TESTIMONY OF:
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Chairman Rubio, Ranking Member Booker, and Committee members, thank you for the opportunity to provide testimony to this Committee on issues important to management of the nation's fisheries resources. Today I appear before you to discuss innovative technologies and strategies to improve the quality and timeliness of fishery stock assessments, so critical to supporting fishery management efforts at the state, national and international levels.

My perspectives in providing this testimony are two-fold. For the past 4+ years I have been a professor of Biological Oceanography at the University of South Florida (USF), in St. Petersburg. One of the major projects I have been involved with is the development of advanced technologies to better assess the abundance and habitat requirements of important reef fish species off west Florida (Fig. 1). The commercial and recreational fishing industries and allied businesses there generate 10s of billions of economic activity based on these fisheries. It is of upmost importance that accurate, timely and credible stock assessments of fish stocks supporting these industries be forthcoming. The work of my colleagues, students and institutions with which we partner is aimed at using advanced technologies to fundamentally change the discourse on the status of fish populations as a basis for providing management advice

Prior to coming to USF, I retired after 34 years of service at NOAA as the Director of Scientific Programs and Chief Science Advisor for the National Marine Fisheries Service. My entire professional life at NOAA was as a fish population dynamicist. I have worked on projects to oversee the provision of stock assessment advice, first in New England and the Middle Atlantic states, then nationally and globally. I have seen fishery management programs be enormously successful and credible in the eyes of the stake holders. I have also observed conditions when fishery management was not successful and the conditions associated with that lack of success. One clear and unambiguous factor in the success of fishery management programs is that they are based on precise, accurate, transparent and timely stock assessments. Fishery management programs for species such as Bering Sea pollock and Atlantic sea scallop are viewed as successes not only because they meet statutory reference points, but that they are profitable and well managed in the eyes of most constituents. The science supporting these management programs is considered state-of-the-art. It involves high technology applications, collaborative research with industry and probative stock assessment that includes continuous quality improvement cycles. Extending these features to the majority of high profile fisheries in the USA remains a daunting challenge for NOAA and the states who's science budgets have stagnated or declined in the past half-decade or more. Today I want to discuss several features of advanced technology applications that can be useful in improving the science basis for fishery management.

How Many Fish in the Sea?

"……speak to the earth, and it will teach you, or let the fish in the sea inform you".
Job 12:8

Modern fishery management approaches, such as those regulating federal fisheries in the USA -- as specified in the Magnuson Stevens Fishery Conservation and Management Act (MSFCMA) -- are based on two primary tenets: (1) that the fishing mortality rate is kept at or below an objectively-determined maximum limit, and (2) that the stock size be held at a level allowing the attainment of maximum sustainable yield (MSY). This specification of quantitative limits and targets is the hallmark of fishery management throughout the developed and increasingly the developing world (FAO 2014). Through regional, national and international fishery management agreements (e.g., via treaties and Regional Fishery Management Organizations), fishery managers seek to balance short- and long-term social and economic performance of the fisheries with the limits imposed by population sizes and sustainable fishing mortality rates. At the nexus of the science-management interface is the process of conducting fishery stock assessments (Fig. 2; Cooper 2006). Stock assessments can be quite complex (Fig. 2) or relatively simple, depending on the nature of the fishery and quality of information available. In their simplest form they include time series of annual landings and estimates of relative fish abundance indexed by catch per unit of fishing effort (CPUE; Cooper 2006). In their most complex form that may include age-specific catch and CPUE data (e.g., from "fishery-dependent" data sources) as well as one or more sets of age-specific "fishery-independent" abundance indices from statistically designed surveys. These data sources are usually combined into retrospective models estimating trends in fishing mortality and stock sizes at age. A projection step associated with the stock assessment process assesses the annual catches that would be derived based on various policy choices including maintaining the fishing mortality at or below some target level.

Properly designed fishery-independent fish surveys are a key element in providing accurate and precise stock assessments. Fisheries are usually biased towards concentrations of relatively large fishes, occurring at high densities. However, a full picture of the abundance and distribution of a managed stock must include all age groups (including the pre-fishery recruits), and areas that may be relatively large but may which contain relatively low fish densities. Traditionally, fishery independent surveys have used gears such as small-mesh trawls (FAO 1982), baited hooks, dredges (for shellfishes), gill nets (of varying mesh) and seine nets (for shallow waters) to develop fishery independent surveys. Where the fishes are widely available to the gears (e.g., haddock caught the trawl survey of the Northeast Fisheries Science Center) these gears provide reliable and relatively precise estimates of the abundance of various ages, for use in retrospective and forecasting parts of stock assessments. However, in many situations, the fishes may be distributed in high-relief habitats such as along reefs and in boulder fields where these gears may not be deployable (e.g., trawls on coral reefs), or where the efficiency of the gear may be low and variable. Also, increasingly, because of the establishment of no-take fishery reserves or other marine protected areas (MPAs) lethal sampling may no longer be allowed for some part of a stock's range.

So called "untrawlable" habitats thus represent a considerable and growing challenge to providing relatively precise and unbiased estimates of relative (or absolute) abundance for use in fishery stock assessments. For example, areas considered "untrawlable" include tropical reef habitats in the Pacific islands, the Caribbean and Southeast United States (e.g., Fig 4), rock reef areas along the west Coast, in Alaska and the Northeast, and cold water coral areas off all the coasts of the United States. Many important fisheries occur in these areas including, in the case of tropical reef systems, species of snapper, grouper, amberjack and other species of commercial and recreational importance.

To address sampling of "untrawlable" areas, scientists have developed a number of approaches using traditional gears (e.g., vertical longlines and gill nets) and advanced acoustic, visual, and optical methods. For example, visual methods, using divers to count along designated transects or at stationary locations has been applied in tropical reef settings (Bohnsack and Bannerot 1986; Ault et al. 2013). However, without specialized mixed-gas diving methods, they are generally applicable to water depths of <30 m, which may leave considerable viable reef fish habitat unsampled.

Acoustic methods, including the use of ship-based echo sounders, have been used in stock assessments since the 1960s (Trenkel et al. 2011). The integration of echoes off fish schools (Fig. 5) can be calibrated using *in situ* derived target strength (TS) measurements of individual animals to estimate the absolute (and relative) abundance of species that may occur over such untrawlable habitats (Fig. 5). However, there remains a key issue with acoustic methods in the "dead zone" 1-5 meters above the bottom where reflected acoustic signals off the bottom may obscure fishes located within this band.

Recent Advances in the Use of Optical Systems for Fish Stock Assessments

Apart from the use of visual sighting surveys in relatively shallow waters, advanced optical methods remain the best option for enumerating fishes occurring in untrawlable habitats, especially ones distributed over wide spatial areas and depth zones. The use of video and still cameras has been applied since the 1960s to a variety of situations (Cailliet et al. 1999; Martin et al. 2004; Spencer et al. 2005; Jones et al. 2009; Williams et al. 2010; Mallet and Pelletier 2014). Recent advances in camera performance and availability of low cost components have made the use of video and still cameras a viable option for fish surveys. One of the significant considerations is whether to use towed, tethered (remotely operated vehicles) or autonomous platforms (e.g., Tolimieri et al. 2009; Clarke et al. 2010; Singh et al. 2013) for such studies. The determining factor is the power requirements for the cameras, lights and other instruments onboard the vehicle, as well as the range of the stock being indexed. Current versions of AUVs equipped with video cameras is limited by battery power requirements.

Other approaches to indexing species in untrawlable habitats include the use of fixed location video pods to count the number of animals in a cylinder around the locations of these deployments Gledhill et al. 2006). These approach, used in the Southeast USA and Pacific

Islands, provide relative indices of abundance but may be difficult to calibrate into absolute stock sizes due to the use of bait with an unknown attraction distance as well as the potential to double count fish swimming around such pods.

Two recent developments in the use of towed camera systems include the joint Woods Hole Oceanographic Institute/NMFS program called "HABCAM" (Habitat camera), and the joint University of South Florida/NMFS program called "C-BASS" (Camera-Based Assessment Survey System). I will discuss these systems in some detail as they relate directly to the use of advanced technology in the stock assessment process.

One HABCAM implementation (http://habcam.whoi.edu/index.html) was specifically developed in collaboration with NMFS to quantify the abundance of Atlantic sea scallop in the Middle Atlantic and Georges Bank regions (Taylor et al. 2008; Gallagher et al. 2010). This fishery is the most valuable in the United States and assessment techniques used prior to the use of camera systems were primarily small dredges which had variable catchability and could not be efficiently deployed in rocky habitats especially in the Georges Bank area. While behavioral reactions of scallops to the presence of the oncoming HABCAM are not a significant source of bias, discerning alive and dead scallop shells was an issue.

The C-BASS system (Lembke et al. 2013; http://www.marine.usf.edu/cbass/?page_id=2) was specifically built to estimate the abundance of important reef fish species such as snappers, groupers, porgys and amberjacks, in untrawlable hard bottom habitats such as exist along the west Florida shelf (WFS; Figs 1, 3-6). The WFS is largely unexplored, although several multibeam expeditions (e.g., Naar et al. 2007) have developed maps for three of the managed areas (Fig. 1). The Florida Middle Grounds (Coleman et al. 2004) has been explored using divers and ROVs, and is an area of relatively high fish abundance ideal for development studies of towed video technologies (Fig. 4). Working jointly with NMFS, the C-BASS team has developed the C-BASS system (Fig. 3) to allow rapid surveying of the carbonate reef systems typical of the WFS (Fig. 1). Abundance estimates (see steps below) were developed using camera transect data from 2013 and 2014 cruises to the area conducted aboard the R/V *Weatherbird II*, as a "proof of concept" for rapid development of fish abundance measures for stock assessment. The C-BASS work will continue for an additional three years under a grant from the national Fish and Wildlife Foundation to undertake studies of habitat damage as a result ot the *Deepwater Horizon* oil spill.

Finfish stock assessments using towed camera systems, pose a number of challenging issues if the estimates from video sampling transects are to be extrapolated to absolute stock sizes. The steps involved in making abundance estimates from "raw" video footage include:

- Estimating fish abundance (numbers of animals viewed per arbitrary sampling unit (per frame, per minute viewed, etc.)
- Calculating the "area swept" (geometry of sampling device)
- Estimating fish density (numbers per area swept, e.g., numbers per meter squared)
- Adjusting for fish avoidance/attraction behaviors (e.g., Stoner et al. 2007)
- Stratifying density by areas of different habitats (e.g., sand, reef, grass flats, etc.) to derive overall abundance estimates

None of these issues is insurmountable and the fact that the CBASS team was able to develop "proof of concept" estimates of target species absolute abundance demonstrates the utility of the concept in producing timely and accurate fishery-independent data for informing fishery management.

Summary

Requirements of the MSFCMA for annual catch limits based on the results of stock assessments impose a daunting burden to assemble, analyze and peer review data for inclusion in the management process. For many regulated stocks, the use of traditional sampling approaches such as trawls is sufficient to provide accurate fishery-independent data. However, for high relief habitats, such as coral reefs and rocky areas, traditional approaches cannot be effectively deployed in these areas and are thus inadequate to provide necessary information for robust stock assessment. The advent of advanced acoustic and optical methods for counting fish offers the opportunity to develop abundance measures for species inhabiting these regions where none were possible in the past. With the advent of advanced video evaluation techniques (National Academy of Sciences 2015), the process of developing more timely estimates from the imagery means that the system may be capable of enhanced throughput for multiple species simultaneously. For example, the process of converting video imagery into species counts (e.g., Fig. 4) derives estimates for all the species encountered. Thus, efficient biomass estimation may be possible for the reef fish assemblage as a whole, thereby speeding the process of population estimation.

Moving from a "proof of concept" to a region-wide stock assessment capability requires that a number of factors be considered, including the location and spacing of video transects (efficient survey design), as well as developing a robust video interpretation capability. An exciting possibility for region –wide reef fish surveys is combining routine acoustic monitoring (Fig. 5) with near-bottom video using towed or autonomous camera systems. In the case of some reef fishes (e.g., red snapper and amberjack) the two sets of technologies would be complementary.

While the development of new vehicles capable of imaging reef fishes enables a new stock assessment paradigm, one of the important ingredients is a precise accounting of the physical area of the various habitat types in the region of interest. Having high resolution multibeam bathymetric maps allows the use of highly efficient stratified designs with sampling intensity disproportionately allocated to areas of likely high reef fish abundance. With less than 5% of the WFS mapped, this represents a significant impediment to the use of the new technology for such surveys.

The examples of the adoption of new technologies to address old or particularly thorny stock assessment problems illustrates a few important points. First, over the years, conservation engineering programs at NMFS and within the states have declined as funding was re-purposed for other, higher priority programs. However, working with existing ocean engineering programs in academia, NMFS was able to develop in strategic partnerships both the HABCAM and C-BASS systems that hold great promise for transitioning to operational system status. Using industry, academic, government partnerships thus takes advantage of the skills and focus of each of the partners to develop and adapt technologies to real-world problems of great practical importance. A further benefit of a robust collaborative technology development capability is the increased credibility such programs can bring in the eyes of the stakeholders. The HABCAM effort in particular has proved its worth in this regard. Last, any sampling method, be it trawls, baited lines, acoustics or optics, has certain biases in terms of what species are encountered, and at what sizes. Rigorous evaluation of the inherent biases of new "disruptive" technologies, as well as traditional methods is now possible using new generation technologies and analysis tools. I encourage Congress and the Administration to see as a priority the collaborative development of approaches to evaluate and implement new technologies into the process of providing stock assessment advice to sustain and take full advantage of the economic and social benefits of our nation's fisheries.

Thank you for your attention, and I will answer your questions to the best of my ability.

References

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Zurcher, N., McMlellan, D.B., Ziegler, T.A., Hallac, D.E., Patterson, M., Feeley, M.W., Ruttenberg, B.I., Hunt, J., Kimball, D., and Causey, B. "Assessing coral reef fish population and community changes in response to marine reserves in the Dry Tortugas, Florida, USA." *Fisheries Research* 144(2013): 28-37.

Bohnsack, J.A. and Bannerot, S.P. "A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes." *NOAA Technical Report NMFS 41*. 1986. 15pp.

Cailliet, G.M., Andrews, A.H., Wakefield, W.W., Moreno, G., and Rhodes, K.L. "Fish faunal and habitat analyses using trawls, camera sleds and submersibles in benthic deep-sea habitats off central California." *Oceanologica Acta* 22.5(1999): 579-592.

Clarke, M.E., Whitmire, C., Fruh, E., Anderson, J., Taylor, J., Rooney, J., Ferguson, S., and Singh, H. "Developing the SeaBED AUV as a Tool for Conducting Routine Surveys of Fish and their Habitat in the Pacific." *Proceedings of the IEEE/OES* 2010.

Coleman, F., Dennis, G., Jaap, W., Schmahl, G.P., Koenig, C., Reed, S., and Beaver, C. "Final Report to the National Oceanic and Atmospheric Administration Coral Reef Conservation Grant Program." (2004). 135pp.

Cooper, A.B. *A Guide to Fisheries Stock Assessment – From Data to Recommendations*. University of New Hampshire, Sea Grant College Program, 2006.

FAO. 1982. *Bottom Trawl Surveys Design, Operation and Analysis*. Document prepared by M.D. Grosslein and A. Laurec. Interregional Fisheries Development and Management Programme, Fishery Committee for the Easter Central Atlantic. FAO, Rome.

FAO. 2014. The state of world fisheries and aquaculture (SOFIA). Food and Agriculture Organization of the United Nations (FAO), Rome, 243 pp.

Gallager, S., Howland, J., York, A., Lerner, S., Wilby, A., Walden, L., Simmonds, D., Rosonina, P., DeMello, A., Vine, N., and Taylor, R. "Characterization of Scallop Abundance and Benthic Habitat Using optical and Acoustic Imaging Technology." Final Report to NMFS, NEFC. (2010). 27pp.

Gledhill, C.T., Ingram Jr., G.W., Rademacher, D.R., Felts, P., and B. Trigg. 2006. "NOAA Fisheries reef fish video surveys: yearly indices of abundance for gag (*Mycteroperca microlepis*)." SEDAR10-DW12. SEDAR, North Charleston, SC. 28pp.

Jones, D.O.B., Bett, B.J., Wynn, R.B., and Masson, D.G. "The use of towed camera platforms in deep-water science." *International Journal of the Society for Underwater Technology* 28.2(2009):41-50.

Lembke, C., Silverman, A., Butcher, S., Murawski, S., Shi, X., and Grasty, S. 2013. Development and Sea Trials of a New Camera-Based Assessment Survey System for Reef Fish Stocks Assessment. *MTS/IEEE OCEANS 2013*. San Diego, CA. Sept. 23-26, 2013.

Mallet, D. and Pelletier, D. "Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952-2012)." *Fisheries Research* 154(2014): 44-62.

Martin, J.C. and Yamanaka, K.L. "A visual survey of inshore rockfish abundance and habitat in the southern Strait of Georgia using a shallow-water towed video system." *Can. Tech. Rep. Fish. Aquat. Sci.* 2566(2004): 52pp.

Naar, D.F., Mallinson, D., and Coleman, F. "Final Report for Florida Middle Ground Project." (2007): 20pp.

National Academy of Sciences, Board on Mathematical Sciences and Their Applications. 2015. "Robust methods for the analysis of images and videos for fisheries stock assessment". National Academies Press, Washington, DC 76 pp.

Singh, W., Omolfsdottir, E.B., and Stefansson, G. "A Camera-Based Autonomous Underwater Vehicle Sampling Approach to Quantify Scallop Abundance." *BioOne* 32.3(2013): 725-732.

Spencer, M.L., Stoner, A.W., Ryer, C.H., and Munk J.E. "A towed camera sled for estimating abundance of juvenile flatfishes and habitat characteristics: Comparison with beam trawls and divers." *Estuarine Coastal and Shelf Science.* 64(2005): 497-503.

Stoner, A.W., Ryer, C.H., Parker, S.J., Auster, P.J., and Wakefield, W.W. "Evaluating the role of fish behavior in surveys conducted with underwater vehicles." *Can. J. Fish. Aquat. Sci.* 65(2007):1230-1243.

Taylor, R., Vine, N., York, A., Lerner, S., Hart, D., Howland, J., Prasad, L., Mayer, L., and Gallager, S. "Evolution of a Benthic Imaging System from a Towed Camera to an Automated Habitat Characterization System." *OCEANS* (2008):1-7.

Tolimieri, N., Clarke, M.E., Singh, H., and Goldfinger, C. "Evaluating the SeaBED AUV for Monitoring Groundfish in Untrawlable Habitat." *Marine Habitat Mapping Technology for Alaska* (2009): 129-141.

Trenkel, V.M., P.H. Ressler, M. Jech, M. Giannoulaki, Chris Taylor. 2011. Underwater acoustics for ecosystem-based management: state of the science and proposals for ecosystem indicators. Marine Ecology progress Series 442: 285–301

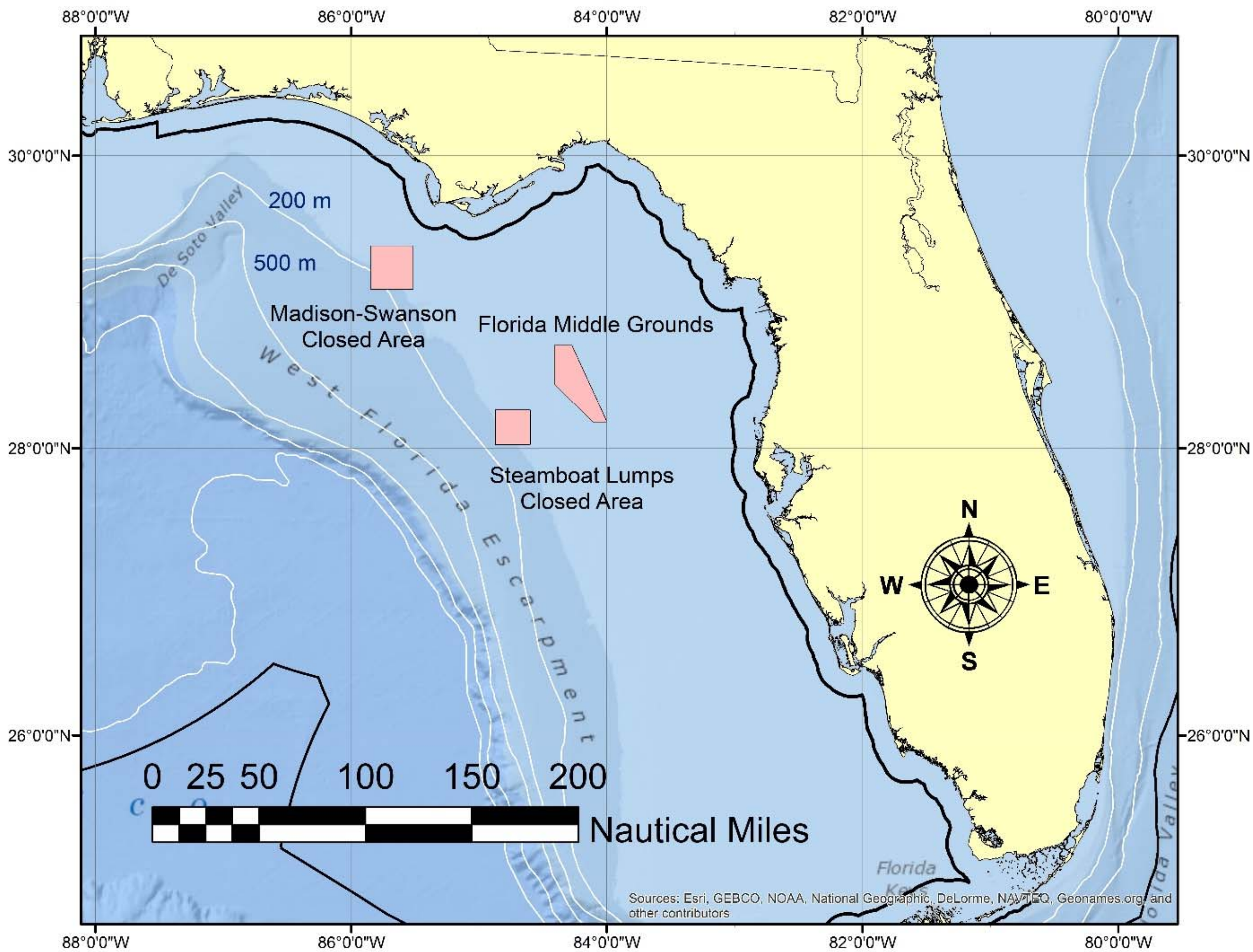


Figure 1. Map of the continental shelf off Florida. The broad, relatively shallow area off west Florida is termed the West Florida Shelf (WFS). Three fishery management controlled access areas are plotted (pink).

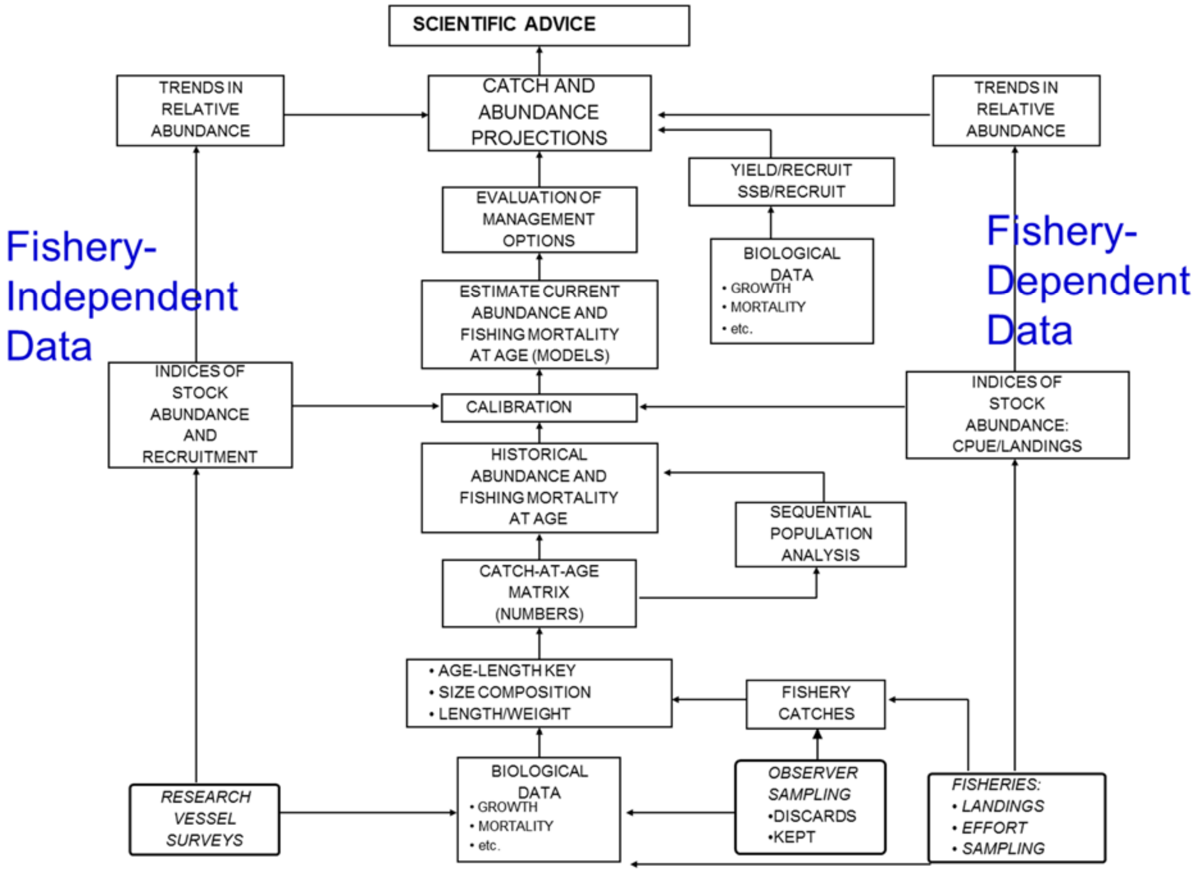
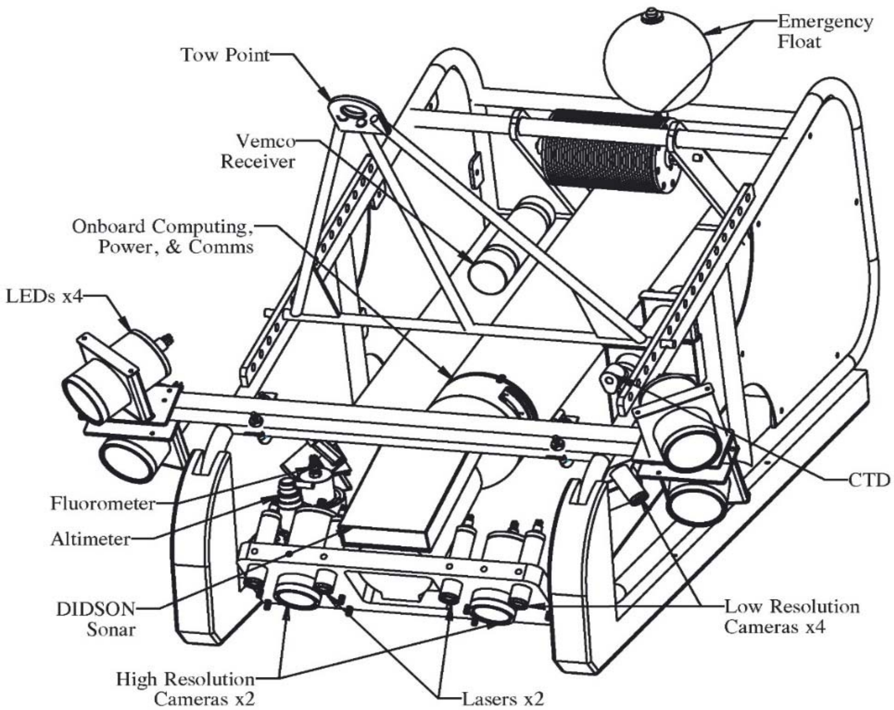


Figure 2. Process control diagram of steps involved in an idealized fishery stock assessment. The process uses both fishery-dependent data and fishery-independent data to estimate trends in population size, recruitment and fishing mortality rates.



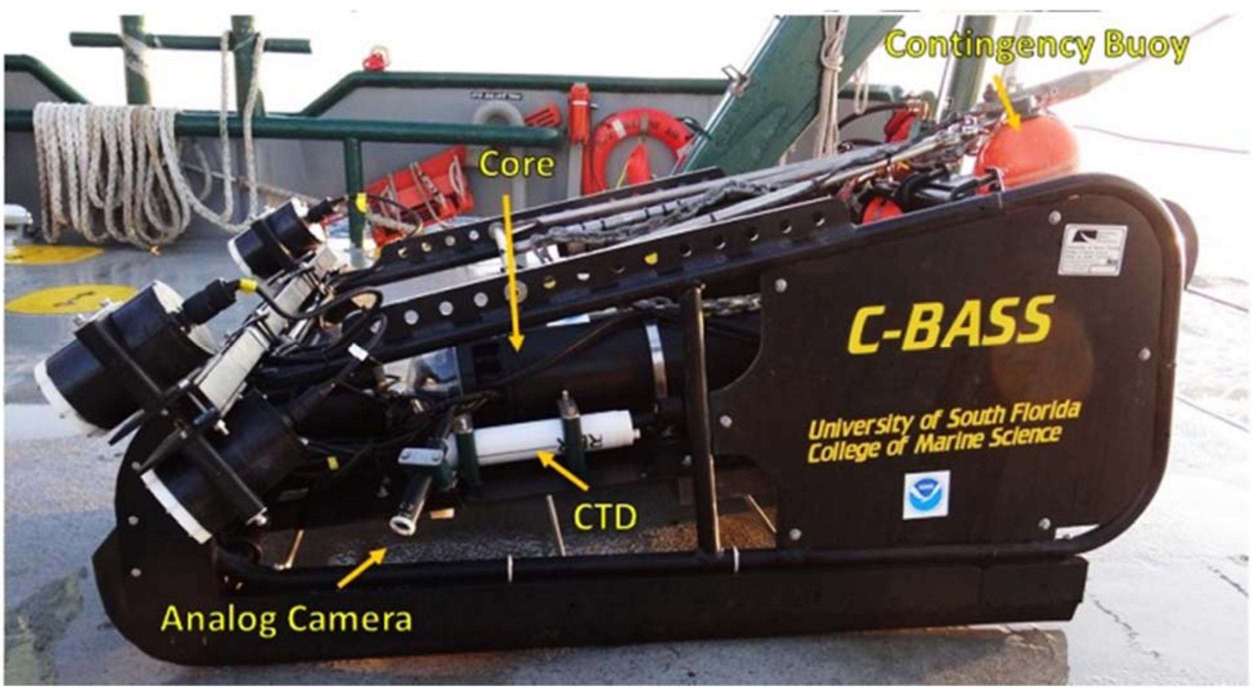


Figure 3. Schematic (top) and actual views of the Camera-Based Assessment Survey System (C-BASS) towed camera vehicle, illustrating he placement of cameras and other instruments.

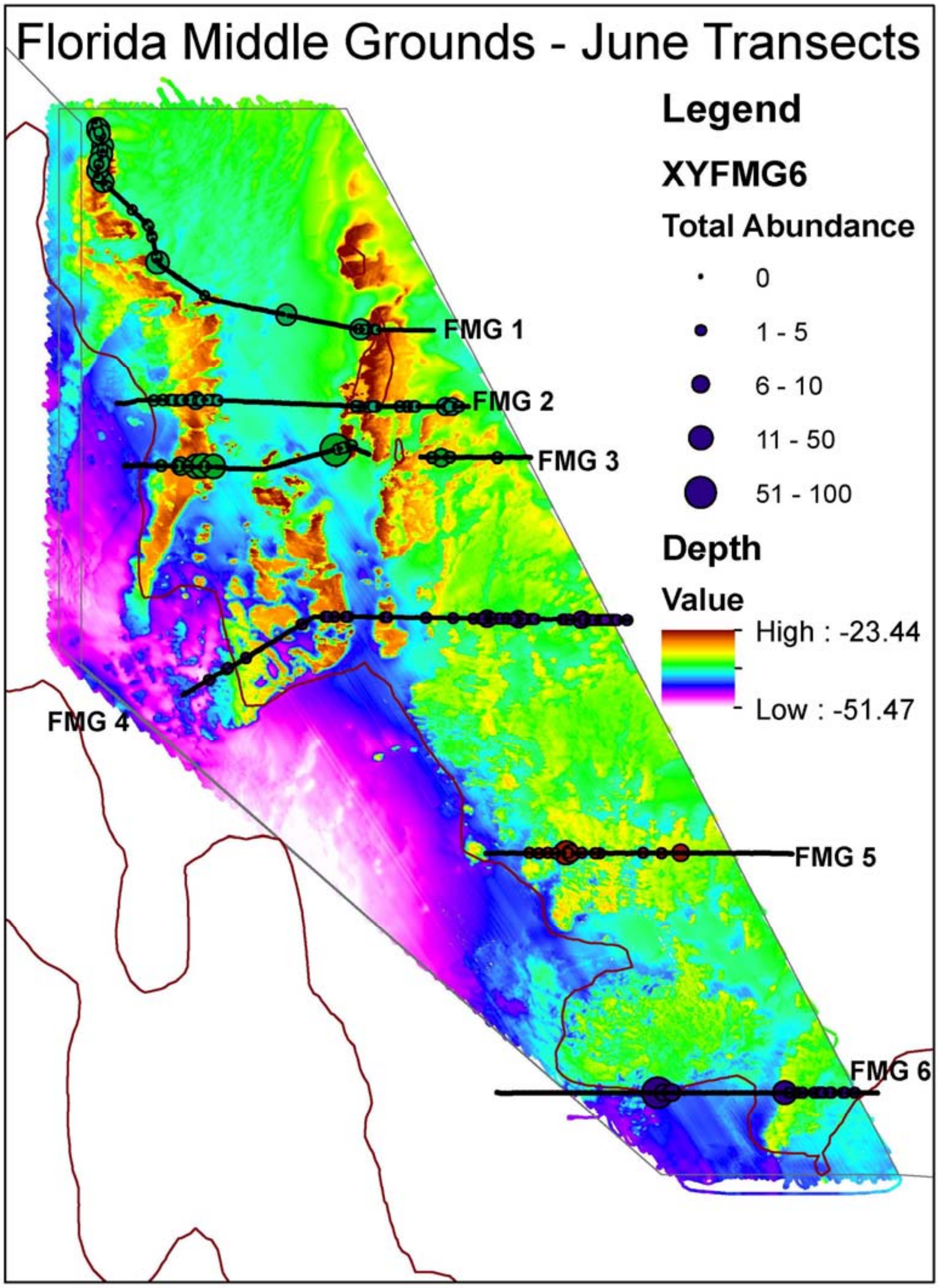


Figure 4. High resolution bathymetry (colored areas) and the abundance of fishes sighted in C-BASS transects during June, 2013 in the Florida Middle Grounds. The blue circles represent the absolute number of fish observed in one minute video segments along each transect conducted.

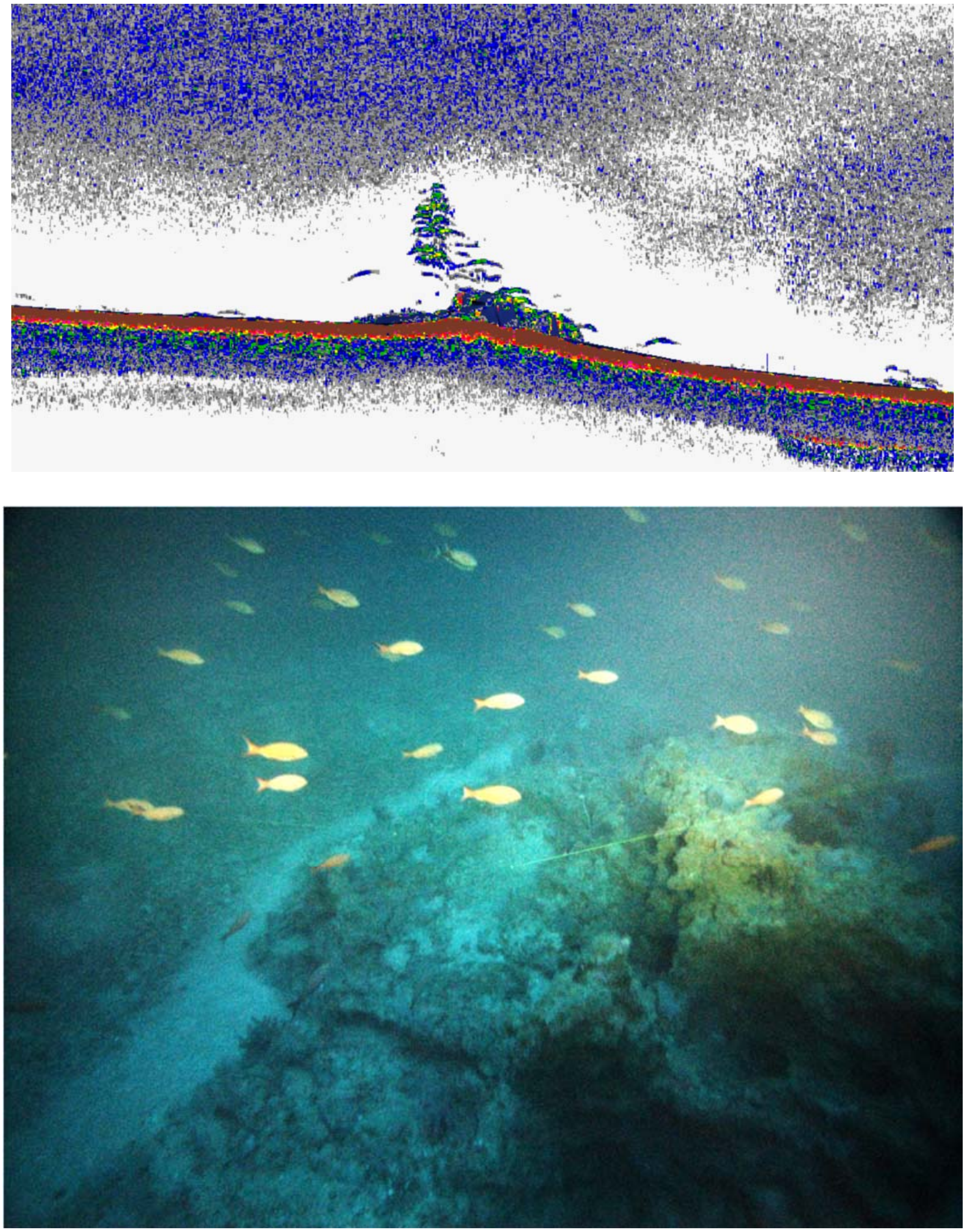


Figure 5. Top, an EK-60 sonar image of a school of red snapper imaged in the Madison-Swanson fishery closed area. Identity of the fish was established with C-BASS imagery. Bottom, a school of vermillion snapper imaged with the C-BASS towed camera system on the west Florida shelf.

Figure 6. Image of an amberjack observed in 2014 on the west Florida shelf.