An Overview of Visual Survey Research and Imaging Technology Development at the Southwest Fisheries Science Center

Kevin Stierhoff, George Cutter,
David Murfin, and David Demer

Southwest Fisheries Science Center, NMFS, NOAA
La Jolla, California
kevin.stierhoff@noaa.gov

Overview of Visual Survey Research and Technology at the SWFSC

The Fisheries Resources Division (FRD) at the Southwest Fisheries Science Center (SWFSC) in La Jolla, California has been conducting visual surveys of benthic fishes and invertebrates since 2001. Initially, a remotely operated vehicle (ROV) program was developed by the Benthic Resources Group to monitor populations of a newly-listed endangered species, white abalone (*Haliotis sorenseni*). However, the research focus of this program soon expanded to include surveys of market squid (*Doryteuthis opalescens*) spawning habitat (Zeidberg et al. 2011), distribution and abundance of groundfishes (primarily rockfishes in the genus *Sebastes*), and benthic habitats throughout southern California (CA). These ROV surveys have generated a vast collection of images, including nearly 900 hours of video and 37,000 high resolution photographs.

The Advanced Survey Technologies (AST) Group at SWFSC has developed camera systems, and is collaborating to develop algorithms for automated detection, measurement, and identification of fish in underwater video, still, or stereo images (Matai et al., this volume; Rzhanov and Cutter, this volume). The AST group has developed single- and stereo-camera systems that are deployed by divers or from vessels as tethered systems, attached to an ROV, or placed on moorings or landers (Fig. 1). The AST group has also developed a towed, undulating, optical and environmental sampling system (FasTowCam)

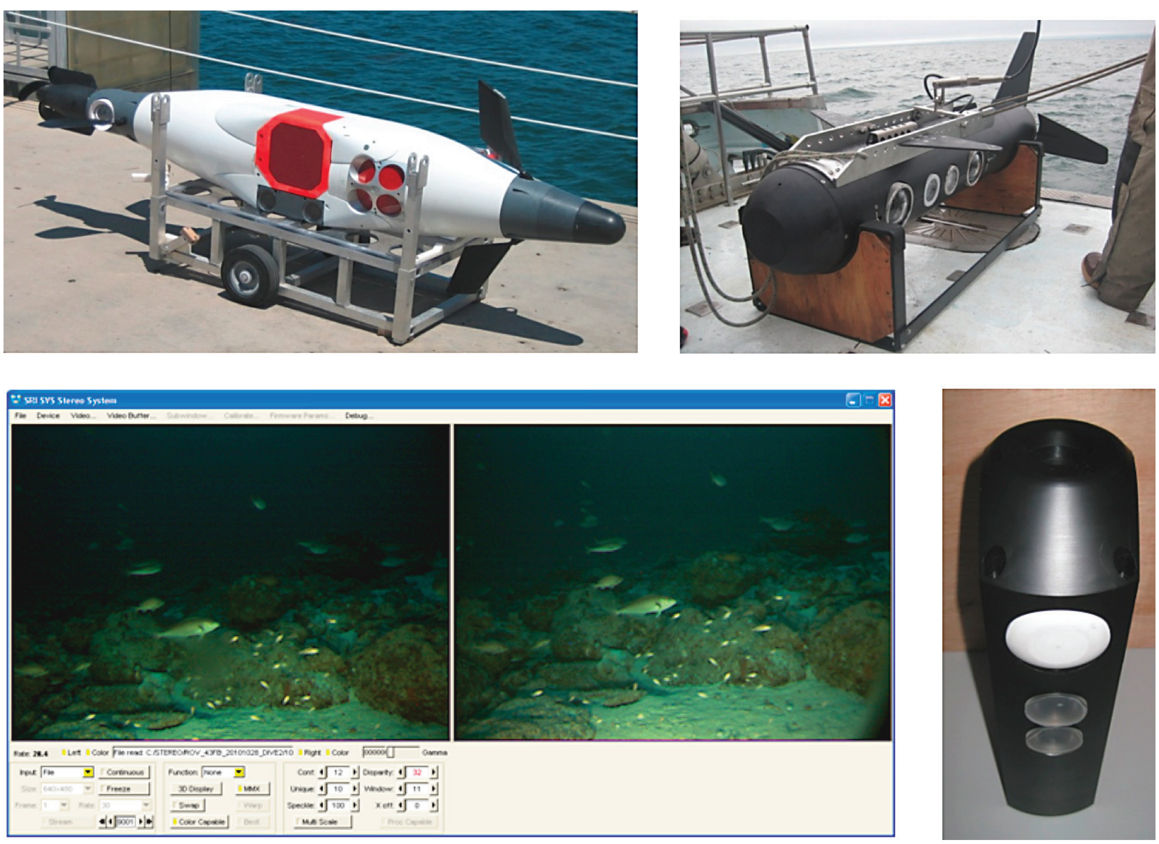


Figure 1. Examples of visual survey technologies developed by the Advanced Survey Technology Group. Clockwise from top left: NMFS autonomous underwater vehicle (AUV); the towed, undulating, optical and environmental sampling system (FasTowCam) with integrated stereo camera, strobes and CTD; the self-contained micro-echosounder system with adaptive-sampling camera (Acoustic-Optical Sampler; AOS); and images of ocean whitefish (*Caulolatilus princeps*) from the self-contained stereo camera deployed on the SWFSC ROV at 43-Fathom Bank.

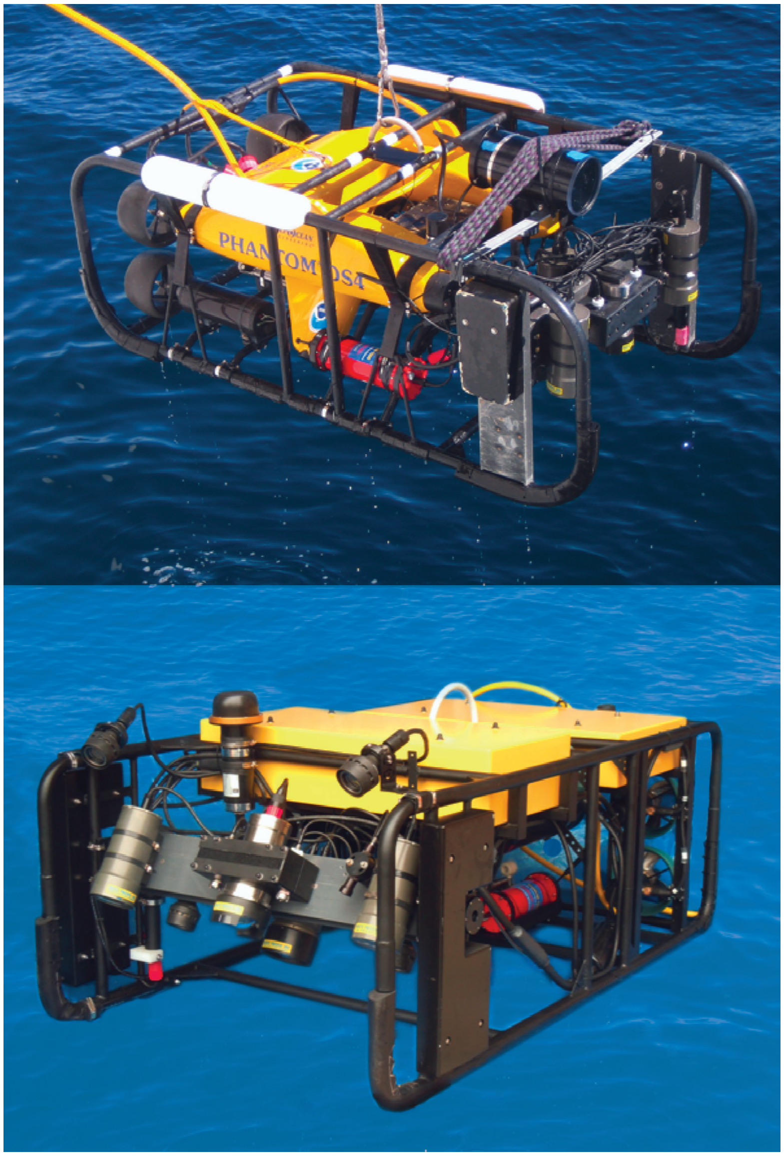


Figure 2. The SWFSC Phantom remotely operated vehicle (ROV, top) with the Videre stereo camera system attached above the camera tilt tray, and the new, Mini Zeus high-voltage, high definition (HDHV) equiped ROV (bottom).

with integrated stereo camera, strobes and connectivity, temperature and depth sensor (CTD) to augment acoustic surveys of coastal pelagic species (CPS; e.g., sardines, anchovies, and jack mackerel). Additionally, AST develops and operates the NMFS autonomous underwater vehicle (AUV, http://swfsc.noaa.gov/AUV/) that includes a stereo camera system adjacent to a scientific echosounder to collect images of acoustic targets for identification and measurement. Similarly, AST has developed a self-contained micro-echosounder system with adaptive-sampling camera (Acoustic-Optical Sampler; AOS) which was designed for deployment on large marine animals (e.g., elephant seals), and is opportunistically deployed on multiple buoys.

The need to streamline processing of stereo images collected during all of these surveys has led to the development of the semi-automated stereo-image measuring software StereoMeasure; algorithms for automated detection and recognition of fish; and the StereoFeatures application that combines the recognition algorithms and three-dimensional reconstruction for measurement and identification (Matai et al., this volume; Rzhanov and Cutter, this volume). Each of these systems will be detailed below.

SWFSC Remotely Operated Vehicle (ROV) System

Since 2001, the Benthic Resources Group at the SWFSC has been using a modified Deep Ocean Engineering Phantom ROV to conduct visual surveys of benthic fishes and invertebrates (Fig. 2). In its present configuration, the Phantom ROV is equipped with a forward-looking color-video camera (Sony FCB-IX47C with 468x720 lines of resolution and an 18x optical zoom) and a high-resolution-still camera with 4x zoom (Insite Pacific, Inc. Scorpio with Nikon Coolpix 995). The ROV is tracked in real-time using a combination of a differential GPS mounted on the ship, an ultra-short baseline (USBL) acoustic tracking system (ORE Offshore TrackPoint II-Plus), and a Doppler velocity log (Workhorse Navigator, Teledyne RDI). Additional sensors include a CTD (Citadel 2" Micro-CTD, Teledyne RDI), oxygen optode (Model 3975, Aanderaa Instruments), scanning sonar (MS1000, Kongsberg Mesotech), and laser caliper system for measure objects and calculating field of view. All navigation and oceanographic data are synchronized and logged using integrated navigation software (WinFrog, Fugro Pelagos, Inc.).

The Benthic Resources Group recently completed the development of a custom ROV to replace the Phantom system (Fig. 2; http://swfsc.noaa.gov/HDHV-ROV/). Improvements include the replacement of the standard definition color video camera with an Insite Pacific high-definition Mini Zeus video camera, quieter and more powerful brushless DC-powered thrusters (Technadyne), and a tether with three optical fibers that significantly improves the bandwidth for transmission of video and data collected from onboard instrumentation. This system should greatly improve our ability to detect and identify cryptic organisms and minimize the impact of the ROV on fish behavior.

The Use of ROV Surveys to Quantify Fishes and Invertebrates

The primary focus of the ROV program has been to monitor populations of the endangered white abalone in southern California since being listed in 2001. Surveys were conducted at several locations where white abalone were once abundant or present. A combination of multibeam sonar mapping and ROV strip transects were used to comprehensively map white abalone habitat and estimate the densities, abundances, size distributions, and group sizes for their sub populations (Butler et al. 2006). In 2008 and 2010, additional ROV surveys at one site indicated that the white abalone population has continued to decline sharply (Butler et al. In prep.). In both studies, white abalone were identified *in situ* and counted from the video, with the aid of higher-resolution photographs. Due to the cryptic appearance of these abalone, which closely resemble the algae-encrusted rocks and macroalgae on which they reside, automated detection and classification of abalone in images is exceptionally challenging.

Other work has included ROV surveys to quantify the populations of cowcod (*Sebastes levis*) and several species of severely depleted rockfishes and other groundfishes that inhabit deep, rocky, offshore banks (Fig. 3). A substantial subset of those surveys involved a collaborative, optically assisted acoustic survey technique (COAST), wherein active acoustic surveys were used to provide estimates of fish biomass and seabed type over large areas (Demer et al. 2009), and subsequent ROV surveys provided species composition, size distribution, habitat associations, and seabed classification. The data from the ROV surveys are used to apportion acoustic backscatter to various species groups and size classes. In some cases, substantially more post-processing time and effort is required to identify and quantify the abundance, species composition, and size distribution of observed fishes compared to the abalone surveys. Consequently, this is an area of research that would greatly benefit from the ability to automatically detect, measure, and classify fish targets by species.

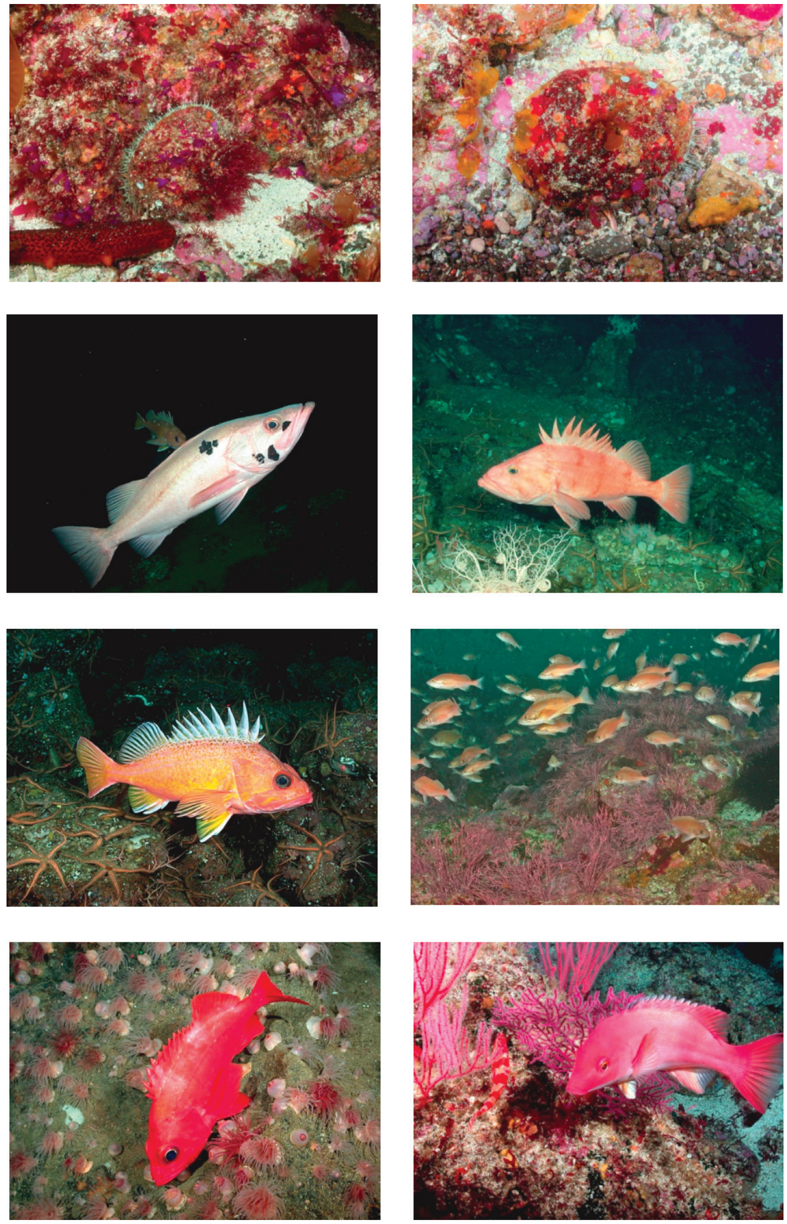


Figure 3. An example of still images collected using the SWFSC remotely operated vehicle (ROV). Clockwise from top left: white abalone (*Haliotis sorenseni*); white abalone; cowcod (*Sebastes levis*); a school of squarespot rockfish (*S. hopkinsi*); a California sheephead (*Semicossyphus pulcher*); splitnose rockfish (*S. diploproa*), greenspotted rockfish (*S. chlorostictus*); and a bocaccio rockfish (*S. paucispinis*).

One area where automated image processing techniques has greatly improved our existing visual survey techniques has been the development of a 3Beam© quantitative measurement system that is used to more accurately quantify the area searched during strip transects with the ROV (Fig. 4, Pinkard et al. 2005). In brief, the 3Beam software detects the location of parallel lasers in compressed video frames, and uses the pitch, roll, altitude, and camera viewing angle to compute the width of the field of view at a user-defined time or distance interval. The software also allows the analyst to review and correct erroneous laser detections from the automated algorithm. In combination with high-resolution and highly accurate distance measurements from the DVL (±1% over 1,500m, Stierhoff et al. In prep.), more accurate estimates of search area and species density can be calculated.

Areas for Improvement on Traditional Visual Survey Techniques

Two of the greatest challenges to this research have been the time required to post-process video observations and to provide sufficient length measurements to construct size distributions for fishes of interest. For a comprehensive community study, where all encountered species are identified and enumerated, it can take as long as 5 hours to annotate 1 hour of video when fish aggregations are dense, diverse, or both; when species are cryptic; or when habitats are highly complex. This analysis time can be significantly reduced, however, when the analysis is restricted to only a few key species of interest, by the use of on-the-fly annotation hardware such as programmable keyboards, or both. Perhaps more problematic is the difficulty in measuring fishes using the laser-caliper system when fish are smaller than the laser spacing, when the lasers cannot be placed on the fish target, or when fish are not perpendicular to the camera and laser system. These constraints on the visual-survey methods has motivated the development of automated methods for detecting and classifying fishes and also the development of stereo-camera systems and image analysis software for detecting features and measuring targets of interest in stereo-images. Given the present and growing number of visual-survey platforms utilizing single- and stereo-camera systems, the development and improvement of automated image-processing methods could provide considerable savings in time and resources.

Toward Automation of Detection, Measurement and Classification of Fish

The limitation of single-camera laser-caliper systems for measurement of fishes has led the AST group to acquire and develop stereo-camera systems. Images from calibrated stereo or multi-view camera systems enable estimation of three-dimensional coordinates of any point imaged by multiple cameras. This feature allows measurement of distances in three dimensions using two or more images, for targets of any orientation within the field of view. Resulting measurements of fish sizes are critical to scattering models for interpretation of acoustic data and accurate estimation of fish biomass, and for characterization of populations from visual-survey data.

More generally, the AST group has procured and developed imaging systems designed to enable the identification and measurement of organisms during various types of surveys covering a variety of habitats from rocky banks to open-ocean pelagic systems. The large numbers of images produced by these systems and the ROV need to be efficiently and consistently analyzed to detect, identify, and measure organisms. The highly effective algorithms for detection and recognition of faces, for example, or other targets in air, motivate development of similar methods for automatically detecting and recognizing fish and other organisms from these underwater systems. However, the seawater medium poses challenges not encountered in air, and complicates direct

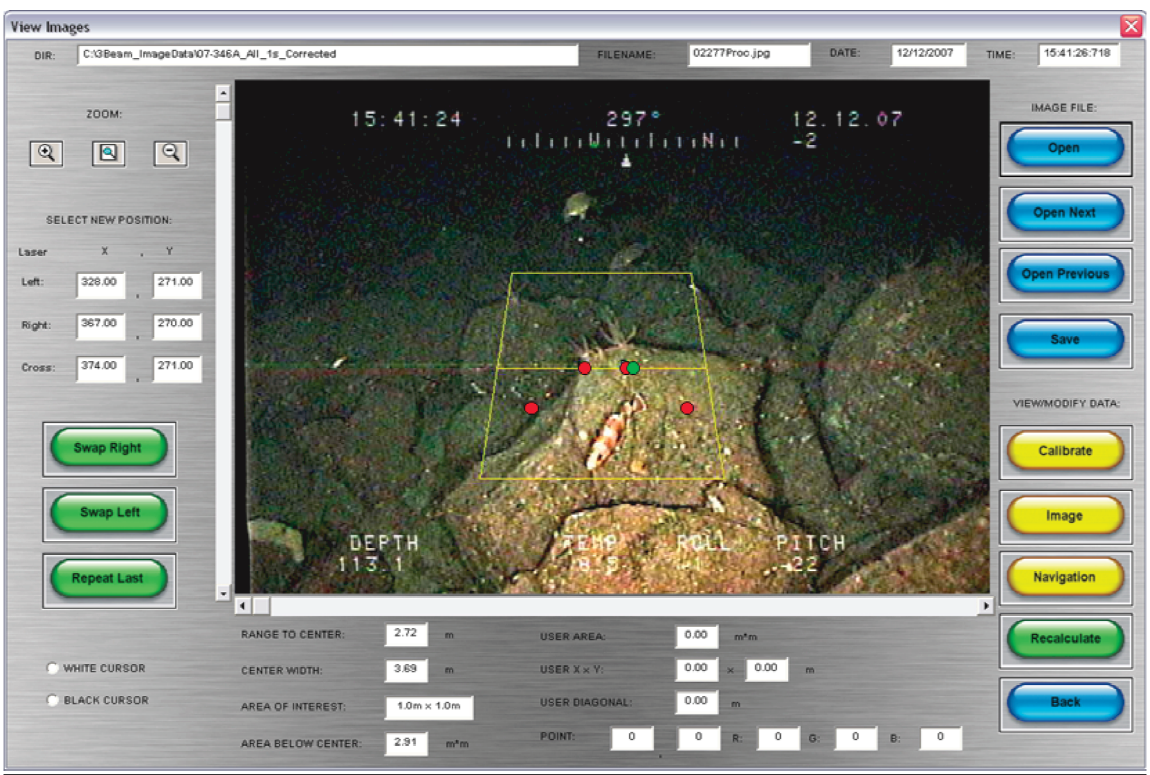


Figure 4. A screen grab from the 3Beam quantitative measurement software, enhanced to illustrate the location of the lasers on the bottom (red and green circles).

implementation of existing algorithms, leading to adaptations of common algorithms. Medium properties can be affected by various conditions that affect the scattering, absorption, and color of light; for example the presence of plankton, suspended particles, or both, and also the types and sizes of such particles.

Toward these goals the AST group is developing methods to automatically process images from single or multiple camera systems to 1) assist image analysts with more automated measurements of fishes (e.g., StereoMeasure; Rzhanov and Cutter, this volume); 2) automatically detect, and identify organisms by adapting algorithms (e.g., Viola-Jones, and principal components analysis) developed for face recognition (Matai et al., this volume); and 3) identification and reconstruction of the entire three-dimensional (3-D) scene including fish targets using algorithms adapted from SIFT or SURF (Rzhanov and Cutter, this volume) for measurement and classification of fish using the combination of shape and pattern by adaptation of recognition algorithms (from stage 2) to stereo images. Such methods will reduce the burden on analysts, increase the rate of analysis, and enable adaptive behaviors of autonomous vehicles.

Citations

Butler J.L., M. Neuman, D. Pinkard, R. Kvitek, and G.R. Cochrane. 2006. The use of multibeam sonar mapping techniques to refine population estimates of the endangered white abalone (*Haliotis sorenseni*). Fish. Bull., U.S. 104:521-532.

Butler J.L., K.L. Stierhoff, and M. Neuman. In prep. On the road to extinction: Population declines of the endangered white abalone, *Haliotis sorenseni*. Available from SWFSC, 3333 North Torrey Pines Court La Jolla, CA 92037-1023.

Demer D.A., G.R. Cutter, J.S. Renfree, and J.L. Butler. 2009. A statistical-spectral method for echo classification. ICES J. Mar. Sci. 66:1081-1090.

Matai J., R. Kastner, G.R. Cutter, and D.A. Demer. This volume. Automated techniques for detection and recognition of fishes using computer vision algorithms.

Pinkard D., D.M. Kocak, and J.L. Butler. 2005. Use of a video and laser system to quantify transect area for remotely operated vehicle (ROV) rockfish and abalone surveys. MTS/IEEE OCEANS '05 3:2824-2829.

Rzhanov Y., G.R. Cutter. This volume. StereoMeasure: measuring fish underwater using stereo photographs.

Stierhoff K.L., J.L. Butler, D.M. Kocak, D. Pinkard-Meier, D.W. Murfin. In prep. Improved methods for quantitative underwater visual surveys. Available from SWFSC, 3333 North Torrey Pines Court La Jolla, CA 92037-1023.

Zeidberg L.D., J.L. Butler, D. Ramon, A. Cossio, K.L. Stierhoff, A. Henry. 2011. Estimation of spawning habits of market squid (*Doryteuthis opalescens*) from field surveys of eggs off Central and Southern California. Mar. Ecol. 2011:1–11

NOAA Technical Memorandum NMFS-F/SPO-121

Report of the National Marine Fisheries Service Automated Image Processing Workshop

September 4-7, 2010
Seattle, Washington

by
Kresimir Williams, Chris Rooper, and John Harms (editors)

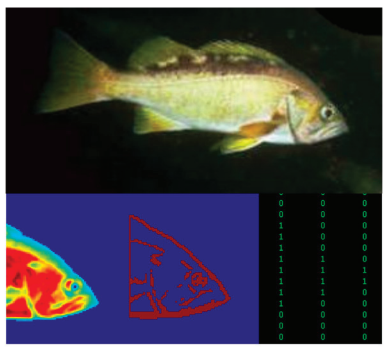
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

March 2012

NOAA Technical Memorandum NMFS-F/SPO-121

Report of the National Marine Fisheries Service Automated Image Processing Workshop

September 4-7, 2010
Seattle, Washington



Kresimir Williams[1], Chris Rooper[1], and John Harms[2] (editors)

[1]Resource Assessment and Conservation Engineering Division
Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115
www.afsc.noaa.gov

[2]Fishery Resource Analysis and Monitoring Division
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, WA 98112
www.nwfsc.noaa.gov

U.S. DEPARTMENT OF COMMERCE
John Bryson, Secretary
National Oceanic and Atmospheric Administration
Jane Lubchenco, Under Secretary and Administrator
National Marine Fisheries Service
Samuel Rauch III, Acting Assistant Administrator for Fisheries

NOAA Technical Memorandum NMFS

This document should be cited as follows:

Kresimir Williams, Chris Rooper, and John Harms (editors). 2012. Report of the National Marine Fisheries Service Automated Image Processing Workshop. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-121, 48 p.

A copy of this document may be obtained from:

Alaska Fisheries Science Center
NMFS, NOAA
7600 Sand Point Way N.E.
Seattle, WA 98115

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