predator spatially correspondent 7-function with force feedback
Through Frame Lift	1815 kg with a 5.1 safety factor, tested to 3629 kg. Uses four point attachment for under-slung payload or skid interface

Canadian Remotely Operated Platform for Ocean Science (ROPOS) (cont'd)

Figure 16. ROPOS with crane-based Launch and Recovery System (LARS) (Canadian Scientific Submersible Facility). ROPOS is equipped with state-of-the-art HD video cameras,

ROPOS is equipped with state-of-the-art HD video cameras, a high-sensitivity full-frame 12.1 megapixel digital still camera, and over 3700 watts of lighting (Table 2, Figure 17). All video and digital still images are geo-referenced and recorded in a digital format. The ROPOS system includes an Integrated Real-time Logging System (IRLS) which is an intuitive annotation tool that brings together frame grabs, digital still pictures, and many other files with flexible organizational elements that create a dataset that can be tailored to a given research project. In addition to its normal configuration with forward looking cameras, the ROPOS digital still camera has been used to create photomosaics of the seafloor (Figure 18). In this application, the camera is positioned low on the vehicle and oriented it so it is pointed vertically down. The majority of the lights that are normally located on the 'brow' of the vehicle are repositioned onto the swing arms and manipulators. With the camera and lights repositioned in this configuration, an array of overlapping images can be combined to create a high-resolution mosaic of an area of seafloor.

One of the strengths of ROPOS is its capacity to integrate and use complex scientific and engineering tools for a wide range of seafloor tasks by: interfacing with sensors via RS-232, RS-485, RS-422, Ethernet and single-mode fibers; providing 5 VDC, 12 VDC, 24 VDC, and 115 VAC power (other power requirements can be accommodated) and hydraulic connections to run a variety of hydraulic tools. Hundreds of tools and sensors have been used and interfaced on ROPOS.

Canadian Remotely Operated Platform for Ocean Science (ROPOS) (cont'd)

Table 2. ROPOS imaging systems.

PRIMARY HD CAMERS	Insite Pacific Zeus-Plus HD camera (10x Zoom) mounted on a pan and tilt with extend function
PILOT CAMERA	WATEC (Wide-Angle low light camera (tilt function)
SECONDARY HD CAMERS	Insite Pacific Mini-Zeus HD camera (tilt function)
DIGITAL STILL CAMERA	12.1 megapixel Nikon D700 digital still camera with 14-24 mm AFS f2.8 lens (tilt function)
AUXILIARY CAMERAS	DSPL Nano SeaCam, 3x Bowtech L3C-550 colour camera, WATEC Wide Angle
VIDEO SCALING	2 pairs of 10 cm spacing scaling lasers
VIDEO RECORDING	2x Digital Rapids StreamZHD recorders with closed-caption encoders (geo-referencing)
LIGHTING	3 x 400W HMI, 3 x 350 W LED, 2 x 150 W HID, 8 x 150 W LED

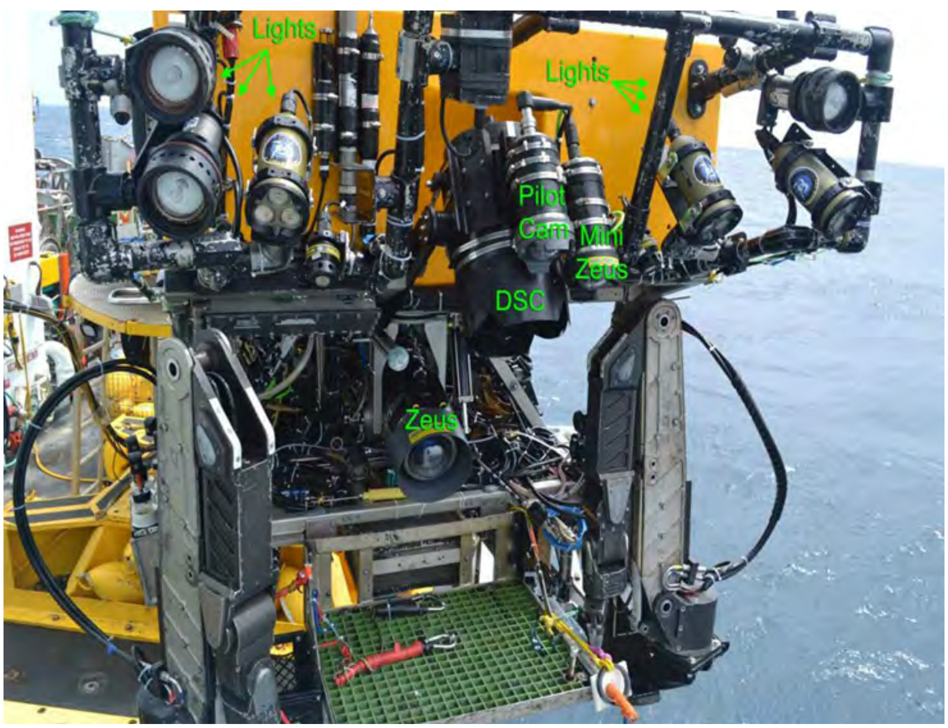


Figure 17. ROPOS ROV showing the location of HD videos, digital still camera and lighting (University of Washington Interactive Oceans).

Canadian Remotely Operated Platform for Ocean Science (ROPOS) (cont'd)

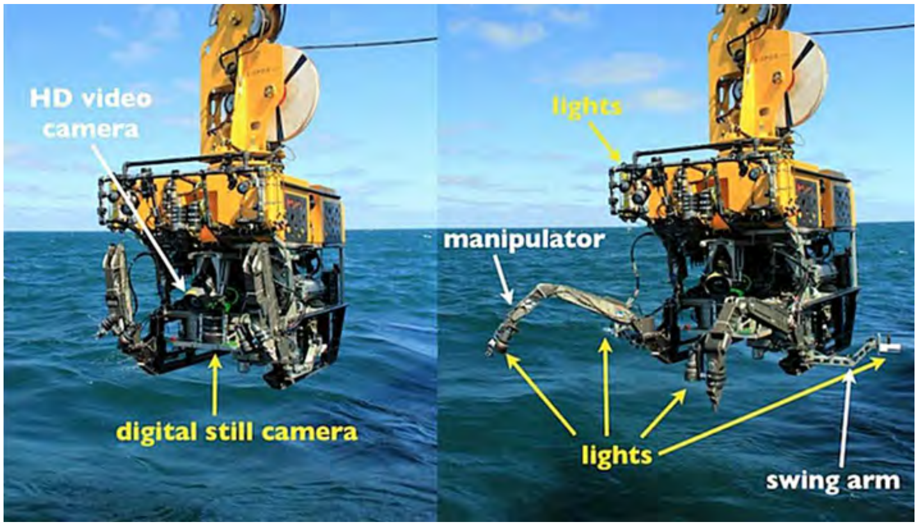


Figure 18. ROPOS with the digital still camera and lights repositioned to optimize the vehicle for a down-looking still image survey (University of Washington Interactive Oceans)

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Websites

Canadian Scientific Submersible facility website:
http://www.ropos.com/index.php/ropos-rov

Other ROPOS relevant websites

http://www.interactiveoceans.washington.edu/story/_ROV_ROPOS
http://ooi.washington.edu/story/VISIONS_13
http://ooi.washington.edu/story/Robotic_Vehicles
http://www.schmidtocean.org/story/show/2048
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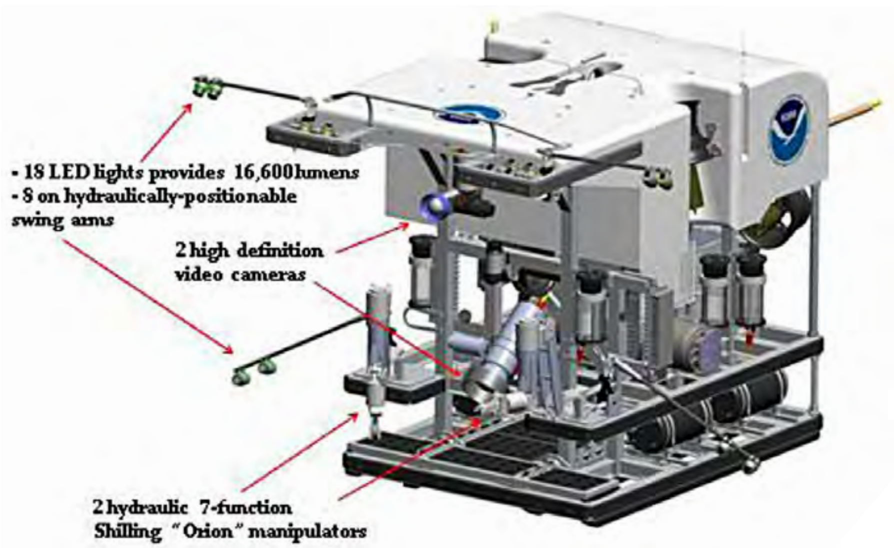
Okeanus Explorer's Dedicated Dual Body ROVs

Presenter: Nizinski, in collaboration with Lovalvo

Commissioned in August 2008 as the Nation's ship for exploration, NOAA Ship Okeanos Explorer explores the world's oceans for the purpose of discovery and the advancement of knowledge. The ship has telepresence capabilities, which allows it to stream up to three high definition video feeds to shore in real-time via broadband satellite communications. Thus, discoveries are shared live with audiences ashore. The ship supports a sophisticated ROV system that was developed and is maintained and operated by the Office of Ocean Exploration and Research's Deep Submergence Group (Fig 19). Details of the Okeanos Explorer and her ROV missions can be found at: http://oceanexplorer.noaa.gov/welcome.html

Figure 19. Okeanos Explorer Deep Discoverer ROV and Seirios camera sled

ROV DEEP DISCOVERER (D2)



CAMERA SLED SERIOS

Deep Discoverer, or "D2", is a 6,000 m rated ocean exploration remotely operated vehicle (ROV). Operating from the NOAA ship Okeanos Explorer, D2 is part of an advanced two-body tethered system. Its two high definition cameras and 16,600 lumens of hydraulically positioned LED lights produce broadcast-quality high definition video streamed live

Okeanus Explorer's Dedicated Dual Body ROVs (cont'd)

to internet connections around the world via telepresence. Navigational sensors, including a fiber optic gyroscope and doppler velocity log, 40 HP of electric propulsion, and an integrated control system capable of precise auto-pilot flight and station-keeping, allow pilots to image the most obscure objects of the subsea world. D2 transmits real-time sensor measurements of conductivity, temperature, depth, pressure, and more through its high speed fiber optic communications. Additionally, a hydraulic pump powers two 7-function manipulators and an extendable utility drawer. Three large syntactic foam blocks give D2 the ability to install up to 400 lbs of additional equipment making Deep Discoverer a very flexible platform for ocean exploration. Following is a list of general attributes:

(2) Schilling Orion Manipulators
(1) Kongsberg OE14-122/23 Pan, Tilt, and Zoom Color Camera
(1) Paroscientific 8B7000-1 Depth Sensor
(1) RD Instruments Workhorse Navigation Doppler Velocity Log WHN600-I-UG20
(2) Deepsea Power & Light Matrix LED Lights
(16) Deepsea Power & Light SeaLite Sphere LED Lights
(2) Deepsea Power & Light Micro Lasers
(1) Insite Zeus Plus HD Camera
(1) Insite MiniZeus HD Camera
(1) Insite Titan Tilt, Pan & Zoom Camera
(3) Insite Aurora Color Cameras
(1) IXSEA PHINS Fiber Optic Gyro
(1) Tritech S8540 SeaKing Dual Frequency Scanning Sonar
(1) Seabird SBE9Plus CTD
(1) PNI Corp TCMXB Compass
(1) LinkQuest Tracklink USBL
(2) Parker 1144X 10 HP Vertical Thrusters
(2) Parker 1142X 5 HP Axial Thrusters
(2) Parker 1142X 5 HP Lateral Thrusters
(1) Parker 1144X 10 HP Hydraulic Motor
(1) ROS R-25 RS-485 Rotator
(1) ROS PT-25-FB Pan and Tilt

The second component of this two-part system, Seirios, is a stainless steel framed platform of cameras, lights, and sensors attached to the ship by the electro-optical-mechanical 0.68 cable. Seirios, also 6000 m rated, carries an articulated HD camera and six 400 W HMI lights for video production and improved lighting for D2. Fore and aft lateral thrusters enable Seirios to turn 360 degrees to maintain illumination in a desired direction. Seirios can also move laterally, within the constraints of the its cable. With the ROV attached by a 30 m neutrally buoyant tether, one significant reason for utilizing Seirios in this two-body configuration is to decouple Deep Discoverer from the ship's motion. A suite of sensors provide real-time measurements of parameters such as conductivity, temperature, depth, and pressure, which are transmitted through high speed fiber optic communications.

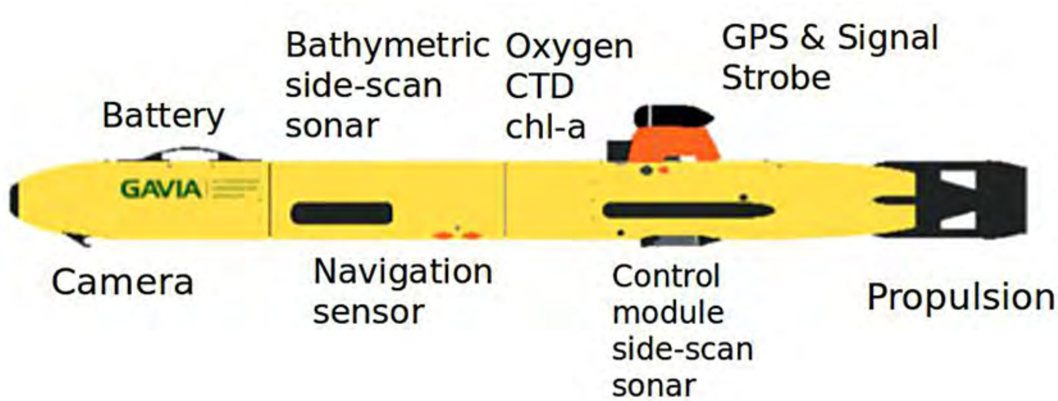
GAVIA Autonomous Underwater Vehicle

Presenters: Kannappan, in collaboration with Trembanis

The GAVIA Autonomous Underwater Vehicle (AUV) is fully autonomous underwater robot that can execute a programmed mission transect running at either a constant altitude above the seabed or a constant depth below the surface and collect data along this transect (Fig 20). The Gavia AUV houses a Point Grey Scorpion 20SO research camera at the nose of the AUV and an LED light strobe is located behind the camera (synced to the camera). The other sensors it carries are side-scan sonar (900 and 1800 kHz), bathymetric side-scan sonar (500 kHz), dissolved oxygen, chlorophyll-A and CTD (Conductivity, Temperature and Depth). The AUV is capable of very accurate localization using the onboard navigational systems: Differential Global Positioning System (DGPS), Inertial Measurement Unit (IMU) and Doppler velocity log. The AUV system is organized into physically separable modules namely, the camera module, battery module, bathymetric sonar module, navigation module, control module, and propulsion module. The AUV modules can be easily assembled and deployed from a ship. One primary advantage of the system is its ability to localize accurately, which in turn helps to run tight transect lines to collect measurements from an area. One drawback is the limited communication bandwidth available, which prevents real-time data transfer. The AUV has been used to measure abundance of scallops, sponges, and conduct geoacoustic habitat mapping in a variety of marine and freshwater settings.

For more information about AUV systems and our datasets, visit the website http://subseaobservers.com/

Figure 20. GAVIA autonomous underwater vehicle



GAVIA Autonomous Underwater Vehicle (cont'd)

Technical Specifications:
Weight: 77 kg
Depth: 500 m depth rating
Length: 2 m
Duration: 4 hours
Habitat Mapping Sensors-
Side-scan sonar (900/1800 kHz)
Bathymetric side-scan sonar (500 kHz)
Digital Still Camera with Strobe
Water Quality Sensors-
Salinity
Temperature
Oxygen
Turbidity
Chl-a

Selection of related publications

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Human-Occupied Submersibles

Presenter: Yoklavich

The Southwest Fisheries Science Center Fisheries Ecology Division Habitat Ecology Team (http://swfsc.noaa.gov/HabitatEcology/) carries out research on deep-water California demersal communities in untrawlable habitats. For over twenty years, we have used a human-occupied submersible (HOV; Figure 21) to conduct hundreds of visual surveys of juvenile and adult demersal fish species and their habitats on the continental shelf and slope in 20-440 m water depths off southern and central California. Results of these surveys in conjunction with seafloor habitat maps have been used to (1) implement and initiate long-term monitoring of spatial management strategies, such as marine protected areas (MPAs), in federal and state waters; (2) improve stock assessments for overfished species that occur in complex rock areas; (3) characterize fish and habitat associations; and (4) determine distribution and abundance of marine debris, corals, sponges, and other invertebrates in deep water.

Figure 21. The yellow Delta (right) and red Dual Deepworker (left) research submersibles accommodate one scientific observer and one pilot, and were operated to a maximum depth of 365 m (Delta) and 440 m (Dual Deepworker) at a survey speed of 0.5-1.0 kts.

Human-Occupied Submersibles (cont'd)

Collaborators in our program are from University of California, Santa Barbara and Moss Landing Marine Laboratories, among others.

Our HOV surveys follow protocols that have been vetted and peer-reviewed in the scientific literature. A pilot operates the HOV while an experienced scientist identifies and counts all fish species along a quantitative transect and estimates fish length using paired lasers as a guide. Each transect is annotated in real-time by the scientific observer and documented with multiple video cameras inside and outside the HOV. The HOV is equipped with a Doppler velocity log and ring-laser gyrocompass to accurately locate and measure each transect, a manipulator arm for specimen collections, and CTD sensors to record temperature, conductivity (salinity), pressure (depth), and oxygen concentration during the dives. The primary advantage to using an HOV is that in situ scientific observations enhance the detection and identification of a diverse group of similar-looking, often cryptic species in high-relief rock habitats. The ability to reliably identify and count target species is a key requirement of accurate stock and habitat assessments. Other advantages in using an HOV include: portable platform used on a variety of support vessels and in a variety of ocean conditions; highly maneuverable and tractable particularly in high-relief topography; and a relatively small environmental impact in terms of artificial light, sound, and motion produced by the HOV. In addition, the reaction of fishes to an HOV has been found to be far less than reaction to a Phantom remotely operated vehicle (ROV) while in survey mode. Presently the main disadvantage in using a small HOV is that these vehicles are no longer available. The obvious solution to this challenge is for the underwater research community to commit to HOVs as a valuable survey tool and to secure funding to build and maintain a new HOV for underwater research on the west coast.

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GENERAL DISCUSSION

A summary of participant's comments and recommendations

Utilization of the ocean's resources has increased dramatically over the last 50 years and the rate of change is going to increase more in the next few decades, as is the need for monitoring the change. In the Northeast, annual trawl surveys commenced in 1963 and rapidly became the benchmark of change for fishery management beginning in 1976 with the inception of the regional Fishery Management Councils. The trawl surveys are based on depth-stratified, randomly selected, stations across the continental shelf from Nova Scotia through the Mid-Atlantic Bight. However, the area available for such surveys is soon to be restricted by the advent of offshore wind farms. Wind energy areas, which are proposed for the continental shell off virtually every state, could become de facto marine reserves, with possible direct impacts on both fishery independent trawl surveys and commercial and recreational fisher's behavior. Fishery independent stock assessment survey designs may be altered to account for no-fishing zones, and retrospective analyses will require adjusting the station data to eliminate areas that were previously available for trawling. Wind farms may also become nature's fish farms, to the extent that wind towers become new habitats for both invertebrates and their fish predators. This will attract commercial fishing around the perimeter, as is currently observed with areas closed to fishing, whereas recreational fishers may have access to wind farms and concentrate their fishing within the perimeter.

Changes in ocean utilization raise the question of how best to monitor fisheries and their allied resources. Although finfish continue to be extensively and repetitively surveyed in the Northeast, there has only been one comprehensive seafloor survey in the region, and it was conducted during the 1960s primarily to characterize sediments, but also generated a database on benthic organisms. Other surveys have assessed specific communities, such as those associated with scallop beds or dump sites, to address specific questions related to activities like fishing or the impact of ocean dumping on the benthos, but a scheme for systematic broad scale monitoring has never existed. Workshop participants identified a growing interest and need for developing a more systematic approach to characterizing and monitoring seafloor communities, parts of which are the base of the food chain and habitat for commercially and recreationally important finfish.

Wind energy development requires both pre- and post-construction monitoring, with the preconstruction phase including the establishment of an environmental baseline and identifying potentially sensitive and/or unique habitats that should be protected from development. Once the farms are in place, monitoring will continue to evaluate longer-term impacts. This will afford the opportunity to establish sentinel sites for assessing benthic community change. Ultimately it may be possible to have a series of AUVs patrolling wind energy farms and uploading imagery of the benthos from precise locations through time, as well as fixed instrumentation that will overlay environmental data on the image stream. Ocean Cubes (www.OceanCubes.WHOI.edu), as proposed by Woods Hole Oceanographic Institution, is one example of this kind of futuristic ocean monitoring system.

Given the current variety of underwater survey equipment that is being used to characterize different seafloor communities, workshop participants suggested that a series of survey sites be established to allow for inter-calibration among gear types and generation of correction factors for comparison of data sets collected by different sampling systems. A series of geographically unique calibration sites, could be integrated into a sentinel site concept.

Sampling bias associated with any survey gear can result from many factors, including noise, light, motion and pressure waves generated by the gear. Such biases were discussed by workshop participants. Gear disturbance can result in avoidance by some mobile species, leading to underestimates in density, or in attraction of other species, resulting in an overestimation of densities. Some participants have conducted analyses of bias for particular pieces of survey equipment, and this type of study needs to be done with all imaging systems. It is akin to determining trawl efficiency for different gear types. It was stressed that the more we can make the underwater vehicles "fish like", or stealthier, the closer we will be to accurately reflecting the relationships that exist between marine animals and their habitats. The need for studies of bias underline the necessity of creating calibration sites that could be surveyed by all gear types.

The quality of underwater images is important, and discussion of this topic introduced the term, machine vision.

GENERAL DISCUSSION (cont'd)

Machine vision refers to the capability of extracting information from digital images through the use of algorithms. The hope is that machine vision will be used to more efficiently collect accurate data on the detection, quantification, and measurement of organisms and the classification of seafloor substrata. While the basic quality of the image is a function of image processing, it was noted that machine vision is challenged by the complexity of the habitat and the diversity of organisms. A major challenge is matching the equipment utilized to document the seafloor with the habitat type in order to optimize machine vision.

Data management was a topic of discussion at the workshop. It was stated that the challenge in processing increased amounts of digital data is, comparable to learning to drink from a fire hose. In other words, a major challenge is the massive quantity of data generated from image-based surveys. Data management is perceived as a major bottleneck in the field of underwater imagery by many environmental scientists, but by teaming up with experts in informatics such bottle necks can be circumvented. Automation of the identification of animals and habitats is part of the solution, and could be a useful tool, depending on the level of taxonomic and/or physical identification required There are also open source software annotation systems available (for example: http://squalus.whoi.edu/static/annotator.html# contact Scott Gallager [sgallager@whoi.edu] for an explanation) that will help standardize data management and retrieval but a standardized workflow does not satisfy all needs. Some participants indicated that reworking of raw data collected for one purpose is sometimes required to generate a needed final product in another application. This highlights the issue of needing comprehensive metadata as well as the archiving of raw data as part of any management system, so that realistic comparisons can be made over time.

One of the issues all workshop participants faced is the cost of developing and operating undersea imaging equipment. As seen in the presentations, these costs can vary tremendously and reflect the disparity between available budgets. It is true that necessity is the mother of invention, which results in the development of systems that fit available budgets. But, it is also equally true that both cost efficiency and scientific output can be enhanced by reducing redundant and duplicative effort. The participants expressed a need for making underwater survey equipment more available, and that regional and national efforts to improve underwater imaging technology be reviewed and considered in light of the growing demand for this kind of information. The now defunct National Undersea Research Program successfully made sophisticated undersea imaging equipment available to the broader scientific community for a number of decades. With the recent decommissioning of the submersible, DELTA, virtually the last vestige of a privately operated US scientific submersible fleet has been lost. It is time to reconsider the nation's needs for not only shallow water submersibles but also a cadre of undersea imaging systems that span the technological spectrum and are available to the broader scientific community.

The question of how to pay for a pool of undersea imaging systems to be shared among government, academic, and private researchers was briefly discussed. One option is to pursue the idea of a National Ocean Endowment (NOE), supported by contributions from offshore exploitation industries that would then finance environmental monitoring and research. Another option might be developed through the Small Business Innovative Research or the Small Business Technology Transfer programs, which are government initiatives that encourage domestic small businesses to engage in Federal Research/Research and Development (R/R&D) that has the potential for commercialization.

The case has been made that there is a growing need for monitoring change in undersea environments as use of the ocean and its resources increases. Baseline data to measure environmental change, over all habitats and spatial and temporal scales of impact, is generally lacking. Generating needed baseline data is a strong justification for moving forward with developing undersea imaging technology. In addition, our understanding of fundamental ecosystem processes and interactions occurring on the seafloor is rudimentary (particularly with increasing depth). Therefore, the development and expanded use of undersea imaging technology for basic research is important to monitoring change. If we do not understand the consequence of change to seafloor communities as we expand our use of ocean space, we face the prospect of exceeding a regime shift threshold, from which there are no steps back.

Appendix 1: Participants List and Collaborators

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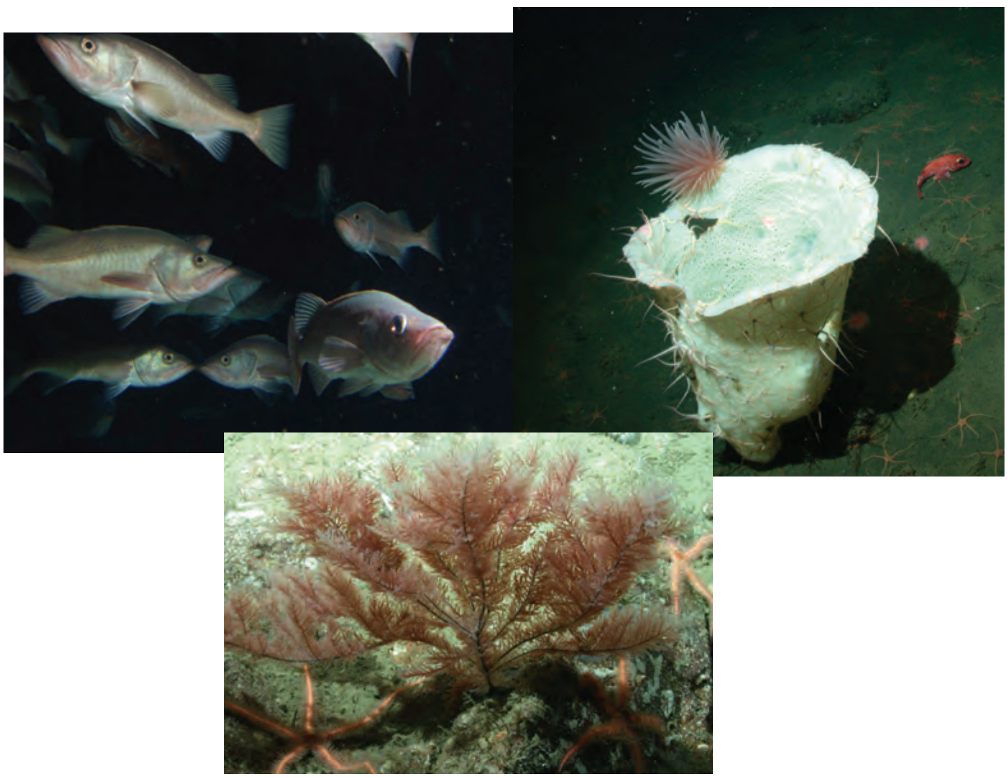

Photos - Mary Yoklavich

Sea Grant
NJ Sea Grant Consortium

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE