Report of the National Marine Fisheries Service Workshop on Underwater Video Analysis

August 4-6, 2004

D. A. Somerton and C. T. Glendhill (editors)

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-68
May 2005

Report of the National Marine Fisheries Service Workshop on Underwater Video Analysis

August 4-6, 2004

D. A. Somerton and C. T. Glendhill (editors)

NOAA Technical Memorandum NMFS-F/SPO-68
May 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., USN (Ret.)
Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries

Suggested citation:

Somerton, D. A. and C. T. Glendhill (editors). 2005. Report of the National Marine Fisheries Service Workshop on Underwater Video Analysis. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/SPO-68, 69 p.

A copy of this report may be obtained from:

Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115

Or online at:
http://spo.nmfs.noaa.gov/tm/

CONTENTS

Other State and Government Research Programs

Invited Experts

Introduction

David Somerton
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Email: David.Somerton@noaa.gov

Christopher Gledhill
Southeast Fisheries Science Center
Pascagoula Laboratory
3209 Frederic St.
Pascagoula, MS 39567
Email: Christopher.T.Glendhill@noaa.gov

Underwater video photography has been an important tool used in research applications by the National Marine Fisheries Service (NMFS) for many years. Recent and rapid development of digital video camera equipment with improved image resolution and low-light sensitivity, as well equally impressive advances in video analysis software, has given underwater video photography new emphasis as an important tool for providing quantitative data useful for assessment of fish stocks and evaluation of essential fish habitat.

To showcase and explore this emerging technology and to provide a forum to allow NMFS researchers from its various programs that use underwater video to meet each other, exchange ideas, and possibly form partnerships, the NMFS' Advanced Sampling Technology Working Group sponsored a workshop on August 4-6, 2004 at the Alaska Fisheries Science Center to bring together university, industry, and government researchers.

Within NMFS alone, 20 separate programs use underwater video either to assess fish or invertebrate stocks or to classify essential fish habitat (EFH) and its use. Researchers from 16 of these programs attended the workshop and presented the objectives of their programs, the role played by underwater video and the technologies used for the collection and processing of video data. Although these projects differ widely in the technologies used to collect video data - including towed, dropped or diver-held cameras, minisubs and remotely operated vehicles – nearly all of the projects conduct research in areas with irregular, hard bottoms that are unsuitable for sampling with trawls or other tools traditionally used in fisheries research.

In addition to NMFS scientists, scientists from two non-federal governmental research projects that use underwater video attended, as did a variety of university and non-governmental researchers specializing in such diverse topics as optical pattern recognition for automatic counting of object, video mosaics for determining larger scale orientation of objects, stereo video for estimating fish length and sampled area, and video databases for allowing the retrieval of video data according to other variables such at time, depth and species.

Using Video to Map Distribution of Habitat and Fish in Alaska

Chris Rooper and Mark Zimmermann
Resource Assessment and
Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email:Chris.Rooper@noaa.gov

The objectives of the habitat research team within the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division are to 1) map fish habitat, 2) determine the characteristics that make some habitats important for fish, and 3) assess the impacts of commercial fishing on fish habitat. Within this framework, underwater video is being used to groundtruth sidescan sonar maps to determine the importance of sponge and coral habitat to juvenile rockfish in five study areas in the Aleutian Islands. Video is also being used to assess the distribution and microhabitat use of fishes and benthic invertebrates. Combining the video assessment of habitat with rockfish abundance and fish condition will provide an assessment of the relative value of habitats to their inhabitants, as well as providing insight into the mechanisms controlling fish-habitat relationships.

To date, we have collected video using a drop camera system and a towed video camera sled. The drop camera system consisted of an aluminum frame with two attached lights and an underwater housing containing one black and white video camera with a recording unit (Fig. 1). Two tail chains and two floats were utilized to orient the drop camera system. The camera unit was a modified Waytech CCD camera, and both the lights and camera were powered by a 13.2 volt nickel-metal hydride battery. The entire unit was self-contained, with the battery and camera housed in a metal tube mounted on the frame. This system is easily used off any

Figure 1. Drop camera system used in the Aleutian Islands in the summer of 2003.

research platform, since you simply lower it over the side of the vessel using any type of line available. The video collected was adequate to provide gross classification of habitat types. For example, at one site we observed a sand bottom with brittlestars punctuated by boulders covered with coral and sponges (Fig. 2), while at another site we saw hard bottom completely covered with sponges and coral (Fig. 3). The major disadvantage of this system is the lack of real-time video. Additionally, black and white video

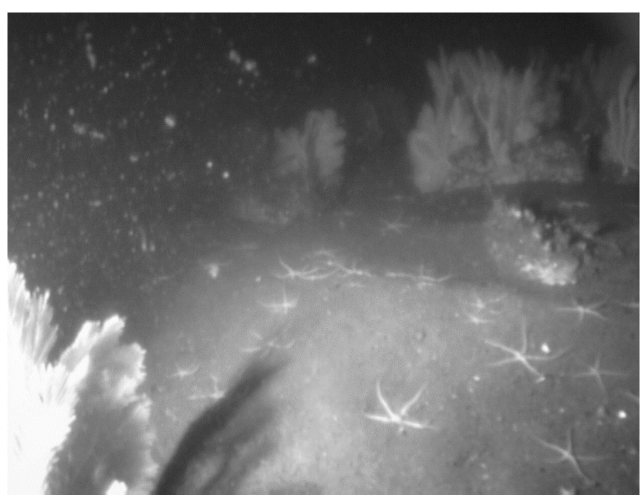

Figure 2. Still frame from the drop camera system collected in habitat consisting of intermittent sand and boulders with coral and sponge covering.

was not ideal for identification of fish, coral and sponges, and the unit cannot be towed, limiting its utility for line-transect work.

In summer 2004, video was collected with a towed, automatically compensating observation system (TACOS); description and sample video can be found at http://www.afsc.noaa.gov/race/groundfish/habitat/tacos_seguampass.htm). This camera sled was equipped with four underwater lights that were powered from the research vessel. The TACOS unit also utilized a down-weight 20 m in front of the camera sled to stabilize the sled motion. The down-weight had an altimeter mounted on it for navigational purposes. The TACOS video system was equipped with analog (Tritech Osprey color CCD) and digital (JVC-HD1) video cameras and a three-laser visual measuring system (Fig. 4). The video was geo-referenced to sidescan sonar mosaics using a calibrated Trackpoint II ultra short baseline system. The video from the analog camera was fed to the research vessel in real time to allow navigation of the camera sled. The digital video camera (high definition) was mounted in a self-contained housing and is not viewed in real time.

Four TACOS transects, each 1,000 m in length, were video taped in three study areas. Data analysis has yet to be completed, but we will use an event-logging program to count the rockfish observed in both of the videos. Habitat changes and the percent cover of coral, sponge and other benthic invertebrates will be recorded from the high definition video along each transect. This data will then be imported into a Microsoft® Access database containing other data collected during the project, such as catch data from trawl hauls. Each entry will be geo-referenced and time stamped.

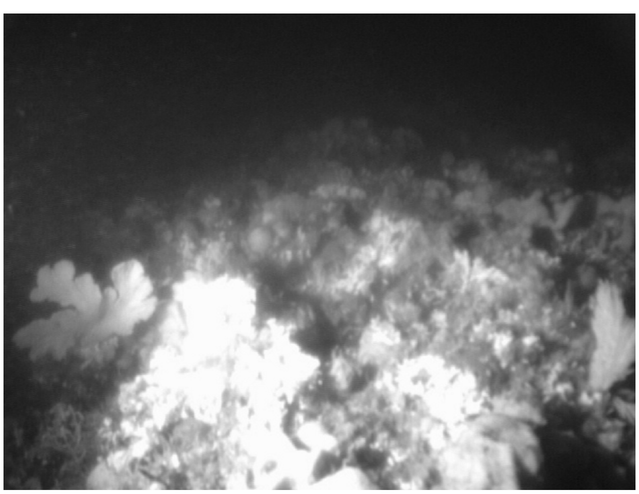

Figure 3. Still from from the drop camera system collected in habitat consisting entirely of hard bottom with a covering of coral and sponge.

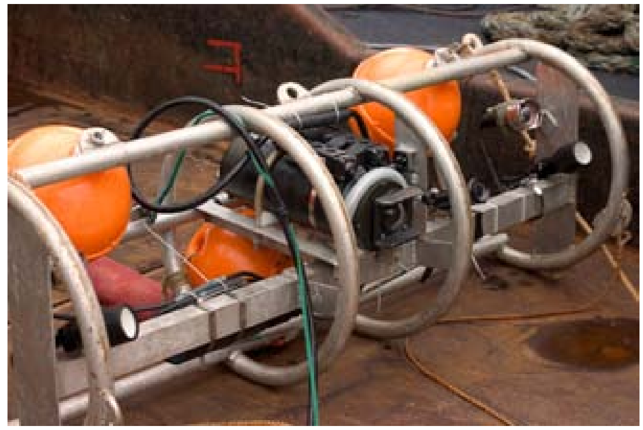

Figure 4. The TACOS video system used in the summer 2004 field research.

In future projects, we hope to enhance our video collections by using higher resolution digital CCD cameras linked to the research vessel via fiber-optic cable and IEEE1394 connections, giving us more options in terms of data storage, time and location stamps on the video, etc. without loss of picture quality. Moving to a fiber optic system will allow us to store the video directly to a computer hard drive, and monitor the high definition video in real time. We also hope to build and demonstrate our own stereo video system to accurately describe fish length and size of coral and sponge on the seafloor.

Underwater Video Observations Made with a Towed Video Camera Sled Near Seguam Pass, Alaska

Harold H. Zenger, Jr.
Resource Assessment and
Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Harold.Zenger@noaa.gov

The area near Seguam Pass in the Aleutian Islands has been fished for decades, and at one point the North Pacific Fishery Management Council cited it as possibly having experienced significant trawl damage, especially to gorgonian corals. In 1999 the Alaska Fisheries Science Center's (AFSC) Resource Assessment and Conservation Engineering (RACE) Division conducted a study to observe the status of that demersal environment. A robust, maneuverable observation platform was required because the region is notorious for swift currents and irregular terrain. RACE scientists adapted the design for a towed automatically compensating observation system (TACOS), developed at the Commonwealth Scientific and Industrial Research Organization (CSIRO) laboratory in Hobart, Tasmania. In August 1999, we conducted a short cruise to videotape images of that demersal habitat. The objectives of this study were to 1) examine whether the corals in heavily trawled areas are more damaged and less abundant than in nearby, less-trawled areas, and 2) attempt to verify the extent to which fish and invertebrates use coral for shelter.

The camera sled is a cylindrical frame constructed of aluminum with three, 12-inch trawl floats secured to the upper frame. A 2 m drag chain that controls height above bottom at about 1-2 m counterbalances flotation. The frame is a protective cage and furnishes mounting points for a color video camera, four flood lights, laser measuring array, electrical junction box, and a bathythermograph (Fig. 1). A four-point bridle is attached at the upper and lower extremes of the outer rings. The bridle is secured to the bottom of an electrical tow cable above a depressor weight. The cable is deployed from a remotely controlled hydraulic winch. Live-feed video output allows the operator to control cable length, thus responding to changes in the bottom terrain.

Videos were recorded at 25 sites. Subsequent review showed that the demersal topography is extremely varied, ranging from very irregular, rocky substrate covered with dense "gardens" of benthic invertebrates to large, almost barren sand dunes. On several occasions what appeared to be Atka mackerel (*Pleurogrammus monopterygius*) spawning activity was recorded from large, offshore rock piles and pinnacles. Rockfish (*Sebastes* spp.) were frequently observed in close association with sponges, hydrocorals, and fan corals (Fig. 2). The only area with apparent trawl damage was on the known fishing grounds between Amlia and Seguam Islands where widespread broken hydrocorals were found.

Five primary habitat types were observed: 1) relatively shallow (80-87 m), rocky, heavily overgrown "gardens" of sessile invertebrates composed mainly of sponges, hydroids, bryozo-

Figure 1. Towed automatically compensating observation system(TACOS) camera sled.

ans, and hard corals (hydrocorals) occupied by schools of roaming Atka mackerel and scattered Pacific cod (*Gadus macrocephalus*), prowfish (*Zaprora silenus*), skates (*Bathyraja* spp), and sculpin (Cottidae); 2) deeper (152-165 m) areas with large rocks and boulders on black volcanic sand with relatively heavy growth of large sponges and fan corals occupied primarily by rockfish with scattered Atka mackerel; 3) still deeper adjacent areas (165-185 m) where large rocks gave way to sand dunes and large sand waves occupied by scattered Pacific cod, skates, and Pacific halibut (*Hippoglossus stenolepis*); 4) large offshore rock piles and cliffs (87-112 m) with relatively heavy growth of stalked sponges, fan corals, hard corals, hydroids, and bryozoans occupied by scattered Pacific cod and very large numbers of Atka mackerel, females lying hard on bottom and males in spawning color — possibly evidence of Atka mackerel spawning activity; and 5) relatively flat or rolling deep bottom (150-163 m) area within the historical fishing grounds for Pacific cod and Atka mackerel (now closed to trawling), with bottom type ranging from stones to cobbles to large rocks with sparse growth of small sponges, small fan corals and soft corals with scattered small groups of on-bottom Atka mackerel, mostly associated with larger rocks, scattered Pacific cod, rockfish, and skates. This latter area has extensive broken hard corals (apparently *Stylaster* sp. and *Errinopora* sp.) and very few standing specimens. The broken hard corals probably resulted from extensive exposure to fishing. The lack of standing specimens is probably the result of those species' slow growth rate. Much of the substrate appears to be too small to support the growth of large fan corals and large sponges, given the severe currents they would have to withstand.

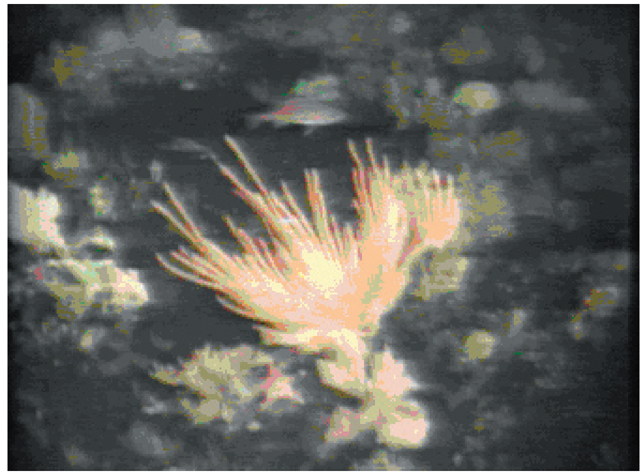

Figure 2. Rockfish in open sponge and fan coral habitat.

Use of Video and Sector Scanning Sonar for Studying Tanner Crab Aggregations

Bradley G. Stevens
Kodiak Fishery Research Center
Alaska Fisheries Science Center
310 Research Court
Kodiak, Alaska 99615
Email: Bradley.Stevens@noaa.gov

For roughly 10 months of the year, female Tanner crabs (*Chionoecetes bairdi*) remain buried in the sediment in low-density aggregations of 1-3 crabs per m^2. These aggregations span areas of about 1 km^2, and may be separated by tens of kilometers. During a 2-month period surrounding mating and larval release, crabs emerge from the sediment and form mounds of 100-5,000 crabs (Stevens et al. 1994). Mounds can be up to 5 m long and 2 m high. Meta-aggregations may include 100,000 crabs, in up to 200 mounds.

Since 1991, submersibles, video camera sleds, and remotely operated vehicles (ROVs) have been used to observe crab mounds in Chiniak Bay, Kodiak Island, Alaska, at depths from 125 to 200 m (Stevens et al. 2000a). They allow excellent close-up observation of small areas (several square meters), but the density of crabs is so great that abundance cannot be estimated adequately. The center of crab density moves only a few hundred meters from year to year. A moored current meter was installed in March 1999, and replaced annually, in order to record bottom temperatures, salinity, and current patterns near the aggregation site. The peak of aggregation occurs almost exactly with the highest spring tide in late April, and coincides with larval hatching by crabs held in the laboratory (Stevens 2003). A major obstacle to studying Tanner crab density and aggregation is that it has not been possible to quantify the extent and density of crab aggregations using video technology. During periods of peak aggregation, crabs are too concentrated to be counted accurately with video sleds. A video sled can only be used when crabs are at low densities; once they begin to aggregate, the sled causes too much disturbance, and mounds are so large they obscure the camera. The area viewed by ROVs is also too small. In addition, making daily observations of crab abundance with ROVs or video sleds from a surface ship is expensive, and such efforts cannot be conducted over long periods of time. We have also investigated the use of laser line scan (Tracey et al. 1998) and sidescan sonar (Stevens et al. 2000b) which helped us locate 200 derelict crab pots but no crab mounds; neither technique is cost-effective for use over long periods of time. As a result, we have considered the feasibility of using high frequency (325 MHz) sector scanning sonar for estimation of crab density by capturing images from the sonar and analyzing optical density with Image-Pro Plus® (Fig. 1). Sonar equipment could be modified to operate in time-lapse mode at pre-determined intervals and record the data to a computer hard drive. Interpretation of the sonar images should allow users to create a quantitative density index that would allow assessment of crab abundance during aggregation events. We would like to further develop such a system. The first goal will be to capture image frames, and analyze them with existing software.

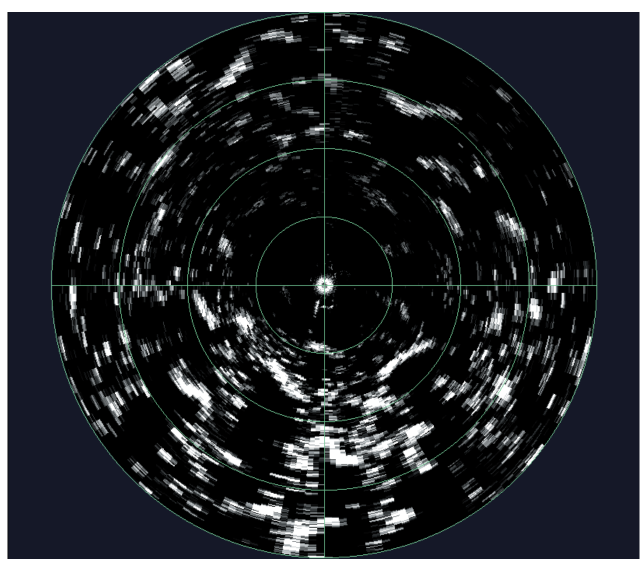

Figure 1. Sonar image of crab aggregation on 5 May1999. Radius is 10 m. White splotches are crab aggregations (except at center point).

The second step would be to build a self contained system for underwater use that would turn on a scanning sonar unit, make several sweeps of the area, record the data to a hard drive, then turn off again. Using a chartered boat and a remotely operated vehicle, the system would be placed at an optimum location during crab aggregation and operated for several weeks. Comparative data would be collected at a non-aggregation site, where few crabs are present, and density estimates would be made (as well as possible) by video techniques for comparison. Hatching and spawning of Tanner crabs is synchronized with spring tide cycles. In Chiniak Bay, Tanner crabs have used "traditional" spawning grounds in the same area for 11 years. Traditional trawl survey technology works well for low densities of crabs, but large catches create problems with statistical analysis. Because such large catches occur at low frequencies, they have traditionally been viewed as "outlier data", and sometimes eliminated. However, our research shows that probably 90% of all female crabs occur in meta-aggregations during a 2-month period surrounding larval release, and thus are not susceptible to assessment using traditional trawl survey methodology. In addition, males are in very low abundance at aggregation sites, so interpretation of sex ratio data is rendered unreliable. Despite repeated searches, we have not found any concentrations of female Tanner crabs at any other sites around Kodiak. They probably exist, but at a spatial scale that has not yet been determined. These results make it more apparent that the aggregation site in Chiniak Bay is a rare find, and an important site to continue monitoring in the future. Sonar is a standard tool for assessment of midwater fish stocks, but it has not been used to assess benthic fishery resources. Sidescan sonar has been used to study the impacts of trawling on the seafloor (Krost et al.1989), and more recently, to estimate the extent of crab pot loss and ghost fishing (Stevens et al. 2000b). Sonar tools can be used to provide more accurate estimates of crab abundance than can be achieved with traditional trawl survey technology. This would be a great addition to our arsenal of assessment tools.

Citations

Krost, P., M. Brenhard, F. Werner, and W. Hukriede.
1989. Otter trawl tracks in Kiel Bay (Western Baltic) mapped by side-scan sonar. Meeresforschung 32:344-353.

Stevens, B.G.
2003. Timing of aggregation and larval release by Tanner crabs, *Chionoecetes bairdi*, in relation to tidal current patterns. Fish. Res. 65:201-216.

Stevens, B.G., J. A. Haaga, and W. E. Donaldson.
1994. Aggregative mating of Tanner crabs *Chionoecetes bairdi*. Can. J. Fish. Aquat. Sci. 51:1273-1280.

Stevens, B. G., J. A. Haaga, and W. E. Donaldson.
2000a. Mound formation by Tanner crabs, *Chionoecetes bairdi*: Tidal phasing of larval launch pads?, p. 445-453. *In* J. C. V. V. Klein and F. R. Schram (eds.), Crustacean Issues 12: The biodiversity crisis and crustacea. Proceedings of the Fourth International Crustacean Congress, Amsterdam, The Netherlands, July 20-24, 1998. Vol. 2. A. A. Balkema, Rotterdam, Rotterdam.

Stevens, B. G., I. Vining, S. Byersdorfer, and W. E. Donaldson.
2000b. Ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots off Kodiak, Alaska: Pot density and catch per trap as determined from sidescan sonar and pot recovery data. Fish. Bull. 98:389-399.

Tracey, G. A., E. Saade, B. Stevens, P. Selvitelli, and J. Scott.
1998. Laser line scan survey of crab habitats in Alaskan waters. J. Shellfish Res. 17:1483-1486.

Use of Video at the AFSC's Newport Laboratory

Al Stoner
Fisheries Behavioral Ecology Program
Alaska Fisheries Science Center
2030 S. Marine Science Drive
Newport, Oregon 97365
Email: Al.Stoner@noaa.gov

Research conducted by the Fisheries Behavioral Ecology Program is directed toward providing critical information needed to improve survey techniques and to improve predictions of population distribution, abundance and survival for economically significant marine resource species.

The Program focuses on behavioral mechanisms associated with the performance of fishing gear, predator-prey dynamics, habitat requirements, and responses by fishes to environmental variables. Almost all of the research is conducted with live animals and video tools including stationary cameras, towed video sleds, infra-red lighting, and high-frequency imaging sonar are used on a daily basis. Field operations using video techniques are focused on estimating densities of juvenile fishes and characterizing their habitat associations, observing behavior of fishes around towed and fixed fishing gear, and *in situ* observations of movement and activity patterns related to environmental variables (Fig. 1).

Figure 1. Small camera sled used in the field at Kodiak Island, Alaska.

Figure 2. Large video room at the Newport Laboratory.

Video tools are used extensively to monitor the behavior of fishes in laboratory experiments designed to examine feeding, predator-prey interactions, habitat choices, swimming performance, vision and olfactory capabilities, activity rhythms, and interactions with fishing gear (Fig. 2). New tools are currently being developed for motion analysis and three-dimensional tracking of fishes and groups of fishes in our laboratory experiments using stereo videography.

Aerial Video of Beluga Whales In Cook Inlet, Alaska: Transitioning from Manual to Computerized Analysis

Christy Sims, Rod Hobbs, and Dave Rugh
National Marine Mammal Laboratory
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Christy. Sims@noaa.gov

Since 1994, the AFSC's National Marine Mammal Laboratory (NMML) annual aerial surveys of beluga whales in Cook Inlet Alaska have made video recordings of observed beluga groups (Fig. 1). This video data is then used to estimate group size and other population parameters. Counts from videotapes are very precise and repeatable when compared to real time counts by aerial observers. The video can also be used to collect other data such as the time a whale spends at the surface, whale image size, and coloration.

Our standard video analysis is very labor intensive, requiring around 100 hours of viewing per hour of recorded tape. With the advancements in digital video, we have begun looking for a way to transition from traditional manual counting of video to a computer-assisted method. Several different software options were researched from pattern recognition to video animation software. Finally, video analysis software called VideoScript appeared to have the potential to answer our need to decrease analysis time with computer assisted analysis at an affordable price. VideoScript is available as a free download as well as a licensed professional version for both Macintosh and Windows operating systems, however the Mac software has more capabilities than the PC version. Currently, a custom script has been written to allow us to analyze our data in VideoScript maintaining all of the video clips and documentation overlays on the computer. This approach duplicates our manual analysis which uses plastic sheet overlays, but with improvements in efficiency, consistency and documentation.

This is our first step at computer-assisted analysis and we plan to further automate the process. Our next step will be to utilize several tools in VideoScript that can track and measure beluga images, further improving the efficiency of our analysis. Our final goal would be image recognition of the beluga, allowing a fully automated analysis. However, this may require a more sophisticated, custom software package.

Figure 1. An aerial view of a group of belugas and an enlargement of the area enclosed within the yellow box. The beluga "dots" can be seen against the grey glacial waters of Cook Inlet and counted as they surface.

Underwater Video Systems Designed and Built at the Alaska Fisheries Science Center

Scott McEntire
Resource Assessment
and Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Scott.McEntire@noaa.gov

A variety of underwater video cameras are in use at the Alaska fisheries Science Center, many of which have been developed in-house. These can be roughly categorized into four types. First, self-contained video systems consisting of a pressure housing for batteries, video recorder and control electronics connected to external camera and lighting. Cameras are low light charge-coupled device (CCD) and intensified charge-coupled device (ICCD) with infrared or red light-emitting diodes (LEDs) or low voltage high intensity discharge (HID) lighting. These are used to monitor fish behavior and gear performance of trawl and pot gear at depths up to 2,000 m.

Second, self-contained drop video systems consisting of a progressive scan camcorder with battery and synched high rate strobe that is totally automatic and designed to be deployed from vessels of opportunity with minimally trained personnel (1,500 m depth rating). Third, time lapse video systems consisting of low electrolysis housings for camcorders with Sony LANC control for long-term deployment (3 months). Fourth, live feed towed and drop video systems consisting of small winch camera systems that are suitable for use from inflatables 13 feet and up are in use to scout dive sites and collect video images to over 200 m. These consist of small battery powered winches with small diameter armored cable, and high bright monitors with video overlays of GPS and depth.

Future developments include: 1) recording directly to digital, without a compression Codec using PC104 single-board, embedded computers; 2) reduce costs and size of IR camera systems; 3) improve lighting efficiency by moving from halogen to LED arrays and low power HID lights; 4) simplify integration of serial sensor data with video; and 5) develop a remote stereo system for deployment on trawl gear to depths greater than 1,000 m.

Tracking Fish in Trawls with the DIDSON Acoustic Camera

Craig Rose
Resource Assessment and
Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Craig.Rose@noaa.gov

Both mechanically scanned sonars and underwater cameras have significant limitations for observing the behavior of fish in waters with limited ambient light. Cameras require artificial visible illumination, which may affect behavior, or infrared illumination, which greatly limits range. Sonars have much greater range, but lack the spatial and temporal resolution to confidently track and identify individuals.

A new tool, the Dual-frequency IDentification SONar (DIDSON), developed at the University of Washington's Applied Physics Laboratory, makes a significant breach in the barrier to direct behavioral observations. This high frequency (1.0 and 1.8 MHz) scanning sonar provides images with sufficient resolution to clearly distinguish the shapes of individual fish at an update rate (4 - 21 frames per second) that allows tracking between images. It images a sector 29 degrees wide and 12 degrees deep out to a maximum range of 30 m. The sonar has a small enough size (30.7 × 20.6 × 17.1 cm) to be deployed flexibly and effectively protected (Fig. 1). It can be operated in real time with a cable or with a battery pack and recorder, remotely deployed. The DIDSON was used in the aft end of a pelagic trawl to track walleye pollock and Pacific salmon, with the goal of identifying behavioral differences, which could be exploited to reduce salmon bycatch.

While the DIDSON programming has a number of counting, measuring and tracking algorithms, included automated methods, DIDSON imagery collected on the pelagic trawls required manual tracking of targets. This was facilitated by a routine that tracked and recorded the position of the computer cursor over the imagery and annotated it with the time of recording. Using this routine, salmon and pollock were tracked, revealing that salmon dropped back into the net much more slowly than pollock and frequently made short forays forward. Pollock uniformly dropped back into the net at nearly the towing speed. Several trawl modifications have been designed around this difference and are being tested.

Figure 1. A DIDSON acoustic camera within its protective housing.

Reproductive Ecology of Atka Mackerel in the Aleutian Archipelago*

Bob Lauth and Scott McEntire
Resource Assessment and
Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Robert.Lauth @noaa.gov

Rocky substrate is vital to Atka mackerel for successful breeding and propagation. Except for a few studies in Kamchatkan waters (Gorbunova 1962, Zolotov 1993), very little is known about the bathymetric range, spatial extent, and habitat characteristics of Atka mackerel spawning and nesting habitat. Such scientific studies are totally lacking from Alaskan waters. The long-term sustainability of this commercial fish species depends on knowing the location and characteristics of this habitat. Nesting and spawning sites in Kamchatka are in nearshore areas to a maximum depth of 32 m. Bottom type, temperature, and moderate tidal current are other important factors for these nesting sites. Spawning begins in late June and ends in the early fall. Females are batch spawners that lay their adhesive eggs in rock crevices and among stones. Males fertilize the eggs and remain to guard the incubating clutches until they hatch. Nest guarding is important to protect incubating eggs from cannibalism and predation from other fish and invertebrates.

The specific objective for our study is to locate and characterize nesting and spawning habitat in Alaskan waters including its spatial extent, bathymetric range, temperature, and other physical and biological features (Figure 1). The study area will focus on the Aleutian Archipelago from Stalemate Bank to the Shumagin Islands. A portable video drop camera will be used to locate nesting sites. Cameras drops will be made during the time of year when Atka mackerel spawn and nest. Nesting sites are identified by the presence

Figure 1. A male Atka mackerel in habitat typically used for nesting in the Aleutian Islands.

*Not presented at workshop

of aggregations of sexually dichromatic males exhibiting nesting behavior.

The drop camera and winch system is fabricated for use on any size research vessel ranging from a 5 m inflatable to a large ship (Fig. 2). A small inflatable is used to investigate nearshore areas and larger vessels are used for investigating offshore areas and inside island passes. The drop camera frame holds the video camera, 12 V NiMH battery pack, 12 V MR12 halogen and LED lights, and a depth and temperature data logger. Both a low light black-and-white or color camera can be used and lights are interchangeable between a red light-emitting diode (LED) array, or 20 W halogen or high intensity discharge (HID) light. The combination of a low-light camera and red LED array is preferred because it works at all depths and light levels and fish appear unaffected by the red light. The video camera frame is deployed using a portable 24V winch with 300 m of 3/16” armored and shielded 4-conductor cable. The small diameter cable and weighted camera frame (15 kg of lead) produce very little drag so the drop camera can get to the bottom in strong currents or surface winds. The 24 V winch has a speed controller for adjusting the height of the camera frame above bottom. Real-time video feed and winch controls are used to navigate the camera over rocky bottom with high relief while the vessel and camera drift. The NTSC video signal from the camera is monitored and recorded topside and overlaid with time and geodetic position.

The presence of nesting male aggregations will be analyzed in relation to bottom depth, water temperature, and the physical and biological habitat. Videotapes provide a record of the Atka mackerels’ spatial distribution and behavior, as well as information about the physical and biological habitat. Data reduction from videotapes will involve recording events and characterizing habitat. Events will include presence of a nester (i.e., guardian male), a female or school of

Figure 2.The drop camera used for the Atka mackerel nesting habitat studies.

females, or other noteworthy activities relating to Atka mackerel reproductive ecology. Habitat will be characterized by describing the biological and physical attributes. Marine plants and animals will be identified to the extent possible using the recorded video images and the percent of invertebrate coverage.

In addition to depth, temperature and location, and the bottom structure of nesting habitat will be described based on substrate type and the degree of vertical rocky relief. The relation of the nesting sites to other major geographic and bathymetric features of the Aleutian archipelago will also be investigated using Geographic Information Systems (GIS) mapping software.

Use of Underwater Video at the Auke Bay Laboratory*

Robert Stone and Eloise Brown
Auke Bay Laboratory
Alaska Fisheries Science Center
11305 Glacier Highway
Juneau, Alaska 99801
Email: Robert.Stone@noaa.gov

The AFSC's Auke Bay Laboratory (ABL) has been using underwater techniques to study marine fisheries for over 25 years. Scientists have employed scuba, remotely operated vehicles (ROVs), and manned submersibles (HOVs) to collect underwater photos and video footage of the seafloor and marine life. Scientists first used the HOV *Nekton Gamma* in 1978 to study rockfish and coral distribution in Southeast Alaska. Similar studies with the *Nekton Gamma* followed in the early 1980s, and for the most part, were limited to non-quantitative studies. Beginning in 1988, scientists began a 17-year unofficial partnership with Delta Oceanographics and have used their submersible *Delta* each year since to study living marine resources. Much of the research has been quantitative in nature and has included 1) assessment of groundfish stocks, 2) behavioral studies on fish and crabs, 3) assessment of fish habitat, 4) gear behavior studies, 5) effects of fishing gear on seafloor habitat, and 6) site reconnaissance. Many of these studies have employed distance-sampling techniques to estimate abundance of biological populations.

The ABL is currently using the *Delta* and the ROV *Jason II* to study coral and sponge habitat in the Aleutian Islands. The vehicles are deployed at different depths but both are used to collect continuous video footage of the seafloor along predetermined transects. Corals, sponges, and commercially important fish and invertebrates are enumerated using strip transect methodology thus providing a census for these organisms. Transect width is determined using

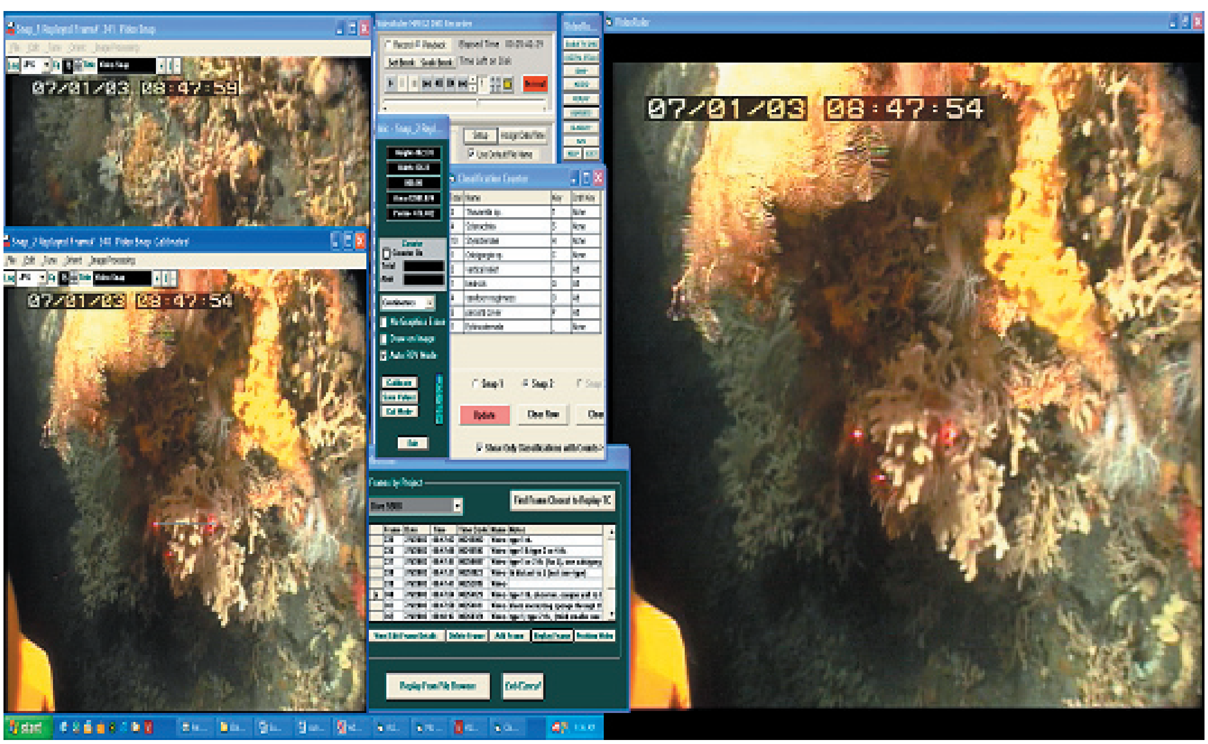

Figure 1. A view of the video event logging software used by the Auke Bay Laboratory to analyze video data collected on ROV and HOV dives on deepwater coral and sponge habitat.

*Not presented at workshop.

semi-conductor lasers fixed at a known distance. Transect length is determined using ultra-short baseline tracking and differential global positioning (*Delta*) or long baseline underwater acoustic and dynamic positioning systems (*Jason II*). Video footage is collected on a High-8 videotape format (*Delta*) or digital video format with a 1-chip color camera (*Jason II*).

In the laboratory, video footage is encoded to an MPEG-2 format at a bit rate of 30 frames per second and copied to DVDs. Video post-processing is completed using VideoRuler 7 Software whereby each event (coral, sponge, or commercially important fish and invertebrate) is recorded with an assigned keystroke. Habitat variables including substrate type, mega- and meso-habitat type, and seafloor rugosity have been defined and are also measured on each transect.

Great advances have been made in event-logging software technology in just the past 2 years. Auke Bay Laboratory scientists have customized the VideoRuler 7 software for use with the current research program and the system works well. Underwater video analysis is a labor and time-consuming process. Sub-sampling methodology can be developed for many habitats which will save time, so, the past limitations of post-processing software is no longer a barrier to underwater video analysis. One major problem is the inability or unwillingness of the entire deep-diving vehicle community to upgrade to fully digital camera systems. Post-processing of High-8 video footage is difficult due to lost resolution at slow playback speeds. Resolution is critical to accurate identifications.

Event recognition software is currently being developed and may show some promise for counting large, conspicuous taxa like the sea whips (*Halipteris willemoesi*). Our current task is to enumerate and identify many complex taxa such as gorgonian corals, hydrocorals, bryozoans, hydroids, and sponges (Fig. 1). Unfortunately, software designed to discriminate such complex taxa is unlikely.

Estimating the Density of Thornyheads, *Sebastolobus* spp., Using a Towed Video Camera Sled

Robert Lauth[1], Waldo Wakefield[2], and Keith Smith[1]

[1] Resource Assessment and
Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, Washington 98115
Email: Robert.Lauth @noaa.gov

[2] Fishery Resource Analysis and Monitoring Division
Northwest Fisheries Science Center
Newport Research Station
2030 S. Marine Science Drive
Newport, Oregon 97365
Email: Waldo.Wakefield@noaa.gov

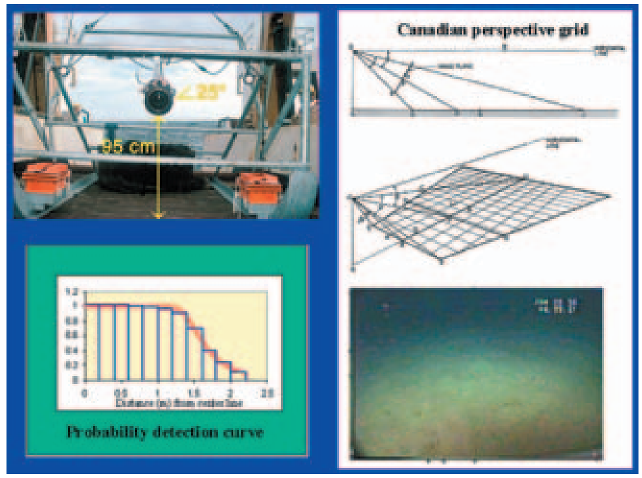

Figure 1. Video camera sled outfitted with Deepsea Power and Light (DSPL) Autonomous Video Camcorder System (AVCS; upper left), perspective grid (and field of view) used to determine size of objects and location on the seafloor (upper right), probability of detection function used in line transect methods for thornyheads (lower left) and a typical view from the sled mounted video cameras (lower right).

A video camera sled was used to obtain an independent estimate of the density of *Sebastolobus* spp. (thornyheads) at three different depths (450 m, 750 m, and 1,150 m) within a given space and time (Lauth et al. 2004a, b). Camera sled video footage was processed using an oblique grid plane and line transect methods. Thornyheads were randomly distributed across the seafloor within the sampling area, and variation in the dispersion over increasing spatial scales (10 m to 1,280 m) and depths was not significant. Thornyhead density estimates were derived using the program DISTANCE. Densities ranged from 344 to 1005 thornyheads per square kilometer with coefficients of variation from 10% to 18%.

The camera sled (Fig. 1) was constructed of hot-dipped galvanized schedule-40 50.8-mm steel pipe measuring 366 cm long by 213 cm wide by 152 cm high, and weighing about 500 kg. The same basic design was tested and used by Wakefield (1990), Wakefield and Smith 1990, and Lauerman et al. (1996). A rigid bail was attached to a pivot point 61 cm from the front of the sled. The bail allowed for vertical change in the sled's towing point and its attachment point was positioned at the approximate center of gravity when suspended. The video camera sled was connected to the starboard trawl wire using a 70-m bridle made from 19 mm Spectra 7 line. The color video camera system was based on a high-resolution Sony CCD Hi-8 camcorder (400-line resolution) integrated as part of a Deepsea Power and Light (DSPL) Autonomous Video Camcorder System (6,000 m depth rating), lit with two 150 W halogen DSPL Deep Multi SeaLites powered by two 24 V/38 amp hour DSPL SeaBatteries, and controlled by a Pisces Design delay and timing circuit. Batteries were placed one atop each sled runner to lower the center of gravity and balance the sled. A small trawl net was strung between the two skids behind the camera sled to dampen the movement of the sled when being dragged along the seafloor. The sled was towed along the seafloor at speeds between 0.75 and 1.0 m/s for 2 to 3 hours. In order to prevent the tow cable from impacting the seafloor, the bridle and trawl wire altitude in front of the camera was monitored on a precision depth recorder (PDR) using a 12 kHz pinger attached near the end of the trawl wire. Slight adjustments to the ship's speed or the amount of trawl wire out were used to maintain the height of the trawl wire 25 to 35 m above the seafloor.

Citations

Lauerman, L. M. L, R. S. Kaufmann, and K. L. Smith, Jr.
1996. Distribution and abundance of epibenthic megafauna at a long time-series station in the abyssal Northeast Pacific. Deep-Sea Res. (Part I) 43(7):1075-1103.

Lauth, R. R., W. W. Wakefield, and K. Smith.
2004a. Estimating the true density of thornyheads, *Sebastobolus* spp., using a towed video camera sled. Fish. Res. 70:39-48.

Lauth, R. R., W. W. Wakefield, and K. Smith.
2004b. Estimating the size selectivity and catching efficiency of a survey bottom trawl for thornyheads, *Sebastolobus* spp., using a towed video camera sled. Fish. Res. 70:27-37.

Wakefield, W. W.
1990. Demersal fishes of the upper continental slope off central California. Scripps Instit. Oceanogr. Ph.D. Thesis. 281 p.

Wakefield, W. W., and K. L. Smith, Jr.
1990. Ontogenetic vertical migration in *Sebastolobus altivelis* as a mechanism for transport of particulate organic matter at continental slope depths. Limnol. Oceanog. 35:1314-1328.

Optical Imaging and Analysis at the Northwest Fisheries Science Center

W. Waldo Wakefield
Northwest Fisheries Science Center
Fishery Resource Analysis and Monitoring Division
Newport Research Station - Bldg. 955
2032 S. E. OSU Drive
Newport, OR 97365-5275
Email: waldo.wakefield@noaa.gov

The Northwest Fisheries Science Center's Fishery (NWFSC) Resource Analysis and Monitoring Division (FRAM) Division currently uses the latest optical imaging technologies to map the seafloor and for making direct observations with in situ video as part of ongoing habitat-based groundfish research. For example, the NWFSC is currently involved in an interdisciplinary study off Heceta Bank, Oregon, to determine habitat-specific biomass estimates for selected groundfish species (Fig. 1a). The project utilizes the advanced imaging and sampling tools on both the *ROPOS* ROV and *Delta* submersibles (Fig 1b). The NWFSC is also using the tools aboard the *ROPOS* ROV to explore and map poorly known marine ecosystems such as Astoria Canyon off Oregon.

The Northwest Fisheries Science Center's FRAM Division collaborates with a number of regional research programs along the U.S. West Coast to maintain a coast-wide network of sites where seafloor mapping and direct observation (with optical imaging systems) support ongoing habitat-based groundfish research. Through these coordinated studies and collaborations, a systematic approach is emerging for the classification of marine habitats in both shallow and deep water with increasing attention being given to the inclusion of megafaunal invertebrates as significant biological components of continental shelf and slope ecosystems.

(a) (b)

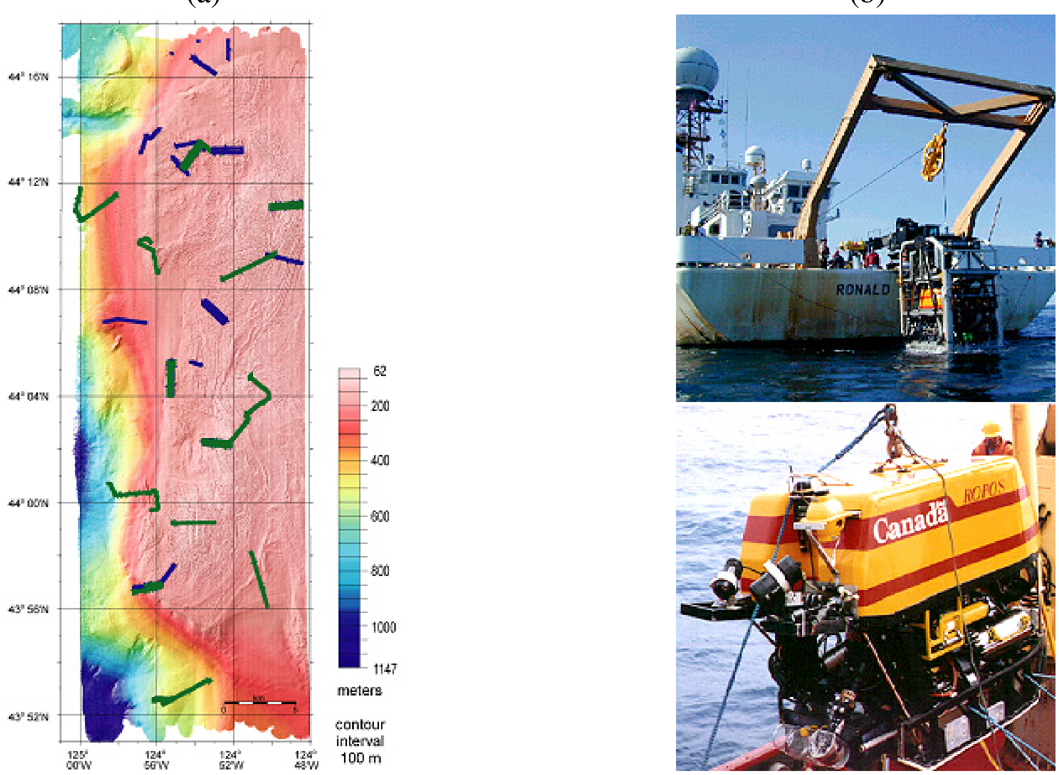

Figure 1a - A side-scan mosaic of the Heceta Bank area off Oregon and the tracklines of ROPOS dives; b. The Canadian ROV ROPOS being launched from the NOAA ship *Ronald Brown*.

Using Video Observations From Submersibles and Laser Line Scanners to Survey Benthic Fishes, Macro-Invertebrates and Habitat Types in Deepwater off California

Mary Yoklavich
Santa Cruz Laboratory
Southwest Fisheries Science Center
110 Shaffer Road
Santa Cruz, CA 95060
Email: mary.yoklavich@noaa.gov

The Southwest Fisheries Science Center's (SWFSC) Santa Cruz Laboratory has developed a research program to effectively respond to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) mandates with respect to West Coast groundfishes. Several West Coast groundfish species have been designated as overfished; it is especially important to characterize and protect essential fish habitat (EFH) of these species and to improve our assessments of these stocks. From past research, we know that adults of many species of rockfishes, in particular, are difficult (or impossible) to accurately appraise with traditional survey methodologies such as surface-based fishing and acoustic gear. This is due to the close association between many of these species and their rugged, rocky heterogeneous habitats. Additionally, classification of habitat attributes on scales pertinent to animal distributions and ecological problems in deepwater marine environments is difficult because of the restricted access to this system. Consequently, we have been developing new tools, technologies, and partnerships to characterize deepwater fishes and habitats since 1992.

We are using direct observation and video transects from occupied submersibles, together with geophysical seafloor mapping techniques, to improve assessments and track the recovery for some groundfish species and their associated habitats. We have applied this approach to de facto marine reserves, in and adjacent to marine protected areas, submarine canyon heads, and rocky areas elsewhere along California. Several funding opportunities for marine groundfish habitat research both within Fisheries and from other NOAA offices (Sea Grant, Undersea Research Program (NURP), Ocean Exploration, NOS), USGS, state agencies, and private foundations have been successfully pursued in implementing our program. Our general research goals are to describe and conserve EFH, identify areas in need of additional protection, and improve assessments of groundfish populations. Our approach is especially critical when focusing on benthic habitats of extreme heterogeneity and biological assemblages of high diversity.

Current Projects

Cowcod Conservation Areas Surveys

In collaboration with Milton Love (University of California Santa Barbara) and researchers from Moss Landing Marine Labs and the California Department of Fish and Game, and with funding from NMFS' Offices of Protected Resources and Habitat Conservation, NURP, NOAA Center For Marine Protected Areas (MPA) Science, and the David and Lucile Packard Foundation, we have initiated a monitoring protocol for fish, macroinvertebrates, habitats, and incidence of fishing gear disturbance on offshore banks in and around the Cowcod Conservation Areas (CCA) off southern California. Underwater surveys of groundfish populations and their habitats were conducted off southern California using non-extractive video-transect methodologies and direct observations from an occupied research submersible (*Delta*; Figs. 1,2).

We asked two fundamental questions of our research: (1) are the CCAs meeting their objective to protect and rebuild the cowcod population? and (2) can we effectively survey cowcod (and, by extension, other benthic fishes) by direct observation rather than by conventional techniques such as hook and line or bottom trawl?

Digital geo-referenced maps of the seafloor acquired from available side-scan sonar, multibeam bathymetry, seismic reflection, and other past geophysical surveys were used to identify and select sites of appropriate bottom type and depth. Past and recent groundfish catch and effort records were also used to assist in locating appropriate survey sites. We tracked the submersible in real-time in relationship to depth and seafloor habitats. We used line transect methodology to estimate densities (and associated CVs) of cowcods on the rocky banks within the CCAs. Absolute abundance of cowcods (juvenile and adults separately) was estimated by expanding the density estimates by the total area represented by the habitats surveyed on each bank.

We also used video transects from this survey to quantify structure-forming invertebrates as components of benthic habitat in the CCAs. There is increasing interest by science and conservation communities in the potential impacts that fishing activities have on megafaunal benthic invertebrates, such as sponges and corals, occurring in continental shelf and slope ecosystems, and the role these large invertebrates have in enhancing the diversity and structural component of fish habitat. We are collaborating with Brian Tissot (Washington State University, Invertebrate Ecologist) to describe patterns in the density, distribution, and size of structure-forming megafaunal invertebrates on the deep rocky banks and outcrops in the CCAs. Our specific objectives are to identify structure-forming invertebrates, quantify their density and size distributions specific to depth and substratum types, and quantify associations between

Figure 1. The *Delta* research submersible accommodates one scientific observer and one pilot, has a maximum operating depth of about 350 m, and a cruise speed of 1.5 knots. We equipped the submersible with three video cameras: a low-light, wide-angle black-and- white CCD camera positioned externally on the bow; a High-8 color video camera and associated lights externally positioned on the starboard side and flanked by paired lasers at a distance of 20 cm apart; and a hand-held digital video camera positioned inside the submersible in the lower port on the starboard side. (photo credit: M. Yoklavich)

large, structure-forming invertebrates and other organisms, particularly fishes. About 520,000 megafaunal invertebrates of 15 taxa were observed in the video footage. Deep-sea corals and sponges were the largest structure-forming invertebrates but were relatively uncommon. The corals were patchy in distribution and were found in low-relief mixed cobble-boulder- sand habitats at 100-225 m depths. Few large invertebrates and almost no fishes appeared to be associated with these animals. Our comprehensive survey and analysis of the distribution, abundance, and species composition of large invertebrates in the Southern California Bight is unique and contributes new and significant information to our understanding of biodiversity, indicators of environmental conditions, and components of essential fish habitats.

We will use these established baselines of groundfish species, megafaunal invertebrates, and associated habitats to monitor changes within the CCAs by conducting direct observation surveys of abundance, size structure, and diversity on a routine basis.

Intercalibration of Direct Observation and Extractive Survey Methods

We are using direct observation methods and video transects from an occupied submersible to survey fishes and habitats in 100 m water depth at the location of longline surveys conducted off central California. Our objective is to compare occupied submersible quantitative transect methods with bottom longline methods for determining abundance, size and species composition, catchability coefficients and selectivity, and appropriate conversion factors for relative and absolute abundance. Quantitative transect methods, collection of accurate visual observation and navigation data, database management and analysis follow protocols based on our past experience with in situ methods. This study includes participation by a commercial longline fisherman in the submersible operations. Our results should contribute to improved assessments of groundfish stocks in untrawlable habitat off California.

Fish and Habitats at Varying Spatial Scales

Many species of groundfishes are strongly associated with specific substratum types. A predictable relationship between organism and habitat presents the possibility of using habitat as a proxy for distribution and abundance of fish species over large areas. The ability to extrapolate up to large scales relies on the capability to map the seafloor, over areas of interest and calculate the availability of benthic habitats. Acoustic systems such as sidescan and multibeam sonars collect wide swaths of seafloor data and thus can map large regions quickly. The interpretation of acoustic data into seafloor classifications however is complex, and requires reliable and accurate groundtruthing to transform the acoustic signal into biologically meaningful information.

In a collaborative effort between USGS, National Marine Fisheries Service, and NOAA's National Marine Sanctuaries Program off California (Cordell Bank, Channel Islands, and

Figure 2. A vermilion rockfish (*Sebastes miniatus*) viewed from the porthole of the *Delta*. (photo credit: M. Nishimoto).

Monterey Bay), Tara Anderson (a post-doctoral fellow) is testing a novel application of a video camera sled to groundtruth seafloor habitat maps in real time. To characterize abiotic and biotic aspects of the seafloor, a series of multidirectional transects are conducted using a mini video camera sled. Video observations are annotated in real time every 30 seconds using an electronic programmable keypad integrated with navigational software. These seafloor characterizations adequately describe substratum types, bedform, relief, and presence of benthic macro-organisms. These data are used to groundtruth acoustic mosaics of the seafloor within hours of its collection, providing an initial description of seafloor habitats and some aspects of their communities. This approach is ideal for those projects that require rapid feedback.

Laser Line Scan Development

One of our challenges is to efficiently relate small-scale observations and assessments of animal-habitat associations to the large geographic scales on which benthic fisheries operate. Laser line scan (LLS) systems potentially can serve as a bridge between fine resolution, low coverage video survey tools (e.g., remotely-operated vehicle (ROV), occupied submersible, towed sled) and coarse resolution, high coverage acoustic technologies (e.g., multibeam and sidescan sonar). In an evaluation of LLS for fishery habitat assessments, the Habitat Ecology Team conducted a survey off the central coast of California using a Northrop-Grumman SM-2000 LLS. A video survey also was conducted using an ROV across parts of the study area to groundtruth the LLS data and to compare observations made from a forwardlooking video camera with those from LLS reflectance imagery. The LLS was successful in generating high resolution (1-2 cm across-track) imagery of rock outcrops, sand waves and ripples, drift kelp, patches of large anemones, groups of fishes off and on the seafloor, starfish, sea pens, and salp chains. As expected, the LLS system provided imagery of higher areal coverage but with a lower degree of taxonomic identification than the ROV video.

Developing the capability to process and mosaic imagery and produce seafloor maps is a significant step in advancing the efficient application of LLS technology. To assess the mapping capabilities of the system, we generated a tiled-image mosaic of georeferenced LLS data with 2-cm pixel resolution across the survey area. The data acquisition hardware down-sampled or did not log all sensor data, which made an accurate expression of the LLS configuration (i.e., instrument settings) difficult to achieve. As a result, a large degree of detail and object recognition observed in the original LLS imagery was lost upon geometric translation. However, combined with information obtained from reviewing the original imagery, the mosaic representation did demonstrate spatial configuration and context of organisms and geologic features at varying spatial scales. This system has been newly revised based on results from our field studies and is now ready for further evaluation as an advanced imaging technology for EFH and improved stock assessments.

For Further Reading

Yoklavich, M. and Love, M.
(In Review) A fishery independent assessment of cowcod in the Cowcod Conservation Areas using direct observations from an occupied submersible.

Tissot B., M. Yoklavich, M. Love, K.York, and M. Amend.
(In Review) Structure-forming invertebrates as components of benthic habitat on deep banks off southern California.

Amend M., M. Yoklavich, Y. Rzanhov, C. Grimes, and W. Wakefield.
(In Review). Mosaics of benthic habitats using laser line scan technology: It's in the details. Proceedings of GeoHab 2002.

Anderson, T., M. Yoklavich, and S. Eittreim.
In Press. Linking fine-scale groundfish distributions with large-scale seafloor maps: issues and challenges of combining biological and geological data. *In* In P. Barnes and J. Thomas (eds), Benthic habitats and the effects of fishing. AFS Symposium 41, Bethesda, Maryland.

Love, M. and M. Yoklavich.
In Press. Fishes on deep rock habitats. *In* L. Allen, M. Horn, and D. Pondella (eds.), Ecology of California marine fishes. University of California Press.

Brock, R., J. Bohnsack, M. Fogarty, S. Murawski, M. Yoklavich, and M. Love.
2003. Marine fisheries of the USA: moving from single-species management to a more holistic ecosystem-based approach, p. 521-531. *In* J. Beumer, A. Grant, and D. Smith (eds.), Aquatic protected areas: what works best and how do we know?, University of Queensland Printery, St. Lucia, Queensland, Australia.

Yoklavich, M., C. Grimes, and W. Wakefield.
2003. Using laser line scan imaging technology to assess deepwater seafloor habitats in the Monterey Bay National Marine Sanctuary. Mar. Tech. Soc. J. 37(1):18-26.

Love, M., M. Yoklavich, and L. Thorsteinson.
2002. The rockfishes of the Northeast Pacific. University of California Press, Berkeley, California. 405 p.

Yoklavich, M., G. Cailliet, R. Lea, H. G. Greene, R. Starr, J. de Marignac, and J. Field.
2002. Deepwater habitat and fish resources associated with the Big Creek Ecological Reserve. CalCOFI Rep. 43:120-140.

Yoklavich, M., H. G. Greene, G. Cailliet, D. Sullivan, R. Lea, and M. Love.
2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fish. Bull., U.S. 98:625-641.

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea, Jr., and G.M. Cailliet.
1999. A classification scheme for deep seafloor habitats. Oceanol. Acta 22(6):663-678.

Yoklavich, M.M.
1997. Applications of side-scan sonar and in situ submersible survey techniques to marine fisheries habitat research, p.140-141. *In* Boehlert, G.W. and J.D. Schumacher (eds.), Changing oceans and fisheries: environmental data for fisheries research and management. U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-239.

Yoklavich, M.M., G.M. Cailliet, and G. Moreno.
1993. Rocks and fishes: submersible observations in a submarine canyon, p. 173-181. In Proceedings of the American Academy of Underwater Sciences: 13th Annual Scientific Diving Symposium.

Fish Surveys and Habitat Investigations of Cowcod and Bocaccio*

John L. Butler
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037-1508
Email:john.butler@noaa.gov

Our goal was to establish a quantitative process of assessing rockfish stocks in the California Bight using new technology. Rockfish schools over local banks were mapped quantitatively with split-beam echo-sounders and habitat was mapped using multi-beam sounders (Fig. 1). Remotely operated vehicle transects were conducted to identify species composition of fish schools and to "ground truth" bottom type.

First, a multi-beam sonar was used to map rockfish habitat and thereby minimize the area to be more comprehensively surveyed. For habitat classification, we combined a 200 kHz multi-beam sonar, state-of-the-art positioning instrumentation, and mature algorithms to produce digital terrain maps of the seafloor

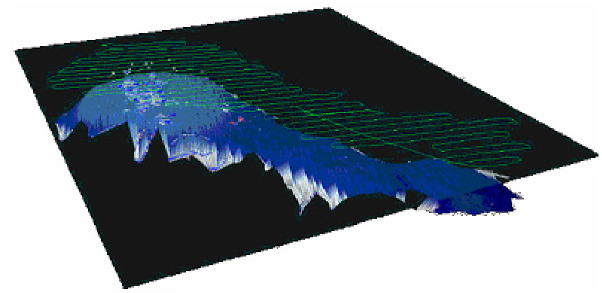

Figure 2. Three dimensional image of Forty-Three Fathom Bank.

(Fig. 2). Additionally, we exploited the frequency- and angular-dependencies of the acoustic backscatter from the echo sounders and the sonar, respectively; that is, backscatter from different seafloor types is dependent on the acoustic wavelength relative to the particulate size, density, and sound speed, and it is a function of the acoustic incidence angle. Therefore, much more information about essential bocaccio habitat can be remotely sensed and classified by combining the data from these instruments and exploiting the fundamentals of scattering physics. High resolution underwater video and still-camera

Figure 1. Fish schools above Forty-Three Fathom Bank.

*Not presented at workshop.

images were obtained with an ROV to validate the acoustic seabed classifications.

Next, volume backscattering strengths at four frequencies were used to remotely identify scatterer taxa (i.e., large fish, small fish, and zooplankton) and to observed their diel behavioral characteristics. The acoustic backscatter data was identified as rockfish via an empirical four-frequency acoustical signature and the ROV video. Again, the backscatter from different fish species is dependent on the acoustic wavelength relative to the particulate size, density, and sound speed, and it is a function of the acoustic incidence angle. One square mile grids were established over key rockfish habitat. These grids were mapped at 0.2 nautical mile (nmi) intervals using split-beam echo sounders (four frequencies).

Because the four different frequencies allow us to distinguish the size of individual fish, schools of small rockfish can be distinguished from larger fish (Fig. 3).

Figure 3. A cow cod (*Sebastes levis*).

Video Surveys of Fish Assemblages in the Pacific Islands Region

Frank Parrish
Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822-2396
Email: Frank.Parrish@noaa.gov

The Pacific Islands Fisheries Science Center employs video to survey fish assemblages using a variety of techniques. For some, the data is derived exclusively from the video images and in others the video is used to augment visual observations made by scientists conducting surveys on scuba or in submersibles. In all methods, the fish data are manually scored from the video and entered into a data base. Automating the transition of information from video images to a digital data base presents a challenge given the diversity of species, the small size of many fish, and the varied habitats of the Pacific Islands. Methodologies currently used in the Pacific can be divided into mobile transects (e.g. scuba, ROV, tow sleds, submersibles - Fig. 1a), stationary archival cameras (baited and un-baited video) and dynamic systems (animal mounted systems such as CRITTERCAM – Fig. 1b). Surveys conducted from submersibles generally rely on the audio portion of the video record to document fish assemblages. It is possible voice recognition software could be employed in this situation to expedite transfer to digital format. In contrast, archival video and video from CRITTERCAM is entirely dependant on the video images. Given the stationary nature of the archival video it may be well suited for image recognition software. The dynamic movements of animals on which CRITTERCAMS are fitted will likely limit automated analysis of these video images. However in all cases improved meta data and event logging software would expedited the transfer of video to a relational data base.

Figure 1. a) Launching the *Pisces V* submersible to conduct surveys (Photo: Hawaii Undersea Research Laboratory). b) A Hawaiian monk seal fitted with National Geographic Television's CRITTERCAM.

Towed-diver Surveys -- A Method for Mesoscale Spatial Assessment of Benthic Reef Habitat: A Case Study at Midway Atoll in the Hawaiian Archipelago

Jean C. Kenyon[1] · R.E. Brainard[2] · R.K. Hoeke[1] · F.A. Parrish[2] · C.B. Wilkinson[1]

[1] Joint Institute for Marine and Atmospheric Research
University of Hawaii
1125B Ala Moana Boulevard
Honolulu, Hawaii 96814, USA
E-mail: Jean.Kenyon@noaa.gov

[2] Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA
2570 Dole Street
Honolulu, Hawaii 96822, USA

ABSTRACT

An integrated method for reef benthic habitat assessment to the depth limits of conventional SCUBA is described, in which divers maneuver boards equipped with digital video, temperature, and depth recorders while being towed behind a small boat. The tow path is concurrently recorded by a Global Positioning System (GPS) receiver onboard the tow boat, to which a layback model is applied to more accurately map the position of the recorded imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-sec intervals.

The results of 15 towed-diver surveys conducted at Midway Atoll in the Hawaiian Archipelago during a mass coral bleaching event in 2002 are presented to exemplify the method and are compared to quantitative results derived from more conventional methods of benthic biotic assessment. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale, roving diver assessments, providing a mesoscale spatial assessment of reef habitats. The spatial coverage afforded by towed-diver surveys provides more comprehensive data to managers concerning the extent, intensity, differential taxonomic response, and bathymetric correlates of bleaching than does data derived from conventional, site-specific surveys alone.

Key Learnings

- Towed-diver surveys are an effective method for assessing benthic communities over large spatial scales.
- The value of towed-diver survey results is enhanced when compared with results of more conventional survey methods (e.g., belt transect) at specific sites.
- Limitations of the method must be balanced with its advantages before implementation.

INTRODUCTION

The manta tow technique, in which snorkel divers are towed behind a small boat, is a versatile method that has been adapted to census specific benthic targets including crown-of-thorns starfish *Acanthaster planci* (e.g. Chesher 1969, Moran and De'ath 1992), introduced algal species (Rodgers and Cox 1999), and derelict fishing gear (Donohue et al. 2000). Manta tows have also proved useful for broader benthic habitat characterization (e.g. Kenchington 1978, Miller and Müller 1999, Lopez Victoria et al. 2000). A primary advantage of the manta tow technique in habitat characterization is that it enables efficient survey coverage of large areas of reef benthos; a disadvantage is the lack of fine taxonomic resolution that can be observed and recorded compared to surveys conducted by free-swimming divers (Carleton and Done 1995). The technique has not customarily included a photographic or videographic component (Bass and Miller 1996) that provides a permanent record of the benthos and that is suitable for quantitative image analysis.

Technological advances in videography over the past decade have catalyzed the development and evaluation of protocols designed to quantitatively assess reef benthos using computer-assisted image analysis (Vogt et al. 1997, Osborne and Oxley 1997, Page et al. 2001). Most field studies have involved video surveys of multiple, short (10-50 m) transects by free-swimming divers (e.g. Aronson et al. 1994, Lybolt and Eaken 2000, Ninio et al. 2000, Crabbe and Smith 2002), from which randomly or regularly selected frames have been assessed for benthic composition and abundance by the projection of random points on the image (e.g. Carleton and Done 1995, Miller and Müller 1999). While such surveys enable reliable, site-specific habitat description, they generally sample but a single habitat, and they do not capture the transitions by which habitat characteristics change over larger spatial scales.

Carleton and Done (1995) coupled the use of a manta tow with a camcorder mounted on the manta-board in an underwater housing so as to record a portion of the benthic survey area; the observer maneuvering the manta-board was equipped with SCUBA rather than snorkel gear. Though the authors report the potential of the technique for sampling on the scale of kilometers, the actual lengths of reported surveys were confined to 200 meters and, despite the SCUBA capacity of the observer, were conducted to maximum depths of 3 meters. No protocol by which the tow path could be georeferenced was described, an important procedure for linking image to position over large, geomorphic spatial scales.

In 1990, the Honolulu Laboratory of NOAA Fisheries inaugurated the use of SCUBA-diver-controlled towboards equipped with videographic equipment to assess benthic variables deemed important to lobster habitat on three emergent banks in the Northwestern Hawaiian Islands (Parrish and Polovina 1994). Since that time the Honolulu Laboratory has continued to develop an integrated towed-diver survey methodology in response to advances in videographic and georeferencing technology and has adapted the method for mesoscale assessment of coral reef benthic habitats. Our methodology differs from other techniques widely used and reported in that: (a) towed divers regularly survey the reef benthos to the accepted limit of conventional SCUBA, (b) the tow track is mapped through the concurrent recording of GPS positions and depth data, and (c) the data extraction and analysis regime includes percent cover quantification of all identifiable components within sampled frames rather than a point sampling strategy. In this paper we present the main components of our integrated methodology, provide a case study of data collected and processed using this methodology during a mass coral bleaching event at Midway Atoll in the Hawaiian Archipelago (Aeby et al. 2003, Kenyon et al. 2004), and compare results with data derived from more conventional belt-transect surveys.

MATERIALS AND METHODS

Personnel allocation

Four people are utilized to conduct each towed-diver survey: two SCUBA divers, a coxswain to drive the surface boat, and an additional crew member to deploy and retrieve the towboards, operate GPS units, and record the time at which videorecording begins and ends. Efficiency is enhanced by the four people composing two teams of two divers, such that surface personnel and divers switch roles at the end of each tow survey. One member of each dive team maneuvers a towboard dedicated to recording observations concerning the benthic habitat ("habitat" towboard), while the other member of the dive team maneuvers a towboard dedicated to recording observations of ecologically and economically important fish taxa ("fish" towboard). This paper focuses on protocols pertinent to benthic habitat characterization.

Towboards and accessory instruments

Constructed of marine-grade plywood and coated in epoxy resin, towboards are equipped with a digital video camera recorder inside an underwater housing with a wide-angle port and color-correction filter, mounted to maintain a viewing angle perpendicular to the bottom. The videocamera automatically records the date and time on the imagery. On each side of the camera bracket, a waterproof, battery-operated laser pointer is mounted, with the inter-laser distance calibrated to project two red dots in the field of view that are 20 centimeters apart. A depth gauge, digital watch, and alarm chronograph set to emit an auditory signal every 5 minutes after activation are mounted on a separate bracket. The camera clock and digital watch are synchronized with the clock of the GPS unit used onboard the towboat. Plexiglas strips affixed to the towboard allow insertion of a vinyl data sheet for recording written information pertinent to the overall tow as well as quantitative visual estimates of benthic composition integrated over 5-min periods. An SBE 39 temperature recorder (Sea-Bird Electronics, Inc.) mounted on the towboard electronically records depth, temperature, and time at 5-sec intervals. While conducting the videotaped survey, the diver maneuvers the habitat towboard to maintain an estimated distance of 1 meter above the substrate. A simple telegraph is operated by the diver who maneuvers the fish towboard to maintain communication with the tow boat, using several prearranged acoustic signals based on dots (short tones) and dashes (long tones).

Each towboard is separately connected to the towboat transom by an adjustable-length (typically 60 m long), 3/8"inch low-stretch buoyant line. Rather than being directly attached to the towboard, the tow line connects to a short bridle with a stainless steel swivel shackle that allows the diver to disconnect the towboard from the tow line if the towboard becomes grounded and cannot be quickly freed by the diver. Each towboard has a 5-m-long trailing line for the divers to grab if they become detached from the towboard. Divers receive special training in the risks associated with conducting surveys. A standard video survey (< 21 m depth) is 50 minutes long. At greater depths (21 – 27 m) the time is adjusted according to no-decompression limits.

Coordination with Collection of GPS Tow Track Data

To georeference all data collected during a tow, a GPS receiver is programmed to record longitude and latitude coordinates every 5 seconds onboard the tow boat. When the divers are ready to begin videorecording, a prearranged acoustic signal is sent to the tow boat, where the crew member marks a waypoint indicating the start point of the videotape recording. The coxswain attempts to drive along a predetermined isobath using a bathymetric chart, depth sounder, and shoreline features (when present) as a guide while maintaining a speed of 2.5 - 3.5 km/hour (1.7 - 2.5 knots). At the end of the benthic survey, before beginning an ascent to the safety stop, another coded signal is sent to the tow boat to record the time and place at which the video recording ended.

The primary GPS positioning error is the difference between the location of the GPS unit onboard the tow boat and the divers, typically some 55 meters behind the tow boat. To reduce this source of error, a series of tows were conducted to determine a model that addresses the "layback" difference between the position of the videocamera and the position of the GPS unit on the tow boat. Normal survey protocols were conducted, with the addition of a surface snorkeler being towed directly above the towboard divers while wearing a backpack containing a GPS unit inside a waterproof bag. The coxswain maneuvered the tow boat over a series of courses that varied in frequency and amplitude of curvature to mimic the most conservative and the most extreme deviations of the divers'/

snorkeler's position from the coordinates recorded by the GPS unit on the tow boat during regular surveys.

Tape Processing and Data Extraction

The quantitative analysis of each benthic videotape begins with the capture of single, still frames as the tape is simultaneously played through a computer and a high-resolution monitor. The high-resolution monitor assists with identification of benthic characters that may be difficult to distinguish on the lower-resolution computer screen. If the frame is too blurry because of momentary excessive speed, or more than an estimated 5% of the benthos cannot be identified due to shadow, the analyst toggles forward frame by frame until the next frame that is suitable for analysis is reached. A sampling interval of 30 sec was selected as best optimizing the joint interests of reproducible results, inter-frame distance, and time required to complete the analysis.

Each captured still frame is next imported into SigmaScan® Pro (SPSS Science™) for tracing benthic components using a stylus and graphics tablet. The benthic area (cm^2) captured within the frame is determined using the projected pair of red laser dots known to be 20 cm apart, and is used as the denominator in the percent cover calculations for benthic components within that frame. For frames in which the dots have not been imprinted because of laser malfunction, the number of pixels composing the still image is used as the denominator in percent cover calculations. The number of benthic categories that can be identified from still frames varies according to the geographic locality surveyed; the variation is attributable to different coral faunas. Categories that are consistent among geographic locality include macroalgae, turf algae, coralline algae, invertebrates other than coral, sand, rubble, carbonate pavement, rock, and unencrusted (recently dead) coral. A spreadsheet called up within the SigmaScan® Pro program receives the computed area (in cm^2 or pixels) of each member of each benthic category as the analyst completes its tracing with the stylus. Tracing proceeds until only

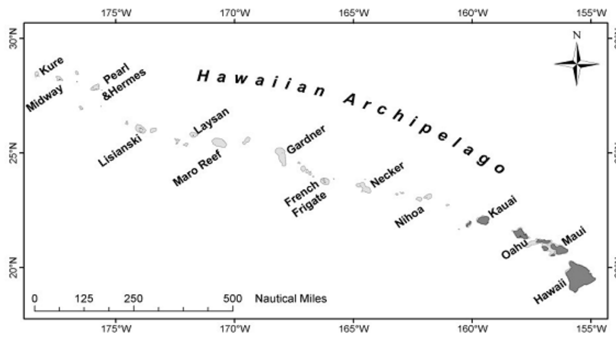

Figure. 1 Location of Midway Atoll in the Hawaiian Archipelago

one category present within the frame remains. These values are then imported into a Microsoft® Excel spreadsheet that has been preformatted with formulas for the calculation of percent cover of each category of imported data. The percent cover of the remaining untraced category is computed by subtracting the sum of the other categories from 100. Lastly, the time-stamp for the still frame is manually entered. The percent cover data and time stamp from each frame-specific Excel spreadsheet are then compiled into a master spreadsheet from which the quantitative habitat data can be summarized over whatever time/spatial interval is desired.

GIS Data Ingestion, Processing, and Display

GPS data are downloaded directly into GIS using a custom-designed (Hoeke, unpublished) ArcView© extension. Data are downloaded as (1) track data files, containing a position and time stamp every 5 sec, and (2) waypoint data files, defining locations of the start and end of the videotaped survey. The customized extension then performs a number of calculations and allows for editing and quality control of the data including (1) a layback calculation to rectify the position of the towboard, (2) merging all track files for a single day, (3) sorting and trimming track files based on waypoint files, interpolating for lost GPS data if necessary, (4) calculating sequential dive numbers, local time, and other attribute fields, (5) adding temperature and depth data, matching SBE 39 and GPS time stamps, and (6) calculating sequential segments for each tow; using segment lengths of 30 sec and 5 min to correlate with the intervals over which analytical and in situ data are compiled, respectively. The extension then adds video analysis data (30-sec segments) and in situ observational benthic data (5-min segments) as separate files. These separate files are spatially represented as polyline files, where each segment of analysis/observation data is a separate polyline. The nodes of these polylines match the nodes in the track file. The attribute tables (*.dbf) of the analysis/observation tables are tied to the track file's attributes by the dive number and the respective segment number. The resulting georeferenced observations can be mapped in conjunction with IKONOS-acquired imagery and viewed on spatial scales of resolution varying from 33 m (the average separation between sequential frames) to the entire length of a tow (i.e. several kilometers).

Case Study: Midway Atoll

Midway Atoll (28°15'N, 177°20'W) is one of the northwestern-most atolls in the Hawaiian Archipelago (Fig. 1). Between 20 and 25 September 2002, 15 towed-diver surveys were conducted at Midway Atoll to assess a mass coral bleaching event (Aeby et al. 2003, Kenyon et al. 2004). Video analysis was conducted by a single analyst. The categories of live coral that could be recognized in recorded videotapes were *Pocillopora*, massive/encrusting *Porites*, *Porites compressa*, *Montipora*, and other live coral (e.g., *Pavona, Fungia*). For each category, percent cover of bleached and unbleached coral were separately quantified. Incidence of bleaching was computed as the percentage of coral cover that was bleached. To examine the correlation between depth and incidence of bleaching, each sampled still frame was paired with its depth using concurrent time stamps on the video and depth recorder.

Comparison with Belt Transect Data

Between 19 and 25 September 2002, belt transects enclosing 50 m^2 or 100 m^2 at each of 20 sites were conducted according to the methods of Maragos et al. (2004), in which the number of colonies as well as the number with bleached tissue was tallied by genus. Incidence of bleaching was computed as the percentage of colonies with bleached tissue. To examine the correlation between depth and incidence of bleaching, for each site the percentage of all colonies with bleached tissue was paired with that site's depth.

Table 1. Summary of towed-diver and belt-transect surveys conducted at Midway Atoll, Northwestern Hawaiian Islands, in September 2002 to assess coral bleaching. NS = not surveyed

Towed-diver surveys

				Average % of total coral cover / average % cover that is bleached				
	Distance surveyed (km)	Average % total coral cover	Average % bleached	*Pocillopora*	massive/ encrusting *Porites*	*Porites compressa*	*Montipora*	Other coral
Backreef	8.7	11.3	77.4	19.5 / 89.9	1.5 / 78.4	0.1 / 0.0	79.0 / 80.7	0.0 / 0.0
Forereef	21.9	1.6	15.0	23.1 / 63.7	76.0 / 8.5	0.8 / 0.0	0.0 / 0.0	0.2 / 0.0
Channel	6.9	1.5	32.4	11.2 / 88.6	83.1 / 17.9	0.5 / 35.0	0.4 / 61.8	4.8 / 67.7
Lagoon	NS	-	-	-	-	-	-	-

Belt transect surveys

				Number of colonies / % with bleached tissue			
	Area surveyed (m^2)	# coral colonies counted	% colonies bleached	*Pocillopora*	*Porites**	*Montipora*	Other coral
Backreef	400	408	56.1	74 / 83.8	59 / 0.0	266 / 61.3	9 / 44.4
Forereef	550	1258	3.7	159 / 30.0	1065 / 0.0	2 / 0.0	32 / 0.0
Channel	50	67	32.8	12 / 66.7	26 / 0.0	8 / 0.0	21 / 66.7
Lagoon	450	303	39.0	128 / 92.2	132 / 0.0	0 / 0.0	43 / 0.0

* Different growth forms/species of *Porites* were not separated using this method

RESULTS

Towed-diver Surveys

The distance between sample frames captured at 30-sec intervals depends upon the tow speed; the average distance ranged from 19.2 m to 38.6 m (mean = 33.0, n = 20 tows). The average benthic area captured in laser-scaled frames was 10,907 cm^2 (SE = 119, n = 700). Towed divers surveyed 37.5 km of benthic habitat within 3 atoll zones (forereef, backreef, channel) (Table 1, Figure 2), from which 1129 frames were analyzed, for a total analysis area of 1231 m^2. The videotape from a standard 50-min tow over a habitat with a diversified benthos (e.g. backreef) requires approximately 16 hours for complete analysis, from capturing still frames to summarization. Coral cover was low (<12%) in all 3 zones (Table 1). Incidence of bleaching was highest on the backreef, lowest on the forereef, and moderate in the broad channel along the northwest exposure (Table 1, Fig. 2). Bleaching was most prevalent in *Pocillopora* and *Montipora*, with a low incidence of bleaching in *Porites* (Table 1). There was a significant negative correlation between the incidence of bleaching and depth (r_s = 0.50, n = 1129, p = 0.00).

Comparison with Belt Transect Data

Belt-transect divers surveyed 1450 m^2 of benthic habitat in 4 zones (Table 1). Incidence of bleaching was highest on the backreef, lowest on the forereef, and moderate in the channel and on lagoon patch reefs (Table 1, Figure 2). Bleaching was most prevalent in *Pocillopora* and *Montipora*, with no bleaching observed in *Porites* (Table 1). There was a significant negative correlation between the incidence of bleaching and depth (r_s = 0.73, n = 20, p = 0.00).

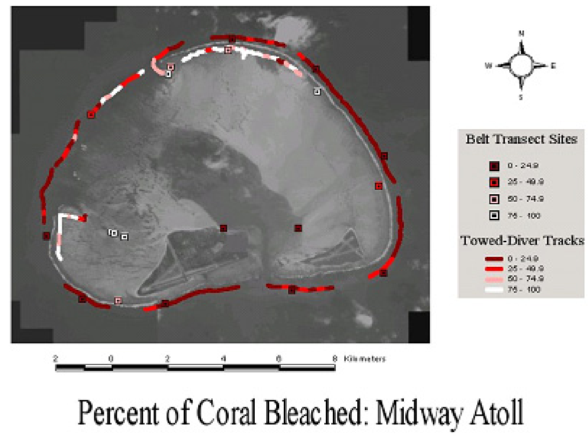

Figure. 2 Locations of towed-diver and belt transect surveys at Midway Atoll, using IKONOS-acquired imagery as a basemap. Sites and track segments are shaded according to incidence of bleached coral; values presented for towed-diver surveys are averages computed over sequential 5-min intervals.

CONCLUSIONS AND RECOMMENDATIONS

Towed-diver surveys provide an efficient method for recording spatial variability in benthic communities on coral reefs when conducted by experienced divers trained in the safety considerations that pertain to this advanced diving technique.

A primary strength of towed-diver surveys is their ability to assess the major benthic components and condition of reef habitats over spatial scales substantially greater than can be observed and documented by free-swimming divers. In the present study at Midway Atoll, belt-transect divers examined more benthic area than was analyzed from towboard videos (1450 m^2 vs. 1231 m^2, respectively); however, results from towed-divers were derived over a survey length of 37.5 km (Table 1), while results from belt transects were derived over transect lengths totaling 725 m. Because the samples (still frames) from towed-diver surveys are spread over a long curvilinear dimension, whereas belt transect surveys are concentrated at specific sites (Figure 2), towed-diver surveys provide a broader spatial assessment of large reef systems with variable habitats. The primary conclusions generated from both methods are congruent: (1) incidences of bleaching were highest on the backreef, lowest on the forereef, and moderate in other atoll zones; (2) *Pocillopora* and *Montipora* were highly susceptible to bleaching whereas *Porites* evidenced little bleaching; and (3) there was a significant negative correlation between depth and the incidence of bleaching. In receiving corroboration from the similar results generated through belt-transect surveys, towed-diver surveys allow extrapolation to broader spatial scales.

Because they are powered by a surface boat, towed divers are able to survey in sea conditions that are too extreme for roving divers or their support skiff to safely work in, e.g. high swell, strong current, or poor anchorage. They provide a permanent visual record that is amenable to re-sampling by different analysts, or to re-analysis when more automated, image-recognition technologies are developed. Inclusion of a GPS receiver on the towing boat allows georeferencing the survey path, and incorporation of a layback model improves the accuracy of positioning the recorded imagery, thereby providing a basis for ground-truthing satellite and aerial remote sensing imagery (e.g. Andréfouët et al. 2002, Bainbridge and Reichelt 1988). The method is particularly useful for assessing remote areas that can only be visited infrequently and for short durations.

A primary limitation of interpreting visual information from a towed camera is the loss of taxonomic resolution compared to the capacity of roving diver classifications. Field equipment as well as computer equipment needed to analyze imagery is expensive, realistically limiting this method to programs with large budgets. Image analysis is time-consuming. Field and computer personnel require special training, the former to ensure safety and accuracy, the latter to ensure consistency and reproducibility. Interested researches should weight the advantages and limitations of towed-diver surveys before investing in and implementing the method.

ACKNOWLEDGMENTS

We thank more than two dozen fellow NOAA-certified divers for building the safety record of towed-diver surveys, the officers and crew of the NOAA ship *Townsend Cromwell* for logistic support and field assistance, and Greta Aeby for sharing belt transect data. Permission to work at Midway Atoll National Wildlife Refuge was granted by the Pacific Remote Islands Wildlife Refuge Complex, U.S. Fish and Wildlife Service, Department of the Interior. Will Smith, of the Hawaii Coral Reef and Monitoring Program of the University of Hawaii's Hawaii Institute of Marine Biology, and Michael Coyne, of the Biogeography Program of NOAA's National Ocean Service, assisted with surveys from which a layback model was derived. Funding from the Office of Habitat Conservation at NOAA Fisheries as part of the NOAA Coral Reef Conservation Program has supported this work since 2001, with particular encouragement and facilitation from Tom Hourigan.

REFERENCES

Aeby, G. S., J. C. Kenyon, J. E. Maragos, and D. C. Potts.
2003. First record of mass coral bleaching in the Northwestern Hawaiian Islands. Coral Reefs 22:256.

Andréfouët, S., R. Berkelmans, L. Odriozola, T. Done, J. Oliver, and F. Müller-Karger.
2002. Choosing the appropriate spatial resolution for monitoring coral bleaching events using remote sensing. Coral Reefs 21:147-154.

Aronson, R. B., P. J. Edmunds, W. F. Precht, D. W. Swanson, and D. R. Levitan.
1994. Large-scale, long-term monitoring of Caribbean coral reefs: simple, quick, inexpensive methods. Atoll Research Bulletin 421:1-19.

Bainbridge, S. J., and R. E. Reichelt.
1988. An assessment of ground truth methods for coral reef remote sensing data. Proceedings of the 6th International Coral Reef Symposium 2:439-444.

Bass, D.K., and I. R. Miller.
1996. Crown-of-thorns starfish and coral surveys using the manta tow and scuba search techniques. Long-term Monitoring of the Great Barrier Reef SOP No. 1, Australian Institute of Marine Science, 33 p.

Carleton, J.H., and T. J. Done.
1995. Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14:35-46.

Chesher, R.H.
1969. *Acanthaster planci*: Impact on Pacific coral reefs. Final report to the U.S. Department of the Interior. Westinghouse Electric Corporation Research Laboratories, Pittsburgh PA, 151 p.

Crabbe, M.J.C., and D. J. Smith.
2002. Comparison of two reef sites in the Wakatobi Marine National Park (SE Sulawesi, Indonesia) using digital image analysis. Coral Reefs 21:242-244.

Donohue, M.J., R.C. Boland, C.M. Sramek, and G.A. Antonelis.
2001. Derelict fishing gear in the Northwestern Hawaiian Islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. Marine Pollution Bulletin 42(12):1301-1312.

Kenchington, R.A.
1978. Visual surveys of large areas of coral reefs. *In* Stoddart, D.R., and R.E. Johannes, R.E. (eds.), Coral Reefs: Research Methods, UNESCO, Paris, p. 149-162.

Kenyon, J.C., G.S. Aeby, R.E. Brainard, J.D. Chojnacki, M. Dunlap, and C.B. Wilkinson.
2004. Mass coral bleaching on high latitude reefs in the Hawaiian Archipelago. [Abstract]. Tenth International Coral Reef Symposium, Okinawa, Japan, p. 135.

Lopez, V. M., J.M. Diaz, and J. C. Marques.
2000. Coralline formations of Tortugilla Island (Colombian Caribbean). Boletin Investigations Marinas 29:51-58.

Lybolt, M., and D. Eaken.
2000. A tested protocol for video sampling of benthic habitats. *In* Hallock, P. and L. French (eds.), Diving for Science in the 21st Century. American Association of Underwater Science, Nahant, Massachusetts, p. 26.

Maragos, J.E., D.C. Potts, G. Aeby, D. Gulko, J. Kenyon, D. Siciliano, and D. VanRavenswaay.
2003. The 2000-2002 rapid ecological assessment of corals (Anthozoa) on shallow reefs of the Northwestern Hawaiian Islands, Part 1: species and distribution. Pacific Science 58(2):211-230.

Miller, I., and R. Müller.
1999. Validity and reproducibility of benthic cover estimates made during broadscale surveys of coral reefs by manta tow. Coral Reefs 18:353-356.

Moran, P.J., and G. De'ath.
1992. Suitability of the manta tow technique for estimating relative and absolute abundances of crown-of-thorns starfish (*Acanthaster planci* L.) and corals. Australian Journal of Marine and Freshwater Research 43:357-78.

Ninio, R., M. Meekan, T. Done, and H. Sweatman.
2000. Temporal patterns in coral assemblages on the Great Barrier Reef from local to large spatial scales. Marine Ecology Progress Series 194:65-74.

Osborne, K., and W.G. Oxley.
1997. Sampling benthic communities using video transects. *In* English, C., C. Wilkinson, and V. Baker (eds.), Survey manual for tropical marine resources. Australian Institute of Marine Science, Townsville, p. 363-376.

Page, C., G. Coleman, R. Ninio, and K. Osborne.
2001. Surveys of sessile benthic communities using the video technique. Long-term Monitoring of the Great Barrier Reef SOP 2, 49 p.

Parrish, F.A., and J.J Polovina.
1994. Habitat thresholds and bottlenecks in production of the spiny lobster (*Panulirus marginatus*) in the Northwestern Hawaiian Islands. Bulletin of Marine Science 54(1):151-163 .

Rodgers, S.K., and E.F. Cox.
1999. Rate of spread of introduced Rhodophytes *Kappaphycus alvarezii*, *Kappaphycus striatum*, and *Gracilaria salicornia* and their current distributions in Kâne'ohe Bay, O'ahu, Hawai'i' Pacific Science 53(3):232-241.

Vogt, H., A.R.F. Montebon, and M.L.R. Alcala.
1997. Underwater video sampling: an effective method for coral reef surveys? Proceedings of the 8th International Coral Reef Symposium 2:1447-1452.

The Use of Digital Video Recorded During Towed Diver Surveys to Estimate Reef Fish Assemblages Over a Large Spatial Scale

Brian Zgliczynski
Coral Reef Ecosystem Division
Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822-2396
Email: brian.zgliczynski@noaa.gov

Towed-diver surveys can be used to conduct rapid assessments of large areas of reef in a short period of time, which can be critical when working at remote sites. Compared to traditional dive surveys, which have limited spatial coverage, the towed diver surveys are more effective at estimating abundance and density of large mobile fishes. Rare or uncommon fishes not encountered during conventional surveys are more likely to be observed during towed-diver surveys because of the larger area covered. While conventional SCUBA surveys are often impacted by adverse environmental conditions, towed divers are less affected and can therefore survey sites where wind, current, and swell are challenging. The towed-diver video analysis permits more detailed assessment of larger-bodied fishes, including the ability to more precisely enumerate the numbers of individuals within large aggregations of fishes observed during the *in situ* surveys. Additionally, a video record of the habitat is available to describe benthic characteristics (i.e., physiographic zones, habitat types, and habitat complexity). Towed-diver surveys involve towing two SCUBA divers behind a boat at a constant speed (~1.5 knots; Fig. 1). Each diver maneuvers one of two towboards that are connected to the boat by a bridle and towline and outfitted with various survey equipment including digital still or video cameras. The divers fly the towboards approximately 1 m above the substrate to keep the records consistent. One of the towboards carries a magnetic switch telegraph system, which allows the tow-divers to relay simple prearranged acoustic signals to the surface support team. The latitude and longitude coordinates of the survey track are recorded using a global positioning system allowing data to later be geo-referenced.

Laboratory analyses of the digital videos recorded during towed diver fish surveys are conducted by viewing 40% of a tape for fishes 20-50 cm total length (TL), and viewing 100% of a tape for fishes >50 cm TL. Tapes are viewed in ten 5-min segments (towed-diver survey time dependent) and fishes are recorded within an estimated 10 m-wide swath. Fishes are identified to species level, where possible, and sizes are estimated according to one of nine size categories (20, 35, 50, 75, 100, 150, 200, 250, and 300 cm TL), the latter using habitat cues and, in certain cases, size-specific behaviors and colorations. Habitat classification information is also recorded during video analysis by assigning a specific value for the physiographic zone, habitat type, and complexity that is viewed during each 1-minute sub-segment.

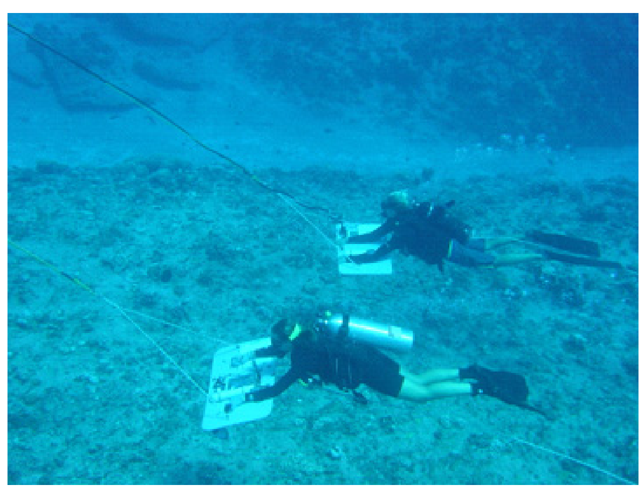

Figure 1. One diver (forward) records the benthos and another diver (rear) records fish during towed-diver surveys using underwater videography at Pathfinder Reef in the Commonwealth of the Northern Marianas Islands. Photo: S. Holzwarth

Botcam –
Bottom Fish Camera Bait Station

Daniel Merritt
Coral Reef Ecosystem Division
Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822-2396
Email: Daniel.Merritt@noaa.gov

Since 1997, the National Marine Fisheries Service (NMFS) in Hawaii has been collaborating with the Hawaii Undersea Research Laboratory (HURL) to conduct visual surveys of commercially important bottom fish species including snappers, groupers and jacks. Using HURL's deep diving manned submarines, the *Pisces IV* and *V*, biologists Christopher Kelley (HURL), Robert Moffitt (NMFS) and others have conducted ongoing surveys of bottom fish at depths from 150 m to 300 m. These surveys employ bait to attract fish to the area of the submarine but use no external light source, which is known to discourage certain target species. Building upon this previous work, HURL and NMFS' Pacific Islands Fisheries Science Center are developing an autonomous bottom camera bait station (Botcam) designed to be deployed in 200-400 m depths which automatically releases bait and records video (Fig. 1). This presentation reviews a prototype Botcam system delivered by Sound Ocean Systems, Inc., Redmond, Washington, and discusses future design directions and considerations.

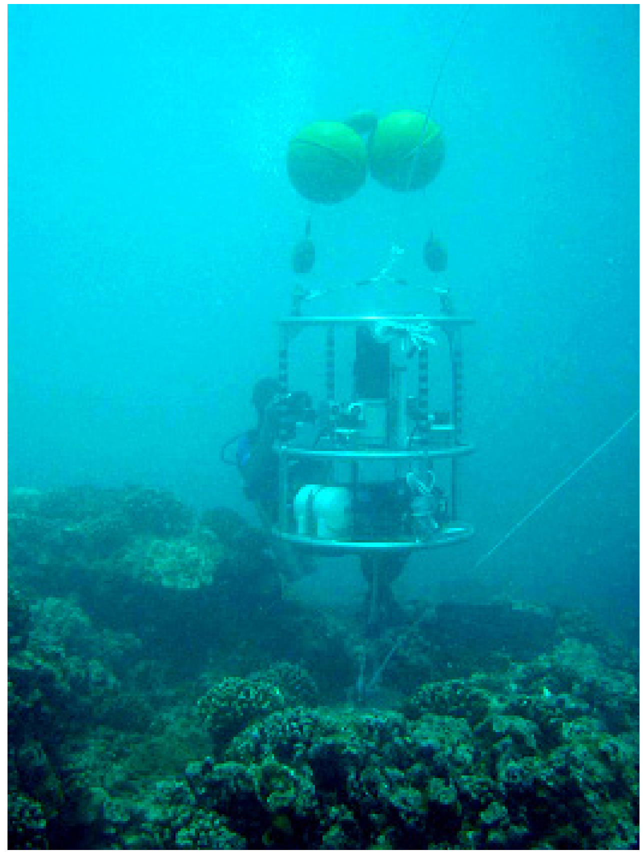

Figure 1. Prototype Bottom Camera Bait Station (Botcam) system deployed inapproximately 30 feet of seawater off the south shore of Oahu, Hawaii. Photo by K. Wong.

SEAMAP Reef Fish Survey of Offshore Banks

Christopher T. Gledhill, Kevin R. Rademacher
and Paul Felts
Mississippi Laboratories
Southeast Fisheries Science Center
P.O. Drawer 1207
Pascagoula,MS 39568-1207
Email: Christopher.T.Glendhill@noaa.gov

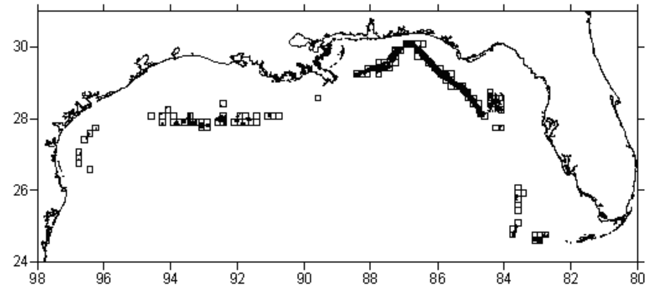

Figure 1. Bathymetry along the continental shelf of the Gulf of Mexico with the primary sample units (blocks) employed by the SEAMAP offshore reef fish survey.

The objective of the Southeast Fisheries Science Center's annual Southeast Area Monitoring and Assessment Program (SEAMAP) offshore reef fish survey is to provide an index of the relative abundances of fish species associated with topographic features (banks, ledges) located on the continental shelf of the Gulf of Mexico (Gulf) in the area from Brownsville, Texas, to the Dry Tortugas, Florida (Fig. 1). The offshore reef fish survey was initiated in 1992, with sampling conducted during the months of May to August from 1992 to 1997, 2001 to 2002, and 2004. No surveys were conduced from 1998 to 2000 and 2003. The 2001 survey was abbreviated due to ship scheduling.

The survey area is large; therefore a two-stage sampling design is used to minimize travel times between sample stations. The first-stage or primary sampling units (PSUs) are blocks 10 minutes of latitude by 10 minutes of longitude (Fig. 17). The first-stage units are selected by stratified random sampling, with stratum boundaries defined by geographic region (four regions: South Florida, Northeast Gulf, Louisiana-Texas Shelf, and South Texas), and by reef habitat area (Blocks $\leq$ 20 km² reef, Block > 20 km² reef). There are a total of seven strata. The ultimate

Figure 2. The SEAMAP camera pod.

sample sites (second stage units) within a block are selected randomly

The SEAMAP reef fish survey currently employs four Sony VX2000 DCR digital camcorders mounted in Gates PD150M underwater housings (Fig. 2). The housings are rated to a maximum depth of 150 m. The four Sony VX2000 camcorders are mounted orthogonally at a height of 30 cm above the bottom of the pod (Fig. 18b). A chevron (or arrow) fish trap with 1.5-inch vinyl-clad mesh is used to capture fish for biological samples. At its greatest dimensions, the trap is 1.76 m in length, 1.52 m in width and 0.61 m in depth. A 0.4 m by 0.29 m blow-out panel is placed on one side and kept closed using 7-day magnesium releases. The magnesium releases are examined after each soak and replaced as needed. The trap is deployed at a randomly selected subset of video stations. Both the camera pod and fish trap are baited with squid. The camera pod soaks for 30 minutes while the trap soaks for 1 hour.

One video tape from each station is randomly selected for viewing. Tape viewers examine 20 minutes of the selected video tape, identify, and enumerate all species for the duration of the tape. Identifications are made to the lowest taxonomic level and the time when each fish enters and leaves the field of view is recorded. This is referred as a time in - time out procedure (TITO). Tapes are viewed from the time when the view clears from any silt plume raised by the gear when it landed. Less than 20 minutes may be viewed if the duration when water is not clear enough to count fish is less than 20 minutes, or if the camera array is dragged. Three estimators of relative abundance are available from the video data: 1) presence and absence; 2) maximum count (each fish of each taxon is counted each time it appears on the screen); and, 3) a minimum count (the greatest number of a taxon that appears on screen at one time). The minimum count is the same at the MAXNO used by Ellis and DeMartini (1995). Presence and absence (frequency of occurrence) and minimum count estimators are advantageous because they avoid the potential of multiple counting of fish. Lasers mounted 10 cm apart are used to obtain estimates of fish length (Fig. 3).

Figure 3. Still image captured from video showing laser dots on a scamp (*Mycteroperca phenax*) and red porgy (*Pagrus pagrus*).

Not all fish can be identified from the videotape. Often, identification to species level depends on observing fish behavior. Identification can be improved with the use of higher resolution cameras (High Definition video or digital still cameras.) Few fish are hit by the lasers so size information is limited. Stereo video or still cameras would enable the measurement of all fish. The tape viewing procedure is time-consuming. On average, a single viewer can process video from three sites (60 minutes of tape) in a 40-hour week. Automation of the viewing procedure using pattern recognition would make the survey data available to stock assessment scientists in a more timely fashion.

Underwater Video Research at the Northeast Fisheries Science Center

William Michaels
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1026
Email: william.michaels@noaa.gov

Underwater video operations are conducted routinely aboard Northeast Fisheries Science Center's (NEFSC) research cruises in support of NOAA Fisheries Strategic Goals such as Stock Assessment Improvement Plan (SAIP) and Essential Fish Habitat (EFH). Underwater video has been deployed on survey sampling gear (trawls and dredges) to examine gear performance and selectivity for SAIP. Underwater video research is also underway to verify acoustic seabed classification, which provides the framework for identifying and monitoring EFH.

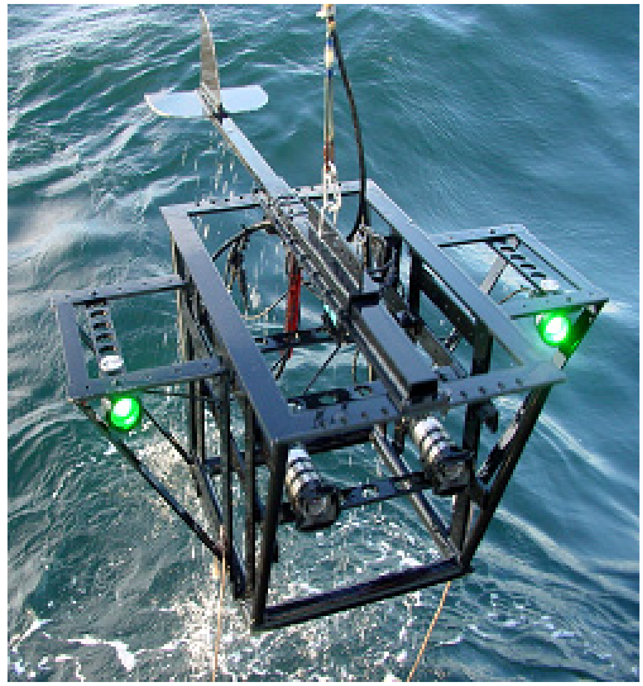

Figure 1. A multipurpose low-light video camera array configured to obtain *in situ* tilt angle measurements of Atlantic herring.

Underwater video has been implemented to improve acoustic population estimates by direct verification of acoustic targets and explains the variability of the estimates as a function of fish behavior (Fig.1).

Figure 2. Herring observed swimming with an upward tilt using CCD video cameras at low-light levels (1 x 10^{-4} lux).

For example, in-situ video observations of herring behavior with their tilt angle measurements in conjunction with their individual acoustic target strength measurements confirms that variability in their acoustic population estimates vary primarily with their behavioral patterns (Fig. 2). Low light CCD and ICCD video cameras are utilized to reduce fish avoidance. *In situ* underwater video has also provided a means to link laboratory measurements and theoretical modeling of herring backscatter with the empirical results from surveys. Efforts are underway to develop an advanced integrated fisheries optical-acoustic-environmental sensing profiler via portable fiber-optic winch system for improving NEFSC fisheries and habitat acoustic survey operations. Existing technological limitations of integrated optical-acoustical survey operations to resolve include accurate synchronization of video streams and acoustic data logging, real-time optical recognition and processing, video and metadata management for integrated marine habitat mapping, limited dynamic range, and minimization of fish avoidance.

Video Scallop Stock Assessment in Alaska

Gregg Rosenkranz
Alaska Department of Fish and Game
Division of Commercial Fisheries
211 Mission Road
Kodiak, AK 99615
Email: gregg_rosenkranz@fishgame.state.ak.us

The Alaska Department of Fish and Game began working on methods for video assessment of weathervane scallop stocks in 2000. The primary objective of the program is to collect fishery-independent data on scallop populations that will aid in management of the resource. Video was chosen because the capture efficiency of scallop dredges is variable and difficult to estimate.

Our equipment consists of a towable aluminum sled equipped with a watertight pressure tube that houses a mini-DV camcorder, an underwater 12 volt battery, and four 75-watt lights (Fig. 1a). The camcorder is aimed toward the substrate through a glass dome port on one end of the pressure tube, and video is recorded on the sled only. Tows of 15 minutes duration at a target speed of 1.5 knots are made at randomly selected stations inside beds defined from logbook effort data from the commercial fishery. Two reviewers count scallops by watching the video after the survey at regular playback speed without pauses.

A subset of tows is reviewed a second time using pause and slow-speed playback to obtain the most accurate counts possible, allowing us to estimate bias in the original counts (Fig. 1b). Observed scallop densities are converted to scallop count estimates using area-swept methodology. Scallop shell height measurements obtained from still images captured from video are used in conjunction with shell height-meat weight data from limited dredge tows to convert the scallop counts estimates to meat weight biomass estimates. To date, surveys have been conducted in the eastern Gulf of Alaska, Shelikof Strait, and in the Bering Sea north of Unimak Island.

Figure 1a.) Launching the video sled used for the scallop survey; b.) view of the seabed showing three scallops.

We hope to upgrade the system to live video feed in the near future. This would increase efficiency by allowing us to collect more useable video footage per vessel day.

Use of Video for Inshore Rockfish Stock Assessment

Chris Grandin
Department of Fisheries and Oceans
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, British Columbia V9R 5K6
Canada
Email: grandinc@pac.dfo-mpo.gc.ca.

The Pacific Biological Station's inshore rockfish group in western Canada uses two video-based methods to assess stocks in the inside waters of British Columbia's west coast: towed cameras, and manned submersibles.

The two types of towed camera arrays used on this study both have the same physical layout (Fig. 1a). A video overlay unit is used to overlay the video signal with sensor data, GPS coordinates (at surface), and time. This enables the application of data analysis methods such as line transect density estimation for stock assessment.

The manned submersible we use is Nuytco's *Aquarius*, a 2-observer, 1-pilot craft, which is shown in Figure 1b with the layout of the cameras and communications used for the September 2003 survey.

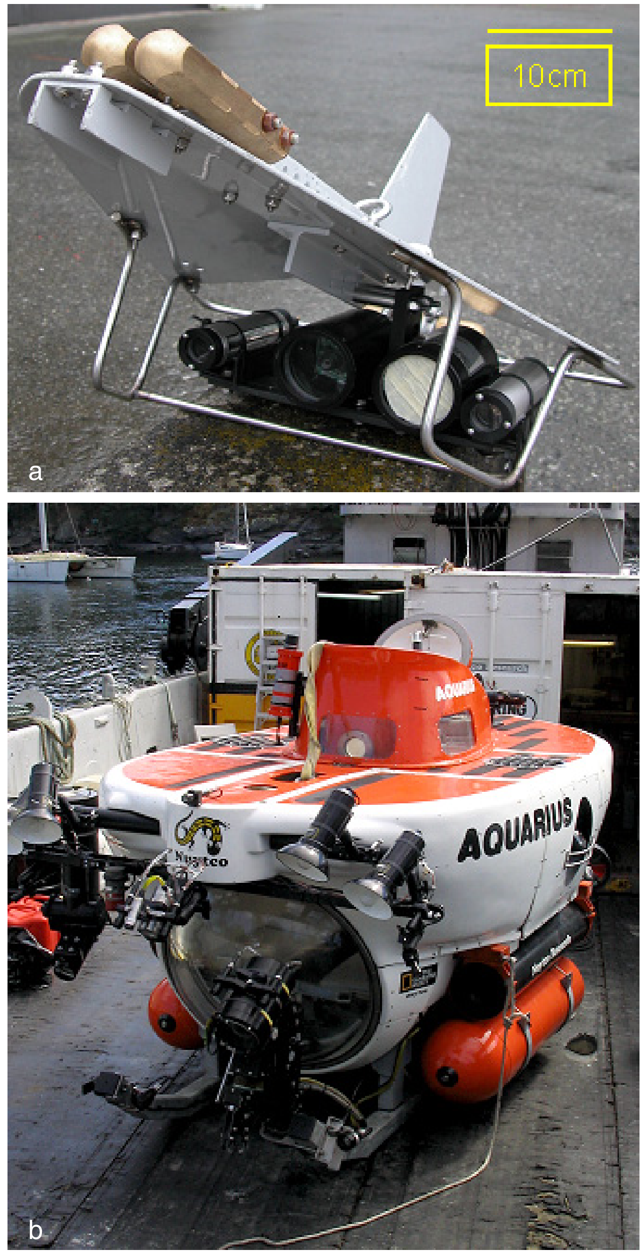

Figure 1a.) The delta wing towed camera; b.) the *Aquarius* submersible.

To create a database of the habitat conditions and fish observations, most researchers follow some manual method such as pausing the tape each time a surface substrate changes or when a fish is seen, then insert the time and species/substrate type into a database. We decided early on that because of the amount of tape we had to analyze, a better method was needed. DVlog software was created to not only automatically store the data into a database on a button press but to also control the DV tape deck remotely. The buttons can be re-assigned to different species and substrate types on the fly (Fig. 2). A person is still needed to view the tape, but the amount of work that person needs to do has been greatly reduced. For more information on DVlog or if you want a copy of the software please email me (grandinc@pac.dfo-mpo.gc.ca.).

Our analysis techniques include line transect density estimation using the program DISTANCE which is available on the web (http://www.ruwpa.stand.ac.uk/distance/) and we are exploring the use of neural networks to determine habitat preference by species. At this point, the neural network is a simple three-layer perception classification model using the video indicators substrate type, relief, complexity, and depth as inputs to the network and the species as the output. The output appears as a probability that the species will be seen given the habitat conditions.

With this network we have so far only reached a rate of 75% correct classification when compared with training data but as more data is collected and new networks are tried we hope to improve this. The ultimate goal is to use remotely sensed data as inputs and have a prediction of species and perhaps even density in real time.

Figure 2. The graphical user interface for Dvlog, the video processing software used for the rockfish assessment project.

Use of Stereo-video Photography in Remote Camera and Diver Transect Assessments of Fish Populations

Euan Harvey and James Seager
School of Plant Biology
University of Western Australia
Perth, Australia
Email: euanh@cyllene.uwa.edu.au

Mark Shortis
Science, Engineering and Technology Portfolio
RMIT University, Melbourne, Australia
Email: mark.shortis@rmit.edu.au

Stuart Robson
Department of Geomatic Engineering
University College
London, United Kingdom
Email: srobson@ge.ucl.ac.uk

Mike Cappo
Australian Institute of Marine Science
Townsville, Queensland, Australia
Email: mcappo@aims.gov.au

We have used stereo-video to assess demersal fish assemblages in two ways; firstly a diver-held stereo-video system and secondly in baited remote underwater video stations.

Diver-held, stereo-video system

Underwater Visual Census (UVC) by SCUBA divers is one of the most popular techniques for assessing the diversity, abundance and length frequency of shallow water reef fish assemblages. However, UVC is not as easy as it sounds. Divers need to identify and count all the species they see, decide if a fish is inside or outside the sample unit and often estimate the lengths of individual fish. UVC suffers from many biases, of which inter-observer variability is probably of the greatest concern. For this reason we have constructed several stereo-video systems which can be operated and maneuvered by a SCUBA diver. The use of stereo-video minimizes biases, and inter-observer variability associated with length estimates of fish (See Harvey et al. 2001a,b, 2002a). The latest version of the system uses SONY TRV 900E video cameras in water-tight acrylic housings (Fig. 1).

The watertight housings are mounted on a base bar 75 cm apart. Using this system we can measure the lengths of fish on the video to within

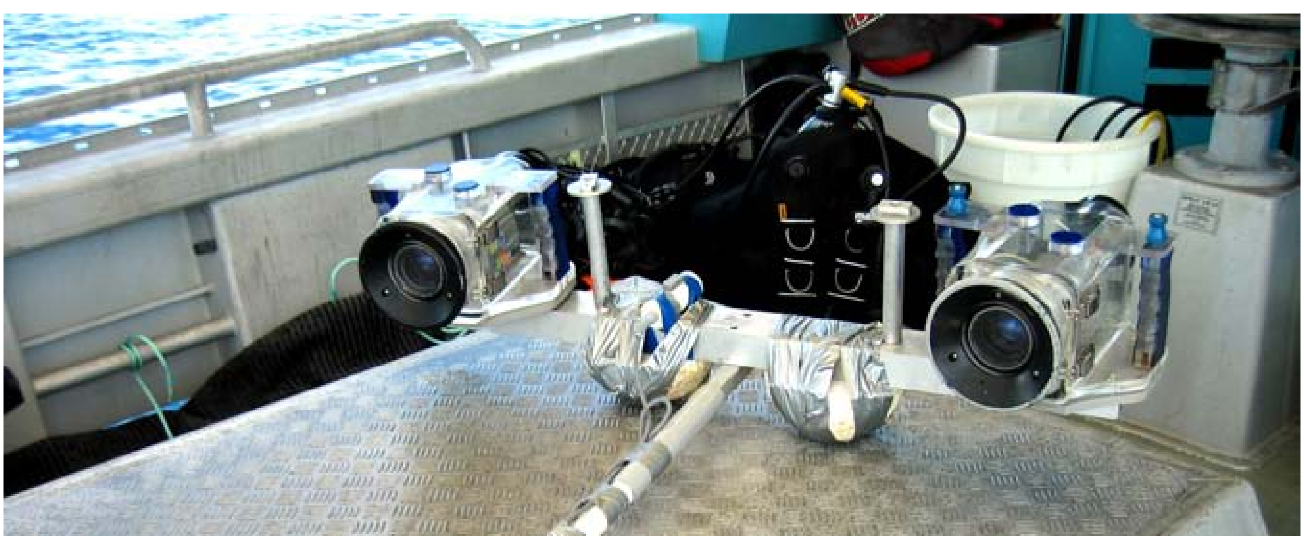

Figure 1. A diver-held stereo-video camera system. A SCUBA diver swims the camera system recording observations and comments directly onto one of the videotapes using a full-face mask containing a microphone (right).

Figure 2. Two stereo BRUVS ready for deployment. These systems use off-the-shelf single CCD Sony HandiCams in PVC housings with acrylic ports.

several millimeters of their real length (see Harvey et al. 2002b). To date we have measured the lengths of fish ranging from 23 mm through to 270 mm at distances of 0.5 m to 9 m from the cameras. We also use the stereo-video measurements to define whether a fish is inside or outside the borders of our sampling unit. Deciding whether a fish is inside or outside a sampling unit is very important and can drastically alter the estimates of density or relative abundance (Harvey et al. 2004).

The system is neutrally buoyant in water, can be operated by any competent diver and deployed from small boats. Harvey et al. (2001a, 2002a) have shown that measurements of the lengths of fish from a stereo-video are more accurate and precise than estimates from novice and experienced scientific divers. Similar results were recorded for distance estimates (Harvey et al. 2004). Using stereo-video measurement software (Shortis and Robson 2004) inexperienced people can make very similar measurements as experienced operators. This has major implications for the involvement of volunteers in monitoring programs.

Stereo-video in Baited Remote Underwater Video Stations (BRUVS)

Baited underwater video cameras were first used for assessing the abundances of juvenile tropical snappers (Ellis and DeMartini 1995), and abyssal scavengers (Priede et al. 1994,1996). Since then baited video techniques have become popular in a variety of forms (Babcock et al. 1999, Willis and Babcock 2000, Willis et al. 2000, 2003; Cappo et al. 2003, 2004; Denny et al. 2004).

Some of the advantages of baited cameras include the ability to non-destructively sample demersal fish assemblages from a wide range of habitats across many depths, both during the day and at night time. Camera stations also attract many species and size classes that are disturbed by SCUBA divers in shallower waters. Video recordings serve as a permanent record for identification and simultaneously provide information on habitat and on the behavior of fish towards each other and towards the gear. Stereo baited remote underwater video stations (stereo

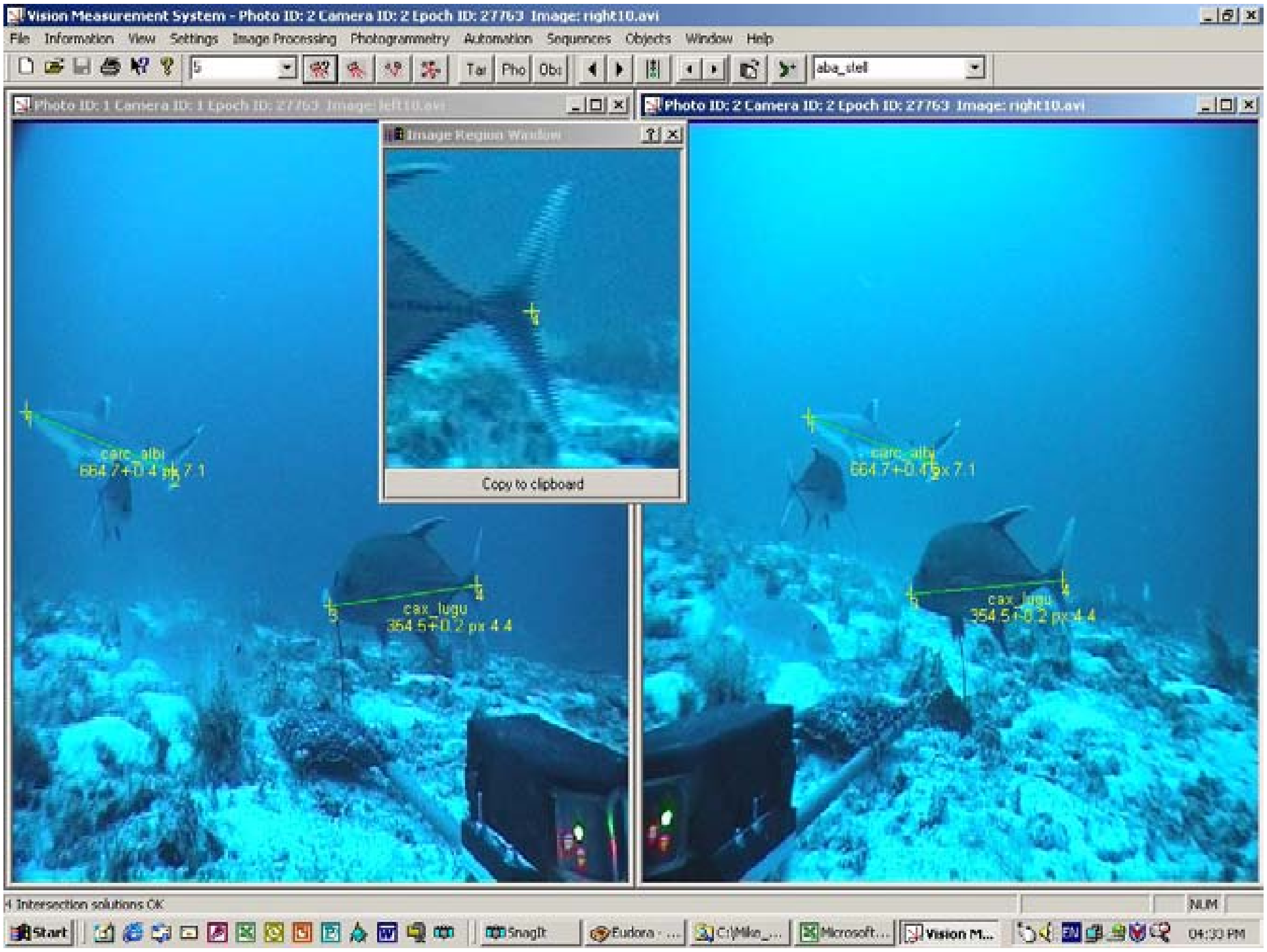

Figure 3. A screen dump of the VMS interface.

BRUVS) (Fig. 2) have several advantages over single-camera BRUVS.

Stereo BRUVS facilitate non-extractive fish measurements of the lengths of fish over a broad range of sizes. Similarly, the distances between individuals can be measured as well as the speed at which they swim (distance between point A and B over a time period). Because it is possible to measure distance, one of the main advantages of stereo BRUVS is the ability to define a sampling area/volume and decide whether a fish is inside or outside of the unit. The inability of single BRUVS to measure distance means that changes in water visibility over time and location will greatly affect the area sampled and the ability to draw conclusions from spatial and temporal comparisons of data sets.

Stereo-video Measurement Software

We used a Vision Measurement System (VMS) (Shortis and Robson, 2004) purpose-built stereo photo comparator to analyze stereo-video imagery. Images from calibrated video cameras are loaded into the software either as single images or video streams (.avi). They are synchronized using flashing diodes, which are visible in the field of view. Measurements of the x,y,z location of a point are made by locating the cursor over the area of interest and clicking with a mouse (Fig. 3).

The software is presently being further developed. Our ultimate aim is the real time automated recognition and measurement of the lengths and volumes of fish and other target organisms. We continue to make small incremental steps towards this goal that decrease processing time, which can be lengthy, and a major limitation of the technology.

Field Applications to Date

There have been thorough tests of the accuracy, precision and calibration of the hand-held stereo-video system using plastic fish silhouettes (Harvey et al. 1996, 2002b) and on fast-swimming tuna in fish cages (Harvey et al. 2003). These have been followed by field tests in tropical and temperate habitats, including coral reefs, algal reefs, seagrass beds and soft substrata ranging in depth from 3 m through 110 m. Fish, sharks and rays from a variety of families have been successfully measured and counted.

Citations

Babcock R.C., S. Kelly, N. T. Shears, J. W. Walker, and T.J. Willis.
1999. Changes in community structure in temperate marine reserves. Mar. Ecol. Progr. Ser. 189:125-134.

Cappo, M., E. Harvey, H. Malcolm, and P. Speare.
2003. Advantages and applications of novel "video-fishing" techniques to design and monitor Marine Protected Areas, p. 455-464. *In* Beumer, J.P, A. Grant, and D.C. Smith (eds.), Aquatic protected areas – What works best and how do we know? Proceedings of the World Congress on Aquatic Protected Areas. Cairns, Australia; August 2002.

Cappo, M., P. Speare, and G. De'ath.
2004. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. J. Exp. Mar. Biol. Ecol. 302:123-152.

Denny, C.M., T. J. Willis, and R. C. Babcock.
2004. Rapid recolonization of snapper (*Pagrus auratus*: Sparidae) within an offshore island marine reserve after implementation of no take status. Mar. Ecol. Progr. Ser. 272:183-190.

Ellis, D. M., and E. E. DeMartini.
1995. Evaluation of a video camera technique for indexing the abundances of juvenile pink snapper, *Pristipomoides filamentous*, and other Hawaiian insular shelf fishes. Fish. Bull., U.S. 93: 67-77.

Harvey, E. and Shortis, M. R.
1996. A system for stereo-video measurement of sub-tidal organisms. *Marine Technology Society Journal*, 29(4):10-22.

Harvey, E. S., D. Fletcher, and M. Shortis.
2001a. A comparison of the precision and accuracy of estimates of reef-fish lengths made by divers and a stereo-video system.
Fish. Bull., U.S. 99:63-71.

Harvey, E. S., D. Fletcher, and M. Shortis.
2001b. Improving the statistical power of visual length estimates of reef fish: A comparison of estimates determined visually by divers with estimates produced by a stereo-video system. Fish. Bull., U.S. 99(1):72-80.

Harvey, E. S, D. Fletcher, and M. R. Shortis.
2002a. Estimation of reef fish length by divers and by stereo-video. A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fish. Res. 57/3: 255-265.

Harvey, E. S., M. R. Shortis, M. Stadler, and M. Cappo.
2002b. A comparison of the accuracy and precision of digital and analogue stereo-video systems. Mar. Tech. Soc. J. 36(2):38-49.

Harvey, E. S., M. Cappo, M. Shortis, J. Buchannan, and S. Robson.
2003. The use of an underwater stereo-video system for measuring the lengths of caged Southern Blue Fin Tuna. Fish. Res. 63 (3):315-326.

Harvey, E. S, D. Fletcher, M. R. Shortis, and G. A. Kendrick.
2004. A comparison of underwater visual distance estimates made by SCUBA divers and a stereo-video system: Implications for underwater visual census of reef fish abundance. Mar. Freshw. Res. 55: 573-580.

Priede, I.G., P. M. Bagley, A. Smith, S. Creasey, and N. R.Merrett.
1994. Scavenging deep demersal fishes of the Porcupine Seabight, north-east Atlantic: observations by baited camera, trap and trawl. J. Mar. Biol. Assoc. UK 74:481-498.

Priede, I.G., N. R.Merrett.
1996. Estimation of abundance of abyssal demersal fishes; a comparison of data from trawls and baited cameras. J. Fish. Biol. 49(Suppl. A):207-216.

Shortis, M. R., and S. Robson.
2004. VMS Reference and User Guide. Geometric Software P/L, 15 Maranoa Crescent, Coburg 3058 AUSTRALIA (http://www.geomsoft.com.au).

Willis, T.J., R.B. Millar, and R.C. Babcock.
2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling, and baited underwater video. Mar. Ecol. Progr. Ser. 198:249-260.

Willis, T.J., and R.C. Babcock.
2000. A baited underwater video system for the determination of relative density of carnivorous reef fish. Mar. Freshw. Res. 51:755-763.

Willis, T. J., R. B. Millar, and R. C. Babcock.
2003. Protection of exploited fishes in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves. J. Appl. Ecol. 40: 214-227.

Video Mosaics

Yuri Rzhanov
Center for Coastal and Ocean Mapping
University of New Hampshire
24 Colovos Road
Durham, NH 03824
Email: yrzhanov@cisunix.unh.edu

Underwater imagery is collected at a short range due to limited visibility and strong attenuation of visible light, making it difficult to observe and evaluate features larger than those fitting in a single frame (including clusters of small features for density estimation). Relatively low accuracy of underwater navigation systems (> 10 cm) does not allow for utilizing the positioning information in assembling separate images in a mosaic because the mosaic typically has sub-centimeter or even sub-millimeter resolution. Video footage, however, is acquired at a temporal and spatial rate that guarantees high redundancy between consecutive frames. Pairwise registration of frames calculates the transformation relating those frames, and thus, recovery of camera motion in image space is possible with high accuracy. Cascading the transformations, video sequences can be assembled in images of a scene greatly exceeding the scene of any single frame (Fig. 1).

Image redundancy – multiple coverage of the same area from different positions – facilitates detection of objects moving with respect to the steady background. These objects, depending on the objectives, can be either removed from the scene, or extracted and registered in a database for future processing (e.g., expert identification or pattern recognition).

Requirements for collection of imagery suitable for creating mosaics are formulated. Camera motion models are presented in the order of increasing complexity: translational, rigid affine, perspective, and full bathymetric. Choice of model depends on actual camera motion, strength of 3D content of sea bottom, available computational resources, etc.

Presence of laser caliper spots in the individual video frames helps to estimate relative distances and hence to find mapping between real and pixel spaces for both video frames. On the other hand, a set of laser spots is a strong, almost steady (within a frame) feature that may seriously hinder the registration process. Techniques for laser-spot detection and removal are presented.

An examples of a mosaics is shown in Figure 26 from the imagery acquired by digital still or video camera; hand-held, or mounted on a sled, towed body, AUV, or manned deep submersible vehicle.

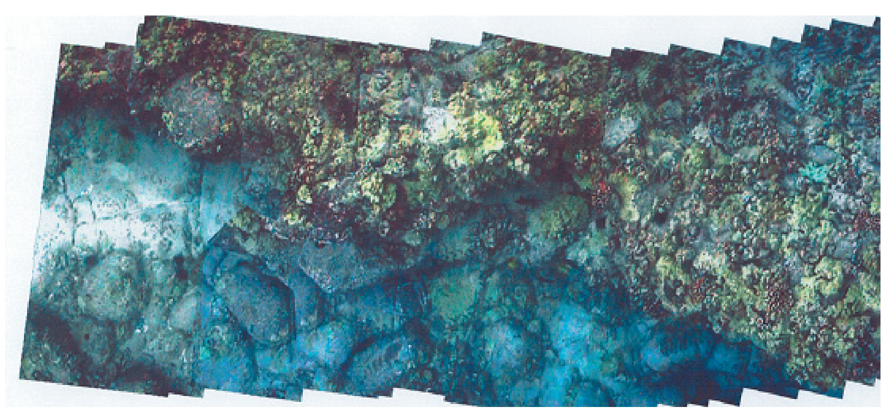

Figure 1. A video mosaic of a coral reef.

High Resolution Underwater Imaging and Image Processing for Identifying Essential Fish Habitat

Scott M. Gallager, Hanu Singh, Sanjay Tiwari, Jonathan Howland, Paul Rago, and William Overholtz
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Email: sgallager@whoi.edu
and
Richard Taylor and Norman Vine
Northwest Atlantic Fishing Community

We currently use a towed digital habitat mapping camera system (HabCam, Fig. 1) developed with funding from the Northeast Consortium together with the SeaBED autonomous undersea vehicle (AUV;Fig. 2) to collect, process and classify high resolution digital imagery of fish populations and the seafloor. HabCam has the capability to collect accurately geo-referenced images while towing at 4 knots, providing a continuous stream of bottom images through a fiber optic cable to the surface. On deck, a real-time processor merges the images into a continuous ribbon followed by classification of habitat and biotic community. SeaBED can be deployed for up to 12 hours while optically and acoustically imaging the bottom, but the data must be downloaded and processed post facto (Fig. 29).

We have been developing automated classification methods to allow the large volume of data to be sorted into more useful information. The associations between substrates and species in conjunction with other factors such as depth and current are then used to develop maps of habitat types at multiple scales. The final goal is to make the collected data readily available to all interested parties, including fishery managers, fishermen, marine researchers, and the public via the internet in an easily navigated and readily understood manner.

There are five basic steps in processing images for characterizing habitat: 1. Image Acquisition, 2. Image Correction and Enhancement, 3. Target Segmentation, 4. Feature Extraction, and 5. Target Classification.

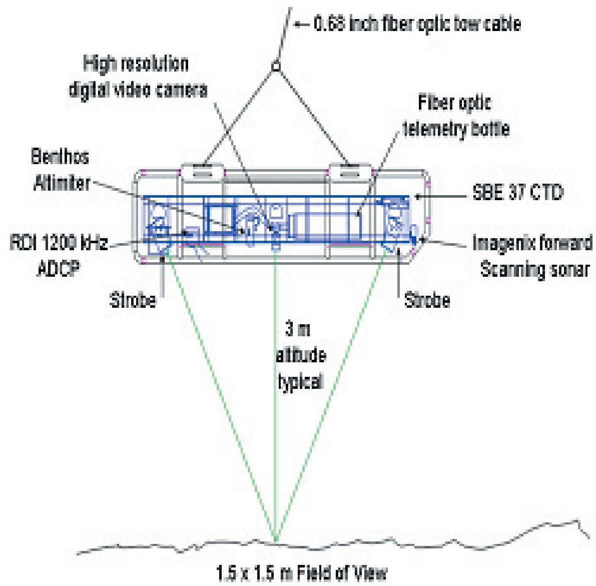

Figure 1. Habitat Mapping Camera System (HabCam) as configured during March 2003 cruise.

Image acquisition of benthic habitat begins with balanced white light (for color imaging) illumination with sufficient intensity to achieve color saturation while minimizing illumination of particulates between the target plane and camera. For moving imaging platforms (1-4 knots), short exposures (2-50 μsec) are critical to achieve images free from motion blur. Mechani-

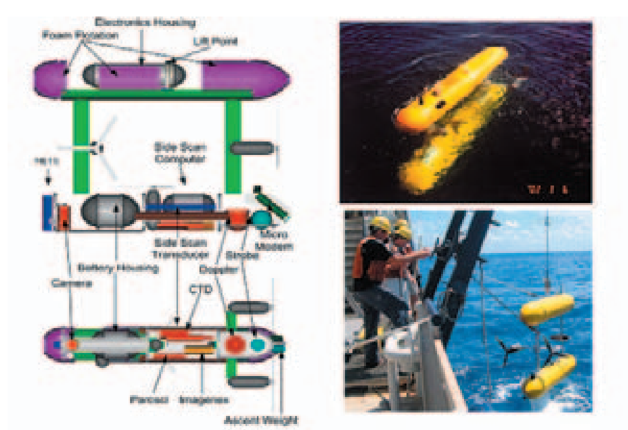

Figure 2. SeaBED AUV during a deployment off Puerto Rico to map coral habitat.

cal and electronic shutters are usually not sufficiently fast to provide short exposures thereby requiring strobes or triggered LED array light sources.

Today's reasonably inexpensive CCDs and CMOS imaging chips can provide 2,000 × 2,000 pixels with 12-bit resolution at 30 frames per second (fps). Considerably higher resolution can be obtained albeit at a slower frame rate, the tradeoff and limitation being bandwidth of the recording device. It is important to simplify the imaging geometry as much as possible. To this end, the camera placed on an orthogonal axis relative to the image plane optimizes the ability to correctly calibrate the imaging system and provide the uniform illumination.

Image correction and enhancement involves balancing the light field to remove light gradients and color correction to account for greater attenuation of light at longer wavelengths. Both processes can be accomplished through various forms of homomorphic digital filtering and by making some assumptions or measurements about the spectral characteristics of the water. Target segmentation is perhaps the most critical and difficult process when studying benthic habitat. Typically, the complex background is very mottled and the organisms are by design, cryptic in nature. We are exploring new methods of segmenting benthic images into different homogeneous textures and identifying boundaries that separate the different regions. Our method of "texture segmentation" uses wavelet coefficients of Gabor wavelets to define features of an image. The wavelet coefficients provide a joint time-frequency characterization of the image. The basic idea behind Gabor wavelets is to decompose images into multiple-oriented spatial frequency channels. The channel envelopes (amplitude and phase) are then used to form the feature maps. We also define color features that are constructed from the color distribution angles of an image. Images are segmented automatically using Gabor wavelets and texture energy gradients.

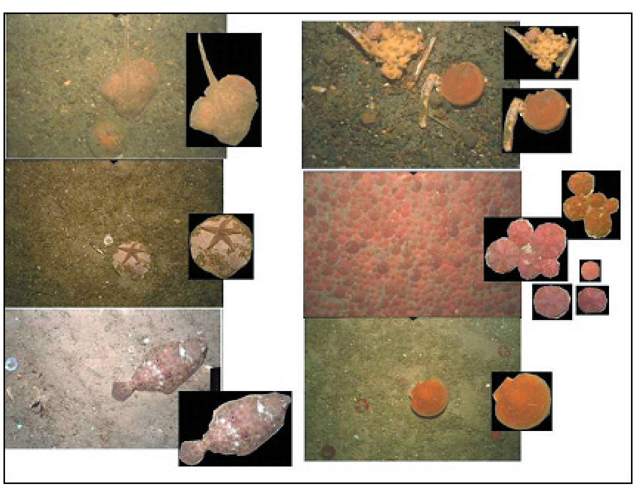

Figure 3. Benthic images taken on Georges Bank (courtesy P. Valentine).

Finally, we define an average measure (composed of all features calculated at all orientations) that is rotation invariant. The rotation-invariance is necessary because a homogeneous texture should be recognizable as such when viewed from any orientation. For example, the spatial frequency of an image of small gravel would be higher than that for an area of cobble, the smaller particle sizes having more edges. Areas are differentiated further where there is partial gravel or cobble and mostly sand or mud. Orientation-invariance is necessary for targets such as flounders, so that they are recognized without regard to the direction they are pointing when encountered. In order to perform segmentation, we next define an energy function which is based on the gradient (composed of the two partial derivatives) in feature space at each point of the image. Depending on the level of contrast, lighting and content of a large benthic region of interest, a threshold value of this energy function is chosen, and areas of the image with energy value larger than the threshold are deemed to be the boundaries separating regions of different homogeneous textures.

Feature extraction is actually performed in wavelet space using the Gabor coefficients calculated during the segmentation process. Color angles and morphological information (size, shape, etc.) are also part of the feature

Figure 4. Image ribbon taken by SeaBed AUV on Stellwagen Bank.

vector for each image to be classified. Finally, to classify the different homogeneous textures, we use classifiers called Support Vector Machines (SVMs). SVMs have the advantage that they are capable of learning in high dimensional feature spaces (which ours tend to be) with a small training set. They accomplish this by simultaneously minimizing a bound on the empirical error and the complexity of the classifier. Given a pattern space of inputs, SVMs operate by finding hypersurfaces in the space that attempt to split the different patterns from each other. The SVM algorithm formulates the training problem as one that finds, among all possible separating hypersurfaces, ones that maximize the distances between the closest elements of each pair of adjacent patterns (Fig. 3).

When an image ribbon is created from many sub-images, we can begin to see large scale textures that are not readily identifiable in individual sub-images. Areas of the composite image abundant in one kind of "texture element" (whether it is a inanimate background object or an organism) will present a different large-scale texture pattern than another part of the image abundant in another texture element. Thus, mud, sand, small gravel, shell aggregations, reefs, and aggregations of cobble/boulder, scallop, or sand dollar, all present different large scale homogeneous texture patterns (Fig. 4).

Our current benthic classification scheme includes the following:

- mud/sand without emergent biological structure.
- mud/sand with emergent biological structure.
- small gravel (< 2 cm) without emergent/attached biological structure.
- small gravel (< 2 cm) with emergent/attached biological structure.
- shell aggregations and/or reefs w/out emergent/attached biological structure.
- shell aggregations and/or reefs with emergent/attached biological structure.
- cobble/boulder without emergent/attached biological structure.
- cobble/boulder with emergent/attached biological structure.

While realizing that substrate is a continuum, we find that there are qualitative differences between habitats of mud and sand and the species that live there (Fig. 5). Accordingly we seek to differentiate these bottom types and the associated biota. The categories listed here are segmented using the approach described above and displayed by pseudo-coloring the original mosaic as a function of texture type. Associations with specific targets (e.g., larval and juvenile fish, echinoderms, hydrozoans) and texture category are made through discriminate analysis.

Inclusion of diverse habitats in the analysis allow for more robust training of the SVMs, providing information about the greatest number of environments immediately useful to fishery managers and for future study by benthic habitat researchers.

The techniques described here may be used in a variety of habitats both benthic and pelagic, in stereo imaging systems, or wherever difficult background lighting situations necessitate the need for advanced image processing.

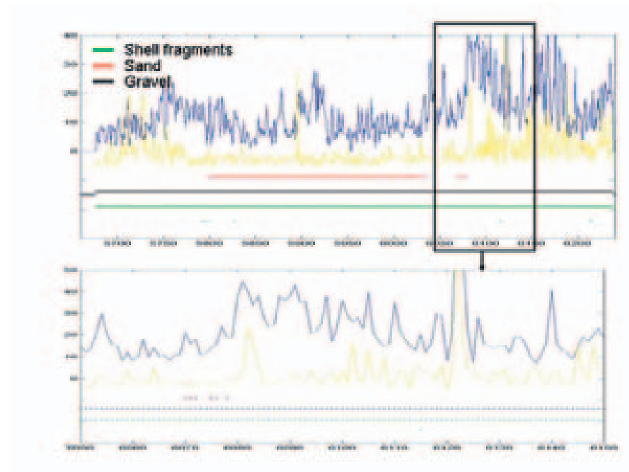

Figure 5. Transect data from the western edge of Georges Bank extracted from images taken by HabCam. The substrate is composed of shell fragments, sand, and gravel. The blue line represents abundance of living sea scallops and the yellow line is dead (upside down) scallop shell. The transect at top is about 5 km in

Archiving, Annotating and Accessing Video as Data

Judith Connor
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
Email: conn@mbari.org

Scientifically useful, high-quality video data can be challenging to analyze and archive for use in ocean science. Over the past 16 years, the Monterey Bay Aquarium Research Institute (MBARI) has processed over 15,000 videotapes as a record of remotely operated vehicle (ROV) dives. The ROVs have high-resolution video cameras and the images are recorded on digital videotapes and archived as a centralized institutional resource.

To provide access to the images and data, MBARI has developed a set of three software applications (with knowledge base, annotation and query components) for annotation and access. The knowledge base, a hierarchical list of over 3,500 biological, geological and technical terms, is the foundation of the system.

The annotation software references the knowledge base, providing consistent spelling and information about objects seen on the video. Columns at the top of the annotation graphical user interface (GUI) (Fig. 1) show timecode, observations, and associations.

Physical data relating to the selected row is available on the right side of the screen. The GUI has quick buttons (below the columns) for special functions such as samples taken, population number, or close-up image, as well as video tape

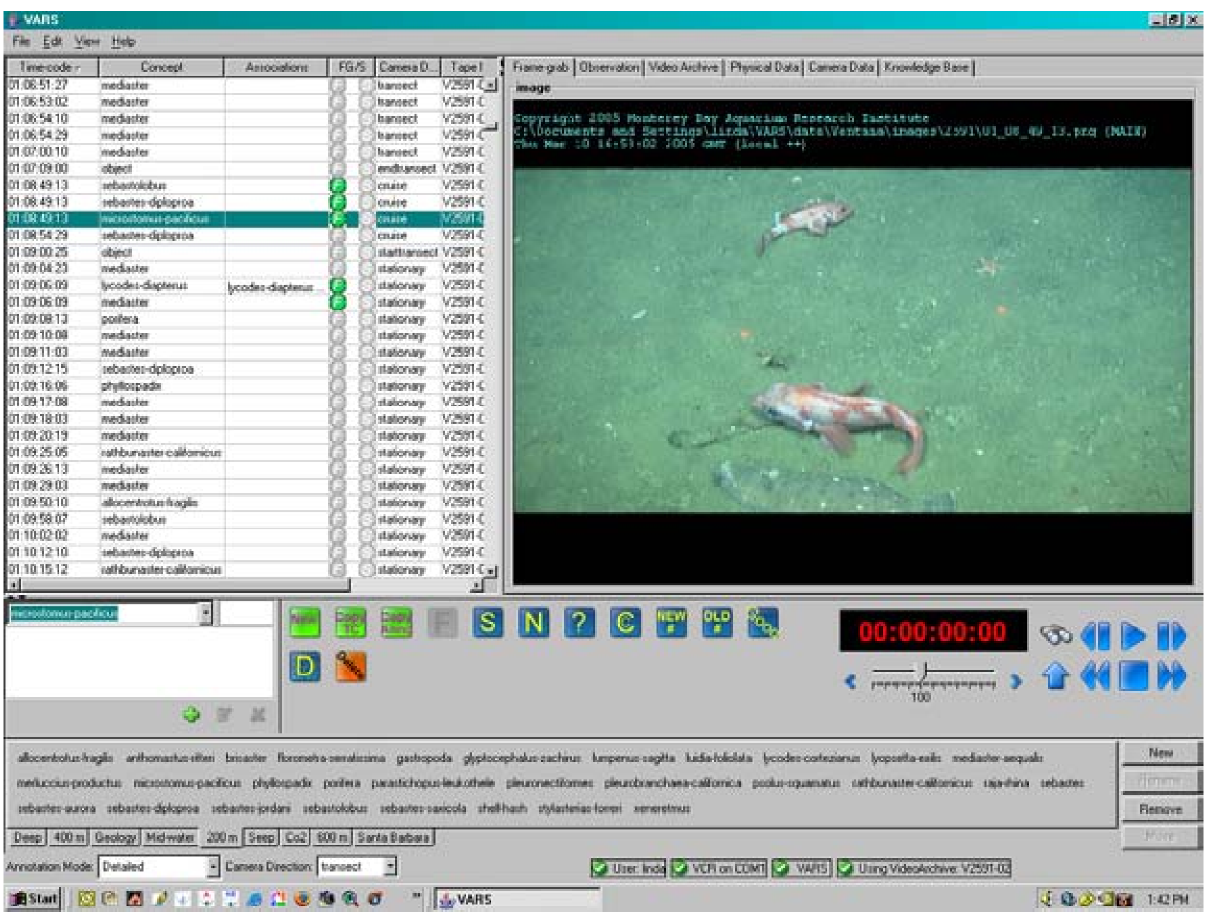

Figure 1. Graphical user interface with the video archiving software.

deck controls. The horizontal list of *Sebastes* species at the bottom of the GUI functions as quick buttons that can easily be changed for an individual user's preferences. Annotation can be done in real time on the ship or later in the laboratory. The system supports frame capture of still images off the video stream to outline the highlights of each dive. The software can be used for everything from simple annotations to outlining the general fauna in an area, to very detailed documentation of each organism, geological features, and other habitat characters.

The query component has a graphical user interface that allows users to extract data from the database to identify the location of video sequences and show the distribution of species or other objects from the database, frame grab images and physical data collected concurrent with the video. Complex queries can be made by constraining temporal, spatial, or physical parameters (e.g., season, location, or depth) from a pull-down menu on the GUI.

The software components were written in the Java programming language to run on multiple platforms and maintain compatibility between shipboard and office environments. This should maximize utility of the software for future external users who adopt the system because they can add the appropriate species, geological features and equipment seen in their own regions. Castor, an open-source, data-binding framework for Java, is used in the annotation and knowledge base components to perform object-to-relational mapping. Data used in the MBARI Video Annotation and Reference System (VARS) are stored in Microsoft SQL Server databases.

We expect to disseminate the full software system royalty-free to the research community in 2005 to help meet the challenges inherent in archiving video data. For more information or to express interest in testing the program, contact MBARI.

Remote Sensing Using Laser Projection Photogrammetry for Underwater Surveys

Thomas H. Jagielo,
Washington Dept. Fish and Wildlife
600 Capitol Way N
Olympia, WA 98501
Email: jagiethj@dfw.wa.gov

Washington Department of Fish and Wildlife researchers have combined the Laser/Video Photogrammetric System with precision navigation to provide an efficient tool for producing quantitative benthic survey data. In addition to the roll/pitch motion reference sensor, CCD video camera and three microlasers utilized in the original system, a Doppler velocity log (DVL), ring laser gyro (RLG), ultra-short baseline sonar (USBL) and Integrated Positioning System (IPS) software were added to provide more precise navigation. This precision allows for geo-referencing, and hence mosaicking of user-specified sized areas within an image along a transect survey. Two additional lasers were also added to test for improvement of scale measurements. Custom software is used to automatically process video data at user-selected distance intervals. The software locates the reference lasers in an image and optical triangulation is used to compute range to a bottom plane in the field-of-view.

Using this information and measurements recorded from the motion sensor, the spatially variant magnification is determined over the entire field-of-view using a simple algorithm. As a result, a variety of parameters are estimated using image-processing techniques including: perspective overlays, range to a point or location, scale in any region of the image, and area measurements. This paper briefly reviews the original system, describes the enhancements, and summarizes data from two cruises. In the most recent cruise during October 2003 the system was deployed in the Channel Islands National Marine Sanctuary located off the coast of southern California.

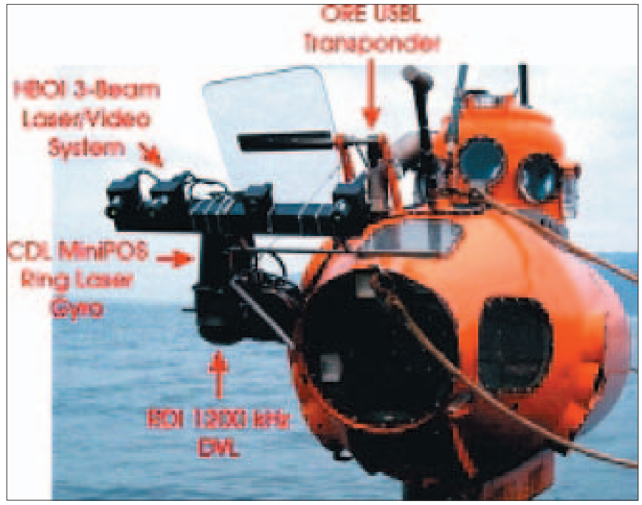

Figure 1. A view of the camera system attached to the *Delta* minisub.

Mounted onboard the submersible *Delta* (Fig. 1), the system collected numerous hours of video and navigation data from survey transects (Fig. 2). Data were collected from both randomly sampled sites and selected areas where groundtruth targets were placed.

Methods to improve these results are also discussed. Deployment of a third generation system is expected in 2005 onboard an AUV. We expect the final system will prove valuable

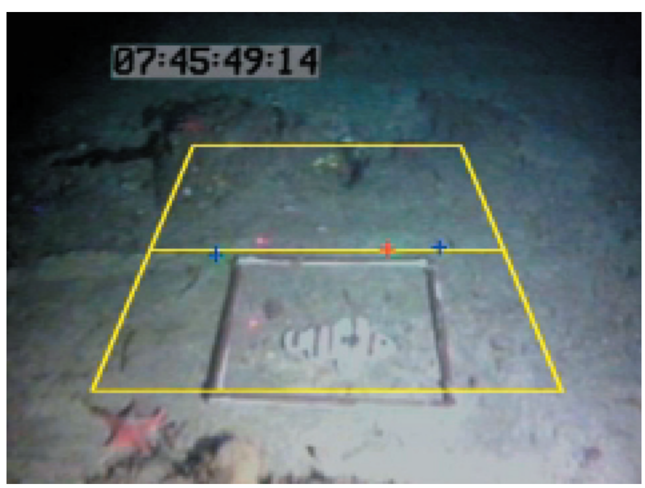

Figure 2. A view of the bottom with the quadrate superimposed. Note the square meter target on the bottom and the three reference laser points (red dots).

for estimating the abundance of commercially and recreationally exploited groundfish species within a study area using stratified random video transect methods.

This unobtrusive, direct-observation technique affords a means to estimate the density of certain benthic fish species in high relief areas that are not accessible to routine trawl survey methods. Differences in fish densities between trawlable and untrawlable habitats have clear implications for estimation of abundance for a number of fish species including rockfish.

Development of a Diver-held Stereo Video Camera

Chris Boynton and Ken Voss
University of Miami
Department of Physics
P.O. Box 248046
Coral Gables, FL 33124
Email: chris@physics.miami.edu
Email: voss@miami.rsmas.miami.edu

After having reviewed the existing literature, we determined that no underwater stereo video system with sufficient resolution for quantitative analysis was commercially available. To develop such a camera, our idea was to perform experiments that would help us determine the required system parameters, so simultaneous with this, we investigated which still cameras would be suitable for the purpose. These experiments required us to develop calibration software and data handling software. Our camera requirements were as follows:

- Ability to be computer controlled, or at least externally triggered, to allow simultaneous images to be obtained. Computer control would be useful to allow the images to be logged as pairs.
- Firewire interface to allow images with sufficient spatial resolution to be downloaded quickly to a computer for processing.
- Sufficient pixel resolution.

In our search, we found an existing system that could be adapted to our use and provide a great leap forward. This system was a stereo video system built by Videre for use in robotics (Fig. 1). The system featured dual electronic cameras that are read out simultaneously over a firewire interface into a computer. The software was already developed for calibration of the system, and data reduction of the images into x,y,z arrays. In addition, software source code was provided for developing applications in Windows and Linux. With this system, which could be run either as still or video camera with a rate less than
1/30 second, we could achieve a result which we did not originally feel was reasonable in this first stage; that is, quantitative digital stereo video.

Figure 1. The diver-held stereo video camera showing the display screen and the control keypad.

We took Videre's system and used it as the basis for our design. The camera, digital compass and pitch/roll sensor, computer with hard drive and 7" display, and a small numeric keyboard are all housed in one container approximately 12" × 8" × 6". The power for the system comes from an external battery (24V, 1.5 –2A).

The display on the back of the camera system (Fig. 34) has information on internal temperature, exposure setting, gain, number of frames taken, and current operational status of the system. Images from each camera are shown in the display along with a real-time histogram of the images to help in setting exposure. Almost out of the figure on the right is the external system battery. There is a SEACON 1508 (8 conductor) connector on the right side of the case which allows another computer to be connected via Ethernet (RJ45), to allow data transfer without opening the case (We have made an external network patch cable that goes between the SEACON connector and a standard RJ45 Ethernet network connector). We have been extensively testing this system in a pool to work out operational problems before going into the field. During this testing we have found various hardware and software problems that have been corrected. We also did an “ergonomic” test in the pool, using the system while swimming with full dive gear, and this test went well. Calibration data was taken during these pool tests, and sample images with plastic fish were recorded just to test the data collection operations.

At this point we are ready to do a field test. We are currently in the process of arranging a test in a nearby location. The main purpose will be to simply operate the system in the open ocean environment and collect images. These images will be reduced manually to test the operation of the system qualitatively. In addition we will be putting samples with known characteristics into the camera’s field of view so we can get quantitative information on operation of the system. These first field tests are within the scope of our original proposal, and we expect to have these completed by the end of October.

We hope to soon have a system which can be calibrated in an absolute manner and provide x, y, z coordinates as a combination of arrays. From these coordinates, one could easily find distances between different points in the array. However, since the system has the capability of obtaining images in rapid succession, it is obvious that some automated data reduction capability must be developed. An obvious application would be in providing three-dimensional images of specific areas in a coral habitat. Simple views would be quite easy to obtain, but mosaics of images that provide three-dimensional images would be somewhat harder to get.

Citations

Harvey, E., and M. Shortis.
1996. A system for stereo-video measurement of subtidal organisms, Mar. Tech. Soc. J. 10-22.

Van Rooij, J,. and J. Videler.
1996. A simple field method for stereo-photographic length measurements of free swimming fish: merits and constraints, J. Exp. Mar. Biol. Ecol.15: 237 – 249.

Woods, A., T. Docherty, and R. Koch.
1994. Experiences of using stereoscopic video with an underwater remotely operated vehicle. Underwater Intervention 1994, San Diego, California, February 1994, p.34-38.

A Review of the Use of Underwater Video in Australia

Euan Harvey
School of Plant Biology
University of Western Australia
Crawley, Western Australia, Australia
Email: euanh@cyllene.uwa.edu.au

Mike Cappo
Australian Institute of Marine Science
Townsville, Queensland, Australia
Email: mcappo@aims.gov.au

In September 2000, the Fisheries Research and Development Corporation (FRDC) hosted a 3-day workshop on Rottnest Island, Western Australia on the use of underwater video in Australian Fisheries (Harvey and Cappo 2001). The rationale for the workshop was based around the fact that Fisheries Research and Development reviews in Australia have identified the need for non-destructive, fishery-independent stock assessment techniques for both target and non-target species, and for assessing the benthic habitats that many species occupy. There was also the need to develop and validate cost-effective techniques that facilitate the comparison of data collected over a range of temporal and spatial scales for benthos, reef and inter-reef fishes. To allow robust spatial and temporal comparisons of data, techniques need to minimize many of the biases inherent in fisheries and benthic habitat assessments. There was also a need to standardize the methods and techniques that are being used by marine researchers around Australia in both shallow subtidal and deepwater environments.

The workshop was attended by 42 participants from research organizations throughout Australia including various State fishery agencies, the Australian Institute of Marine Science, Commonwealth Scientific and Industrial Research Organization (CSIRO), South Australian Research and Development Institute and academic institutions. The workshop also benefited from contributions by international scientists (from the UK, NZ and USA). The aim of the workshop was to share the experience and expertise of participants who have been using video as a tool for sensing the size and abundance of target and non-target fauna in Australian fisheries. Workshop proceedings can be viewed online at http://www.aims.gov.au/pages/research/video-sensing/report/report_text.html.

The specific objectives of the workshop were as follows:

1. Report on the present national state of knowledge regarding the use and applications of videography and stereo-videography for censusing fish populations and benthic habitats;

2. Report on: a) the limitations of stereo-photogrammetry and videography from the perspective of hardware, software and the behavior of fishes and the complexities of benthic habitats; b) the opportunities and advantages of stereo-photogrammetry and videography from the perspective of develop ing new techniques and methods for use in fisheries stock assessment;

3. Demonstrate the use of stereo-video software;

4. Outline further software developments, requirements and time lines for the develop ment of a fully automated system for process ing video records and gain suggestions on changes to software architecture and research priorities;

5. Share the cumulative knowledge of Austra lian based research groups experienced in the use of underwater video as a sampling tool; and

6. Develop multi-disciplinary, multi-agency collaborative research projects to refine, apply and evaluate the techniques in critical fisheries.

Around Australia, and indeed the world, underwater video was and still is seen as a tool that can satisfy many of the needs described above in both shallow and deepwater research. Consequently, underwater video is being quickly adopted for the non-destructive sampling of a very broad range of organisms. Unfortunately, many researchers do not know how to maximize the information and data resulting from their recordings. Furthermore, while it is very easy to record a lot of information, the processing, interpretation, image storage and retrieval can be laborious, resulting in a bottleneck in data analysis. At that time there was a need to make researchers aware of the possibilities and limitations of underwater videography as a tool and to determine the key concerns and research needs and wants. This was achieved by involving key individuals from State fisheries agencies and academic institutions in the workshop.

The outcomes from the workshop included a research and development plan and a set of recommendations about research needs and priorities. Although these recommendations were accepted and supported by the Fisheries Research and Development Corporation, no formal outcomes have resulted yet at a national level. However, at the level of individual researchers and between organizations, there has been greater communication resulting in incremental development of software, hardware and sampling and interpretation processes. In many respects this has resulted in informal standardized operating protocols and the sharing of equipment and knowledge between groups.

In Australia the historical use of underwater video can be divided into four main research categories: habitat mapping and monitoring, interactions between fishing gear and animals, aquaculture and fish ecology, and biology. Since the national workshop, and publications by Willis et al. (2000), a number of research groups have begun using video techniques to assess the performance of Marine Protect Areas in terms of fish numbers and sizes (see Cappo et al. 2003 for review).

Many research groups in Australia are involved in habitat mapping programs where towed or drop video is used as a technique for validating habitat classifications from acoustic techniques such as sidescan, single beam and multi-beam sonars. Notable examples are the SEAMAP program (www.utas.edu.au/tafi/seamap), the Great Barrier Reef Seabed Biodiversity Project (www.reef.crc.org.au/resprogram/programC/seabed/index.htm) and studies of the fish and fish habitats in the Recherche Archipelago (www.marine.uwa.edu.au/recherche). These projects aim to map the distribution, abundance and biomass of seabed communities, determine the richness and uniqueness of seabed communities and identify rare and/or threatened species, habitats and/or communities. Some projects, most notably the work by the CSIRO Division of Marine Research, include real-time data acquisition on the characteristics of seafloor habitats from video footage, as well as detailed post-processing of tapes (www.marine.csiro.au/). There are also coral reef monitoring programs involving fixed video transects (www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop7/sop7-2001a.html).

Underwater video has been used in Australia to directly observe and assess interactions between fishing gear, target fauna and non-target plants andanimals. A major program to understand the effects of trawling on benthic communities is still underway in tropical prawn (shrimp) fisheries (see Pitcher et al. 2000). Video imagery obtained from within traps has been used to minimize interactions between the Australian sea lion and the western rock lobster (*Panulirus cygnus*) fishery (pers. comm. R. Campbell, Department of Fisheries, Western Australia). Barotrauma in trapped deep-water snappers has been assessed using video techniques (www.aims.gov.au/pages/research/video-sensing/papers/lloyd/lloyd_abs.html), and more recently in a national strategy determining the fate of line-caught fish after release (http://www.info-fish.net/releasefish/).

Underwater video has much potential for assessing food consumption, growth and survival in aquaculture, but surprisingly few applications in Australian industry

The benthos beneath fish cages has been monitored using video (Crawford et al. 2001) and underwater stereo-video is being used to measure the lengths and maximum body depths of caged tuna (Harvey et al. 2003).

Within the areas of Australian fisheries research, some emphasis has been placed on the development of non-destructive, fishery independent sampling techniques. These include underwater visual census with video cameras, comparisons of baited remote underwater video (BRUVS) sampling with traditional trawls (Cappo et al. 2004), assessing the fate of discarded bycatch (Hill and Wassenberg, 2000), and using towed video for assessing the structure of spawning aggregations of finfish and the relative abundance and distribution of scallops. Whilst towed video footage can be converted readily to density estimates of target fauna, the baited, stationary video approach has yielded only estimates of relative density. More research is needed to model the sampling area influenced by bait plumes to enable direct estimates of density.

Applications of underwater video in Australia are growing in number, variety and sophistication – partly because of the national workshop funded by the Fisheries Research and Development Corporation. It is hoped that this growth will be matched by national investment in hardware and software solutions to overcome the “bottlenecks” remaining in image processing and tape analysis.

Citations

Cappo, M., E. Harvey, H. Malcolm, and P. Speare.
2003. Potential of video techniques to monitor diversity, abundance and size of fish in studies of Marine Protected Areas. p. 455-464. *In* Beumer, J.P., A. Grant, and D.C. Smith (eds.), Aquatic Protected Areas - what works best and how do we know?”. World Congress on Aquatic Protected Areas proceedings, Cairns, Australia, August 2002.

Cappo, M., P. Speare, and G. D’eath.
2004. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. J. Exp. Mar. Biol. Ecol. 302(2):123-152.

Crawford, C. M., I. M. Mitchell, and C. K. A. Macleod.
2001. Video assessment of environmental impacts of salmon farming. ICES J. Mar. Sci. 58: 445-452.

Harvey, E. S., and M. Cappo.
2001. Direct sensing of the size frequency and abundance of target and non-target fauna in Australian Fisheries. 4-7 September 2000, Rottnest Island, Western Australia. Fisheries Research and Development Corporation. 187 p.

Harvey, E. S., M. Cappo, M. Shortis, J. Buchannan, and S. Robson.
2003. The use of an underwater stereo-video system for measuring the lengths of caged southern blue fin tuna. Fish. Res. 63 (3):315-326.

Hill, B. J., and T. J. Wassenberg.
2000. The probable fate of discards from prawn trawlers fishing near coral reefs; A study in the northern Great Barrier Reef, Australia. Fish. Res. 48:277-86.

Pitcher, C. R., I. R. Poiner, B. J. Hill, and C. Y. Burridge.
2000. Implications of the effects of trawling on sessile megazoobenthos on a tropical shelf in northeastern Australia. ICES J. Mar. Sci. 57(5): 1359-1368.

Willis, T .J., R. B. Millar, and R. C. Babcock.
2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling and baited underwater video. Mar. Ecol. Progr. Ser. 198:249-60.

Recommendations

1. Formation of an Underwater Video Working Group

Nearly all participants of the workshop were fishery biologists who were users rather than developers of video technology and, consequently, felt that the exchange of ideas that occurred at the workshop provided them with ideas to extend their research capabilities or tools to increase their video processing efficiency. The participants suggested two ways of maintaining this exchange: 1) creation of a working group with annual meetings and 2) development of a NMFS underwater video technology web page.

Other technologies for sampling fish or their habitat, such as acoustics, trawls and other fishing gears, have working groups with periodic meetings (i.e., the Fishing Technology and Fish Behavior Working Group and the Fisheries Acoustics Science and Technology Working Group associated with the International Council for the Exploration of the Sea) where fishery biologists can discuss sampling issues and emerging video or related technology with others using the same technologies. However, nothing like this is available for the scientific application of underwater video. The participants therefore recommended the formation of the Underwater Video Working Group, which would be officially sanctioned by NMFS and meet annually to consider special topics (e.g., the use of stereo video), new technologies and updates of ongoing projects. In addition, the working group could facilitate collaborative efforts, perhaps the sharing of specialized video equipment, and promote funding opportunities (e.g., NOAA Ocean Exploration and National Undersea Research Programs) for the development of new hardware for collecting underwater video (i.e. ultra low light cameras or stereo cameras) or software (i.e., event counters, measurement tools, pattern recognition or video databases) that would either increase the capabilities of video collection or reduce the time required to translate the video into readily usable data. In essence, this working group would function much like the existing NMFS survey standardization working groups (i.e., Bottom Trawl Survey Working Group and Acoustic Survey Working Group).

In addition, the workshop participants felt that an important addition to a working group would be the development of a web page that would provide: 1) updates for NMFS programs utilizing underwater video, 2) links to suppliers of video equipment and processing software, and 3) a bulletin board capability that would allow researchers to quickly query others about their specific needs.

2. Develop Technologies for Making Video Processing Easier

The process of analyzing video involves tasks such as counting and measuring fish or other objects, measuring strip or quadrate area, and entering geo- or time- referenced measurements into a database. Although there is some commercial software that partially automates this process, workshop participants felt that many improvements to these products are needed to meet their specific requirements. In order of importance, the most needed software is 1) event logging software that controls the primary recording medium (i.e., tape or DVD); 2) video database software that allows retrieval of video clips using selection criteria such as depth, position, or time of day, or, at least, provides some sort of library facility for the original recordings; and 3) quadrat measurement software that can correct for distance from the bottom and camera attitude. Workshop participants felt that the use of research funds for either of the following two approaches would be fruitful: 1) hire a consultant to review the video processing technology used by other governmental agencies (NASA or Department of Defense), the medical profession, or industry to determine if the appropriate technologies have been developed but not discovered by NMFS fishery biologists, and 2) contract for the development of custom software that would meet the needs of most of the NMFS programs.

3. Technologies that Extend the Operating Capabilities of Video or the Information Content of the Video

Several emerging technologies for the collection of video or video-like data were considered during the workshop. Of these, two were of particular interest. First,in situations, particularly for stock assessment, when the use of lights would alter fish behavior, technologies such as ultra low-light cameras, infrared illuminators or DIDSON acoustic cameras may provide an acceptable alternative to using visible light. Second, in situations when fish length measurements are required, stereo video may be better than the 2- and 3-laser reference systems now in use. Although some of the technologies considered are commercially available, some are either very expensive or require custom development and are therefore beyond the reach of small research programs. Workshop participants therefore felt that there was a need for either increased collaboration between NMFS programs or actual joint ownership of hardware (e.g., similar to the purchase of the autonomous underwater vehicle by the NMFS Advanced Technology Working Group) to allow them to more easily examine the utility of different technologies.

List of Participants

Chris Boynton
University of Miami
Department of Physics
P.O. Box 248046
Coral Gables, FL 33124
chris@physics.miami.edu
Ph. (305) 284-2323
Fx. (305) 284-4222

Judith Connor
Monterey Bay Aquarium
Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
conn@mbari.org
Ph. (831) 775-1728
Fx. (831) 775-1620

Eric Eisenhardt
Washington Department of Fish
and Wildlife
600 Capitol Way N
Olympia, WA 98501
eisenepe@dfw.wa.gov
Ph. (360) 586-6129 x 208

Scott Gallagher
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
sgallager@whoi.edu
Ph. (508) 289-2783
Fx. (508) 457-2158

Christopher T. Gledhill
Southeast Fisheries Science Center
Mississippi Laboratories
3209 Frederic Street
Pascagoula, MS 39567
Christopher.T.Gledhill@noaa.gov
Ph. (228) 762-4591 X284
Fx. (228) 769-9200

Chris Grandin
Department of Fisheries and Oceans
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C., V9T 6N7, Canada
Grandin@pac.dfo-mpo.gc.ca
Ph. (250) 756-7211
Fx. (250) 756-7053

Euan Harvey
School of Plant Biology
University of Western Australia
35 Stirling Highway
Crawley, WA, 6009, Australia
euanh@cyllene.uwa.edu.au
Ph. +61 64882416
Fx. +61 64881001

Rod Hobbs
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Rod.Hobbs@noaa.gov
Ph. (206) 526-6278
Fx. (206) 526-6615

Tom Jagielo
Washington Department of Fish
and Wildlife
600 Capitol Way N
Olympia, WA 98501
jagiethj@dfw.wa.gov
Ph. (360) 902-2837

Jean Kenyon
Pacific Islands Fisheries Science Center
1125B Ala Moana Blvd.
Honolulu, HI 96814
Jean.Kenyon@noaa.gov
Ph. (808) 592-7019
Fx. (808) 592-8300

Tom Laidig
Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Road
Santa Cruz, CA 95060
Tom.Laidig@ noaa.gov
Ph. (831) 420-3942
Fx. (831) 420-3977

Jeff Lasage
Stennis Space Center
Bay St. Louis, MS 39529
Ph. (228) 688-3650
Fx. (228) 688-1151

Bob McConnaughey
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Bob.Mcconnaughey@noaa.gov
Ph. (206) 526-4150
Fx. (206) 526-6723

Scott McEntire
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Scott.McEntire@noaa.gov
Ph. (206) 526-4472,
Fx. (206) 526-6723

Daniel Merritt
Pacific Islands Fisheries Science Center
1125B Ala Moana Blvd.
Honolulu, HI 96814
Daniel.Merritt@noaa.gov
Ph. (808) 592-7032
Fx. (808) 592-8300

William Michaels
Northeast Fisheries Science Center
166 Water Street,
Woods Hole, MA 02543
William.Michaels@noaa.gov
Ph. (508) 495-2259
Fx. (508) 495-2258

Michael Parke
Pacific Islands Fisheries Science Center
1125B Ala Moana Blvd.
Honolulu, HI 96814
Michael.Parke@noaa.gov
Ph. (808) 592-7017
Fx. (808) 592-7013

Frank Parrish
Pacific Islands Fisheries Science Center
2570 Dole St
Honolulu, HI 96822
Frank.Parrish@noaa.gov
Ph. (808) 983-5391
Fx. (808) 983-2902

Chris Rooper
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Chris.Rooper@noaa.gov
Ph. (206) 526-4689
Fx. (206) 526-6723

Craig Rose
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Craig.Rose@noaa.gov
Ph. (206) 526-4128
Fx. (206) 526-6723

Gregg Rosenkranz
Alaska Department of Fish and Game
211 Mission Road
Kodiak, AK 99615 gregg_rosenkranz@fishgame.
state.ak.us
Ph. (907) 486-1858
Fx. (907) 486-1824

Yuri Rzhanov
Center for Coastal and Ocean Mapping
University of New Hampshire
24 Colovos Road
Durham, NH 03824
yrzhanov@cisunix.unh.edu
Ph. (603) 862-0075
Fx. (603) 862-0839

Pete Sheridan
Southeast Fisheries Science Laboratory
Panama City Laboratory
3500 Delwood Beach Rd.
Panama City, FL 32408
pete.sheridan@noaa.gov
Ph. (850) 234-6541 x203
Fx. (850) 235-3559

Christy Sims
Alaska Fisheries Science Center
National Marine Mammal Laboratory
7600 Sandpoint Way NE
Seattle, WA 98115
Christy.Sims@noaa.gov
Ph. (206) 526-6274
Fx. (206) 526-6615

David Somerton
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
David.Somerton@noaa.gov
Ph. (206) 526-4116
Fx. (206) 526-6723

Bradley G Stevens
Alaska Fisheries Science Center
Kodiak Laboratory
301 Research Court
Kodiak,AK 99615
Bradley.G.Stevens@noaa.gov
Ph. (907) 481-1726
Fx. (907) 481-1703

Allan Stoner
Alaska Fisheries Science Center
2030 S. Marine Science Drive
Newport, OR 97365
Al.Stoner@noaa.gov
Ph. (541) 867-0165
Fx. (541) 867-0136

Waldo Wakefield,
Northwest Fisheries Science Center
2030 S. Marine Science Drive
Newport, OR 97365
Waldo.Wakefield@noaa.gov
Ph. (541) 867-0542
Fx. (541) 876-0525

Mary Yoklavich
Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Road
Santa Cruz, CA 95060
Mary.Yoklavich@noaa.gov
Ph. (831) 420-3940
Fx. (831) 420-3977

Harold Zenger
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Harold.Zenger@noaa.gov
Ph. (206) 526-4158,
Fx. (206) 526-6723

Brian Zgliczynski
Pacific Islands Fisheries Science Center
1125B Ala Moana Blvd.
Honolulu, HI 96814
Brian.Zgliczynski@noaa.gov
Ph. (808) 592-2816
Fx. (808) 592-7013

Mark Zimmermann
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
Mark.Zimmermann@noaa.gov
Ph. (206) 526-4119
Fx. (206) 526-6723