Abstract—We describe the application of two types of stereo camera systems in fisheries research, including the design, calibration, analysis techniques, and precision of the data obtained with these systems. The first is a stereo video system deployed by using a quick-responding winch with a live feed to provide species- and size-composition data adequate to produce acoustically based biomass estimates of rockfish. This system was tested on the eastern Bering Sea slope where rockfish were measured. Rockfish sizes were similar to those sampled with a bottom trawl and the relative error in multiple measurements of the same rockfish in multiple still-frame images was small. Measurement errors of up to 5.5% were found on a calibration target of known size. The second system consisted of a pair of still-image digital cameras mounted inside a midwater trawl. Processing of the stereo images allowed fish length, fish orientation in relation to the camera platform, and relative distance of the fish to the trawl netting to be determined. The video system was useful for surveying fish in Alaska, but it could also be used broadly in other situations where it is difficult to obtain species-composition or size-composition information. Likewise, the still-image system could be used for fisheries research to obtain data on size, position, and orientation of fish.

Manuscript submitted 21 January 2010.
Manuscript accepted 27 May 2010.
Fish. Bull. 108:352–362 (2010).

Use of stereo camera systems for assessment of rockfish abundance in untrawlable areas and for recording pollock behavior during midwater trawls

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For modern fisheries stock assessments, fisheries-independent data are necessary to estimate population abundances and population trends. For most marine species, fisheries-independent abundance estimates are primarily obtained from large-scale multispecies bottom trawl surveys (e.g., Gunderson and Sample, 1980) and from acoustic surveys of pelagic fish stocks (e.g., Karp and Walters, 1994). Although acoustic backscatter is used to measure fish abundance, midwater trawl samples are needed to determine the size and species composition of acoustically sampled fish populations. Both of these survey methods require physical sampling of trawl catches and such sampling can result in unrepresentative data in several ways.

Bottom-trawl surveys are limited to the areas they can sample because many research trawls are not constructed to efficiently fish over a rough or rugose seafloor. Thus, surveys with bottom trawls may not be appropriate for some species with affinities for untrawlable habitat or in survey areas where significant patches of untrawlable ground can be found (Zimmermann, 2003; Cordue, 2007). In Alaska, semipelagic species such as northern rockfish (*Sebastes polyspinis*) and Pacific ocean perch (*S. alutus*) are an important part of the commercial catch, but they also show some affinity for untrawlable areas (Clausen and Heifetz, 2002; Rooper et al., 2007).

In addition, inferences from species- and size-composition data obtained from trawl catches can be biased on account of trawl selectivity. Trawls are generally designed to capture larger, market-size fish, and their design for this selected size results in the under-retention of juvenile size classes. In acoustic surveys of walleye pollock (*Theragra chalcogramma*), biases in midwater trawl catches directly translate into biases in abundance estimates for areas where large and small fish are found (Godo et al., 1998). Selective retention of fish is a consequence of size and species-dependent fish behavior during the trawling process. Observation of fish reactions to trawl gear is critical to understanding the behavioral mechanisms responsible for trawl selectivity and to develop future trawl gear for research.

Here, we describe the use of stereo photography to sample rockfish in untrawlable habitats using a drop unit with a stereo video camera (hereafter termed "video-drop" camera), and to study fish behavior in midwater trawls using a trawl-mounted pair of still-frame stereo cameras (hereafter, termed "still-frame" camera). Stereo cameras have been successfully used to measure fish in controlled aquaculture settings (Ruff et al., 1995; Harvey et al., 2003) and in open water

Table 1

Design, manufacturer, and cost (approximate estimates in U.S. dollars) for drop stereo-video camera and still-frame stereo-camera systems used for surveying untrawlable habitat and studying fish behavior in midwater research trawls. Both systems were used in the field in July 2008 and July 2007, respectively. HID=high-intensity discharge; LED=light-emitting diode; UHMW = ultra high molecular weight plastic.

System	Component	Design	Manufacturer	Cost
Drop stereo-video camera	HID light	HID Xenon lights, 12 V, 50 W	Underwater Lights USA	$814
	Video line driver	Balanced line driver and transceiver	Nitek	$133
	Conducting cable	4 conductor wire, 4.72 mm diameter	Rochester Cable	$1601
	Sled frame	Aluminum channel and tubing	Local manufacture	$2000
	Winch and slip ring	CSW-6 electronic win	A.G.O. Environmental	$11,268
	Underwater housings cameras	5″ diameter	Local manufacture	$729
	Underwater housings lights	—	Local manufacture	$729
	LED sync	—	Ramsey Electronics	$24
	Underwater cable and connections	—	Teledyne Impulse	$614
	Batteries	4×12 V 4 Ah NiMH	Energy sales	$396
			Total video system cost	$18,308
Still-frame stereo camera	Strobe	Oceanic 3000	Oceanic	$990
	Cameras	Canon Digital Rebel Xt (8Mp)	Canon USA	$1100
	Lenses	Canon EF 28 mm f/2.8	Canon USA	$450
	Microcontroller & circuitry	—	Local manufacture	$150
	Underwater housings and viewports	10″ floats, 1.5″ acrylic flat viewports	Local manufacture	$1400
	Mounting frame	UHMW plastic and aluminium stock	Local manufacture	$350
	Underwater connections	—	Teledyne Impulse	$650
	Batteries	3×12 V 4 Ah NiMH	Energy sales	$297
			Total still-frame system cost	$5387
	Software	Matlab V 7.6	Mathworks	

(i.e., van Rooij and Videler, 1996; Shortis et al., 2009). The recent development of high-resolution digital cameras has vastly improved the performance and reduced the complexity of image-based sampling because high-quality digital images can be directly analyzed with image-processing software. In general, stereo methods provide highly precise measurements in comparison to single-camera–based photogrammetric methods (Harvey et al., 2002). However, these systems necessitate maintaining a stable two-camera geometry and must be initially calibrated with targets of known sizes. Despite these constraints, stereo photography is widely used in optical-based sampling in a variety of marine studies.

We demonstrate the precision of stereo-camera–based measurements, attainable from initial deployments in the field, in comparison with traditional survey measurements. The results show that stereo-based optical sampling is a viable method for augmenting bottom-trawl data for abundance estimations; the stereo cameras allow scientists to survey sampling areas that are unavailable to standard survey trawl gear. In addition, stereo cameras can be used to observe and quantify the behavior of fish in the process of being captured by trawl gear to further improve estimates of abundance because they allow scientists to determine the potential biases in trawl-based catch data.

Materials and methods

Sampling untrawlable areas with the video-drop camera system

The design of the video-drop system was based on two key needs. Because rockfish are found in areas of high relief, the camera needed to have adequate protection for their electronic components and have the ability to maintain visual contact with the bottom through rough substrate areas. Therefore, essential to sampling with this camera system was the ability to live-view the video and the use of a quick-responding winch system that could be controlled by the operator aboard the research vessel. The specifications of the camera components are presented in Table 1.

The winch used to deploy and retrieve the camera system and navigate the seafloor was a CSW-6 multipurpose win (A.G.O. Environmental, Nanaimo, BC, Canada; Fig. 1A). The winch motor was a $^3/_4$ horse-

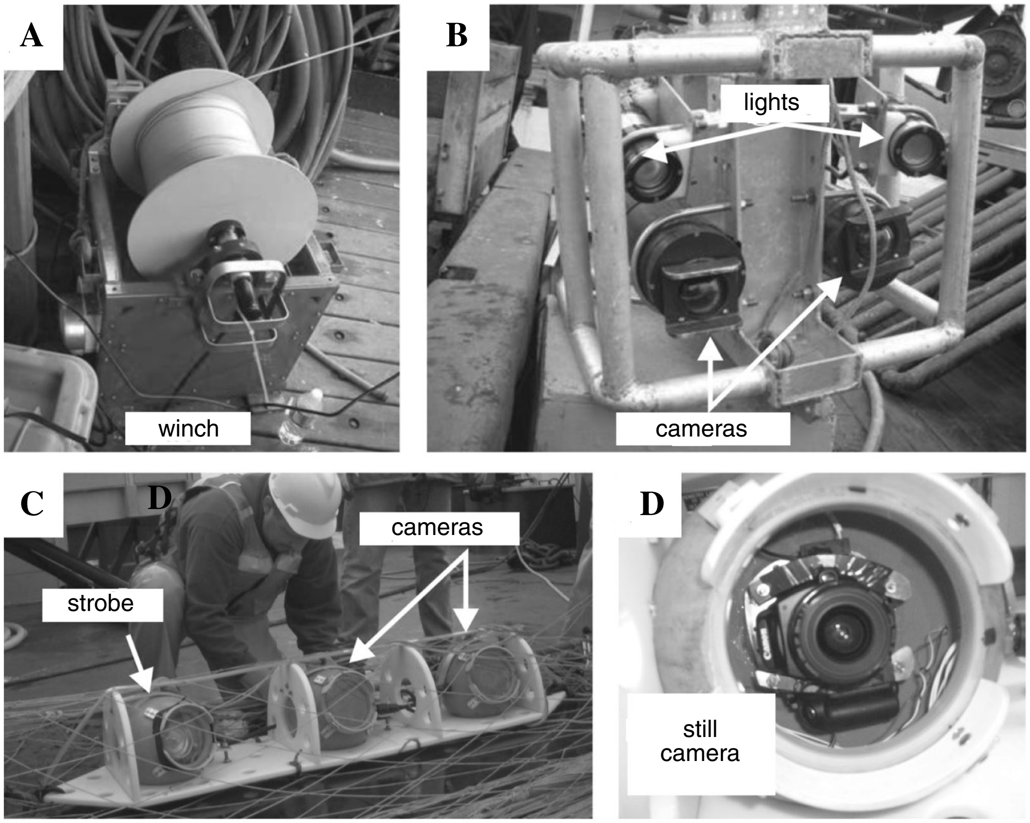


Figure 1

Drop stereo-video camera system showing (**A**) the quick-responding winch, and (**B**) the locations of cameras and lights in the aluminum frame. (**C**) The still-frame camera system, which is deployed in a midwater trawl. (**D**) The camera housings (shown) were constructed from deep-water trawl floats which provided buoyancy and reduced the weight of the cameras.

power Leeson wet-duty motor powered by 100 V AC. The winch speed ranged from 43 m/min (with a bare drum) to approximately 58 m/min (with a full drum). The approximate square-in area of the winch was 48 in^2 (0.031 m^2) and its weight was 155 lb (70.3 kg). The drum was 16 in (40.6 cm) in circumference and was filled with 1312 ft (400 m) of 3/16-in (4.72-mm) conducting wire. The wire had a breaking strength of 3300 lb (1497 kg) and was connected to the camera sled with a cable-grip. The video feed from the cameras was passed up a cable and through a four-conductor slip ring mounted on the winch and routed into a junction box where it was connected to a monitor for real-time viewing.

The protective cage around the camera and lights was constructed of 1.5-in (3.81-cm) aluminum tubing, and the interior members of the frame were composed of 6-in (15.24-cm) aluminum channel (Fig. 1B). A tail chain was attached to the rear of the ventral surface of the cage to drag along the seafloor to help keep the camera unit in contact with the seafloor and oriented forward during deployment. The tail chain was connected to the cage by a short piece of twine to act as a “weak link” in case the tail chain snagged on the seafloor.

The underwater video was recorded by two identical Sony TR-900 camcorders (Sony Electronics Inc., San Diego, CA) located inside the camera housings. The cameras were capable of collecting 720 p progressive scan video images at a resolution of 720×480 pixels. The video was recorded to digital video tapes for a maximum of one hour per tape. Because the cable was too long (400 m) to transmit a standard video signal, it was transformed by using a video balun (in the camera housing) and a receiver (at the winch) to reconvert the video signal back to a viewable picture of the seafloor to use for real-time navigation. Cameras were placed in separate housings constructed of titanium tubing and that had a glass dome port (pressure-rated to 3000 m depth) covering the lens. The lens of each camera was keyed to its port to prevent the camera from being inserted into the housing in a position other than the exact keyed position and stabilized the relative position of the cameras from deployment to deployment—an important consideration for accurate measurement of targets (Shortis et al., 2000). The housings were mounted side by side on the aluminum frame (Fig. 1B).

Illumination was provided by two lights mounted above the camera housings inside the aluminum frame (Fig. 1B). The lights were 50-watt high-intensity discharge (HID) Xenon lights with 5300 lumen output and 3900 Kelvin color temperature. The lights were inserted into 3-in (7.62-cm) diameter titanium housings and the entire light weighed 5 lb (2.27 kg). The lights were powered by a battery located in the camera housing and linked to the light housing by underwater connectors. Four rechargeable 4 Ah 12 V nickel-metal hydride batteries were connected in parallel to provide approximately 1.5 hour of light per deployment. Each light housing was mounted on an adjustable mount that allowed even illumination of the target.

Observing fish behavior in a trawl with the still-frame system

The still-frame system was designed to be light and small enough to be easily attached to the inside of a survey trawl without significantly changing the fishing activity of the net. The system also needed to provide adequate illumination and resolution in order to allow the fish inside the net to be observed at a range of up to 6 m as they passed though a midwater survey trawl 40 m ahead of the codend. A pair of Canon Rebel Xt 8 megapixel digital single-lens reflex cameras (Canon USA, Lake Success, NY) were used to capture fish images. Both cameras were outfitted with 4-gigabyte compact flash memory cards for storage of the images. A high-power wide-angle Xenon strobe (90°, 150 W/s) was used to illuminate the field of view. Three 4-Ah 12 V batteries were mounted in the strobe housing; two were connected to the strobes and the third was used to power the cameras.

The cameras were mounted in separate housings made from 10-in (25-cm) diameter deep-water–rated (1800 m) trawl floats. Images were taken though a 25-mm thick flat acrylic viewport. The strobe and batteries were mounted in a third float housing (Fig. 1C). All three float housings were secured on a sled constructed of 25-mm thick plastic plate and aluminum rails for protection. The approximate weight of the complete assembly in air was 30 kg and was positively buoyant because of the float housings. Quick-release trigger snaps were attached to the ends of the plastic mounting board for attachment to the inside of the trawl. The cameras were aimed across the trawl, perpendicular to the water flow to provide lateral views of fish passing by. The trigger on the camera shutter was controlled by using a microprocessor that was programmed for the study and that located in one of the camera housings. A two-axis tilt sensor was attached to the microprocessor board to allow measurements of fish tilt (deviation of snout-tail axis from the horizontal) and yaw (angle of fish heading in the horizontal plane) to be adjusted from being relative to the camera platform to being in absolute orientation. A pressure switch was used to activate the system once the depth exceeded 20 meters. Images were taken at intervals of 5 s to reduce the influence of light on fish behavior and to ensure that a new group of fish was observed in each frame. The system was capable of taking about 400 images or operating for 33 min of trawl time per deployment.

Calibration of the two types of stereo cameras

The same calibration procedure was used for both stereo-camera systems. The basic procedure required collecting images of a target plate with a printed 10 × 10 square checkerboard pattern of known dimensions (50 × 50 cm squares for the video-drop system, 100 × 100 cm for the still-frame system). This calibration was performed underwater. The video-drop system cage was suspended in the water while the research vessel was secured to the dock. The approximate depth of the camera was 1 m and the distance from the target was 2 m. The checkerboard target was lowered into the water along the vessel until it was plainly visible in both cameras. The target was then slowly moved horizontally and vertically through the field of view of both cameras. Up to 15 min of calibration video was collected by this method. For the still-frame system, an external trigger cable was attached to the assembly, and the system slowly moved about while capturing images of the fixed checkerboard plate.

To calibrate the video-drop system, progressive scan video images were collected at 29.97 frames/s in each camera, and the beginning of the video feed from each camera was aligned by using a light-emitting diode (LED) synchronization light at the beginning of deployment. This process was repeated at the end of the deployment to confirm that the video frames were still aligned. For the calibration procedure, still frame images were extracted from the aligned video at 1-s intervals with Adobe Premier software (Adobe Systems, Inc., San Jose, CA). Synchronization was not necessary for the still-frame system because the cameras were triggered simultaneously. Approximately 20 paired images where the target checkerboard was visible in both cameras were randomly selected for the calibration of each camera system.

The calibration parameters were estimated with the camera calibration toolbox in Matlab, a freely available software analysis toolbox built with Matlab computing language (Mathworks, Inc.; Bouget, 2008; Fig. 2). For each image pair, the position of the corner points of the checkerboard pattern were identified by clicking on the images and the location of these points in the still images was computed by the calibration software to determine the intrinsic parameters of each camera. Intrinsic parameters were used to correct the individual images for optical distortion resulting from the camera lenses. The checkerboard pattern allowed the software to automatically pinpoint exact corner locations based on the color contrast of the square boundaries, making the initial precision of the manual clicking less critical.

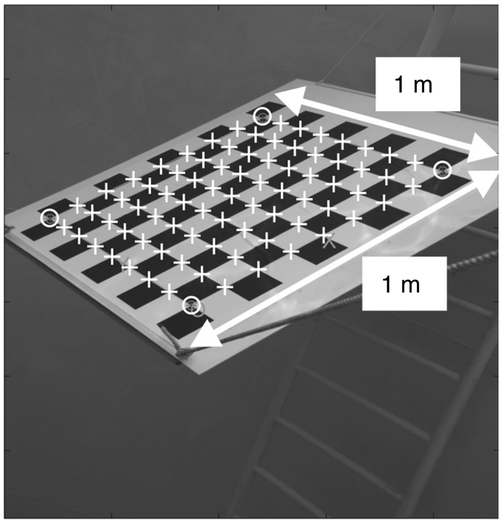


Figure 2

The checkerboard pattern used to calibrate and test the drop stereo-video camera and the still-frame stereo-camera systems. Images used for calibration were processed by using the camera calibration toolbox written for Matlab. An image taken by the still-frame stereo-camera system is shown with the user-selected extreme corners shown as white circles and the automated extraction of all intermediate corners shown with white crosses. This procedure was repeated for up to 20 different images with both systems.

Stereo calibration required that the checkerboard corners be identified in the same order in each of the synchronous image pairs to correctly match up the analogous corner points. These points, once corrected for optical distortion in individual cameras, were used to compute the epipolar geometry, by iteratively solving for the translation and rotation vectors that describe the relationship between the coordinate systems of the two cameras (Xu and Zhang, 1996). Once these matrices were estimated by the software, the three-dimensional position of a target point viewed in both cameras could be determined by triangulation.

Fish measurements with the camera

Fish lengths were measured by using stereo triangulation functions supplied with the camera calibration software package (Bouguet, 2008). For the video-drop system, images were extracted from the two video feeds at 1-s intervals. The images were synchronized at the beginning of each transect before deployment by using the LED synchronization light. The images were checked at the end of each transect to confirm that the cameras remained synchronized.

Length measurements were obtained by identifying the pixel coordinates of corresponding pixel locations in the left and right camera still frames such as a fish snout and tail (Fig. 3). These points were used to solve for the three-dimensional coordinates of the points in the images by triangulation, by using the calibration-derived parameters. Once the three-dimensional coordinates of the fish snout and tail were obtained, the length was measured as the simple Euclidian distance between the points in real space. This measurement method underestimated length for fish whose bodies were curved; however; fish in the video and still camera were almost exclusively seen with little or no curvature in their bodies and the few individuals that were obviously strongly curved were not measured. Length data were collected by using a basic software application built with the Matlab computing language (Fig. 4; available from the authors upon request), which incorporated the triangulation function supplied by the calibration toolbox.

In addition to length measurements, the three-dimensional coordinates extracted from the still-frame images provided data on the position and orientation of walleye Pollock in relation to the trawl (Fig. 5). These data were used to determine distances of pollock targets to trawl components for position of fish and to calculate tilt and yaw for orientation of fish.

Data collections

Field testing of the video-drop system was conducted 12–15 July 2008 at Zhemchug Ridges, located on the eastern Bering Sea shelf adjacent to Zhemchug Canyon where a sizable rockfish population is present in untrawlable and isolated rocky ridge area (Fig. 6; Rooper et al., in press). The camera system was deployed off the side of the vessel FV *Vesteraalen* by a winch suspended from a block attached to the vessel's crane. The camera sled drifted with the prevailing current, while the camera winch operator kept the seafloor in view and avoided any obstacles using real-time navigation. Stereo video was collected over 11 transects, each ranging in length from 3.5 to 49.5 min and covering distances of 95 m to 1673 m. Observations of trawl movements with the still-frame system were made during acoustic surveys of pollock in the eastern Bering Sea in June and July 2007 onboard the RV *Oscar Dyson* (Fig. 6).

Testing of the calibrations for the two camera systems

To test the video calibration five random still images was selected from the video-drop system of the checkerboard taken at the beginning and end of the study. Three intervals of 10 cm, 20 cm and 30 cm each were measured three times from the top to the bottom of the checkerboard (n=3 for each interval) and averaged within each frame. The average from each frame multiplied by the interval combination was then tested in an analysis of variance to determine whether there were significant differences between measurements from the first and second measurement set.

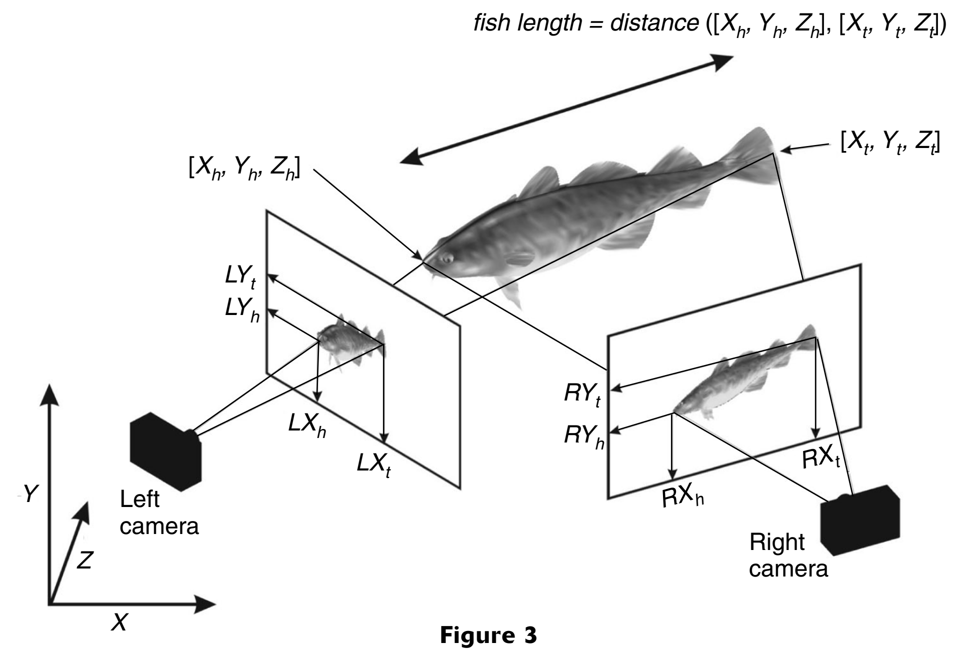


Figure 3

Method for determining fish length measurements by using stereo images. The three-dimensional coordinates of the fish head and tail ($X_h,Y_h,Z_h; X_t,Y_t,Z_t$) were determined by stereo-triangulation and by using the image-based coordinates from the image pairs (i.e., $LX_h,LY_h; RX_h,RY_h$). Fish length was estimated as the Euclidian distance between the three-dimensional points of the head and tail.

Results

Calibration

The estimates of distance of the fish to the trawl determined with the second calibration of the drop-video system were significantly larger and more variable than those from the first measurement set across all three intervals (Fig. 7). Differences between the mean measurements and known values in the second set ranged from 6.6% to 8.2%. However, the 95% confidence intervals for both sets included the actual values for the intervals in all cases, and the coefficients of variation for the measurements ranged to 5.5% of the mean value, indicating that the length measurements were reasonably precise. A similar procedure was also performed with the still-frame system, but only a single set of validation measurements was made before the start of field operations. The results of this set closely matched that of the first set made with the video cameras (Fig. 7).

Fish lengths determined with the video-drop system

The adult rockfish observed in the video were northern rockfish (96.94%), unidentified adult rockfish (*Sebastes* spp., 0.98%), adult Pacific ocean perch (0.49%), and dusky rockfish (*S. ciliatus*,1.60%), whereas most of the juveniles that were identified to species were Pacific ocean perch (Rooper et al. in press). Some of the juvenile rockfishes observed in the video were too small to identify to species. Individuals of each species group were randomly chosen to be measured in proportion with their abundance. Up to 200 randomly selected individual rockfish were measured in each transect, resulting in a total of 1489 length measurements. Rockfish were measured by using fork length only if both the tip of their snout and the end of the tail were plainly visible in both still images. If the randomly chosen rockfish could not be measured, the next available rockfish of the same species group that was deemed measureable was chosen. In a few cases, where the occurrence of a species group was very small (<5 individuals in a transect), none were measured.

A random sample of 20 rockfish that were observed in successive still frames of both video cameras was used to determine measurement precision and to estimate distance of the fish from the camera. These fish were measured in up to four consecutive frames and their estimated length were compared by using linear regression (Fig. 8). The percent difference between successive length measurements was not significantly related to the average fish length (P=0.28); in other words, there was no length-related bias in the measurements. The length data were also tested for a relationship with distance from the camera by using linear regression. There was no bias in the measurements of fish for distance from the camera (P=0.29). The standard deviation of

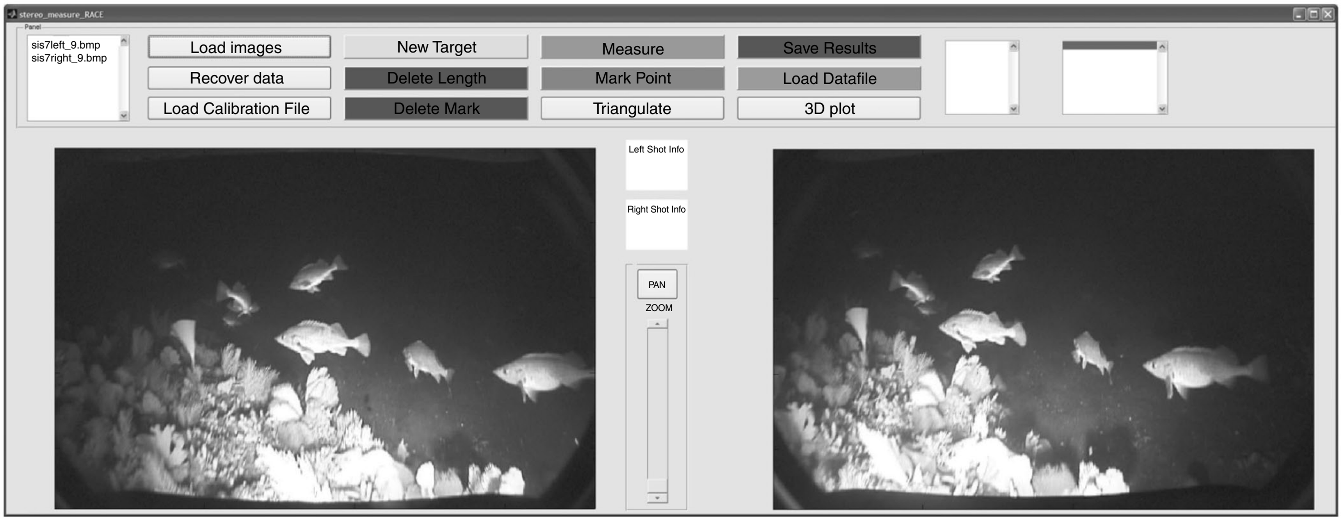


Figure 4

Computerized display of the stereo processing options for the drop stereo-video with a custom-built application written in the Matlab computing language. Synchronous images were extracted from videos taken by two cameras and used to estimate fish length. Images were taken in Zhemchug Ridges in the eastern Bering Sea in July 2008.

the percent difference in multiple measurements of the same fish was 0.076.

Analysis of still-frame stereo images

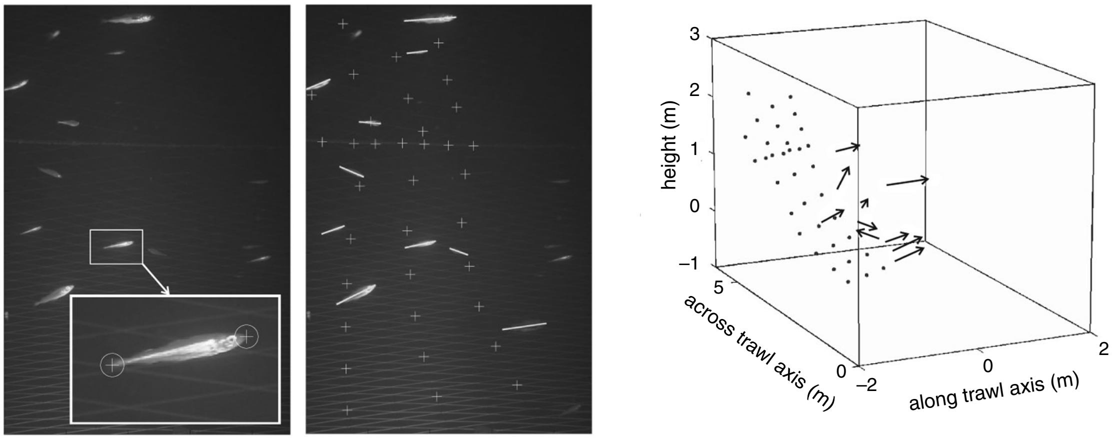
Ten deployments were made with the still-frame system, and ~200 fish were measured per deployment. Catches consisted almost exclusively of walleye pollock (>99%). A comparison between the length frequencies derived from the stereo analysis (n=360) and physical measurements of fish captured in the codend (n=1260, Fig. 9) showed that optical sampling approximates the length-frequency distribution of fish caught, despite the smaller sample size for optical sampling.

In addition to length measurements, the stereo analysis provided data on walleye pollock orientation and their relative position within the trawl. Quantitative descriptions of the distribution of tilt and yaw angles were easily calculated by using the same points in images (head and tail) derived for fish lengths (Fig. 10). To calculate the position of fish within the trawl additional corresponding points along the trawl panel were identified and their three-dimensional coordinates were determined by the triangulation process outlined above (Fig. 5).

Discussion

The potential of stereo cameras for measuring marine organisms has been shown in many studies (i.e., Shortis et al., 2000; Harvey et al., 2003), but here we present a description of the complete implementation of stereo cameras, including equipment costs (Table 1), image analysis process, and expected precision in data from these systems. The two stereo-camera systems described here were studied for their potential to provide information to augment fisheries assessment surveys in Alaska. Specifically, the stereo-camera systems in our study provided species and length data for untrawlable regions located within bottom-trawl survey boundaries and provide a new method for studying the behavior of fish in a midwater trawl. Our main goal was to present field-tested methods to provide quantifiable image-based data for fisheries surveys and our results may help similar research with stereo-camera–based sampling systems.

The video-drop system was useful for estimating rockfish size and species composition in field tests in Alaska. Error rates for size were on the order of 8.2% or less, which equates to about 2.5 cm for a 30-cm fish. Compared with other studies with error rates of ~0.1% to 0.7% in stereo-video systems (Harvey et al., 2002; Harvey et al., 2003; Shortis et al., 2009), the measurement error rate in our study was high. This rate represents systematic error most likely caused by the need to remove cameras from the housing after each deployment because a slight misalignment of the cameras in relation to the position at calibration would reduce the precision of the measurements. Ruff et al. (1995) report an achievable level of precision in measuring fish of 3.5%, based on repeat measurements of individuals, which is also better than the 5.9% observed in our study. The error rates also compare well to the rates of 1–5% for measuring rigid items with parallel lasers (Rochet et al., 2006). However, only fish on or near which the parallel laser beams are projected can be measured. This restriction limits the measurement sample size. In contrast, any fish simultaneously viewed by both cameras in a stereo-camera system can be mea-



A raw image **B** processed image **C** 3D reconstruction

Figure 5

Images of walleye pollock (*Theragra chalcogramma*) from a still-frame stereo camera in a midwater trawl and a 3-D reconstruction of fish in relation to the trawl net. (**A**) Fish lengths were measured by enlarging the image of a fish and indicating the position of the snout and tail (shown as U) in both right and left raw images (only the left image is shown above). (**B**) The chosen fish endpoints are overlaid on the image as lines. In addition to estimates of fish length, stereo-processing allows the position of fish in relation to the trawl to be estimated. Additional points in the images can be determined by finding corresponding left-right image pixel coordinates (B, shown as crosses). (**C**) Following stereo-triangulation, a three-dimensional plot shows the fish targets as arrows and trawl mesh knots as dots.

sured, and thus the number of fish that can be measured is larger from the same length transect. Improvements in the quality of the still-frame images and in the collection of calibration data from a target at the beginning of each transect may allow more precise measurements to be taken in future studies. Given our inability with other survey gears to determine fish size and species composition in untrawlable habitats, the use of stereo cameras holds promise for stock assessments of rockfish and other species. Stereo-camera-based sampling could also be used broadly wherever gears other than bottom trawls are needed to obtain species- or size-composition information.

Lengths of rockfish derived from the video-drop system were generally comparable to trawl catch-based size distributions for the species exam-

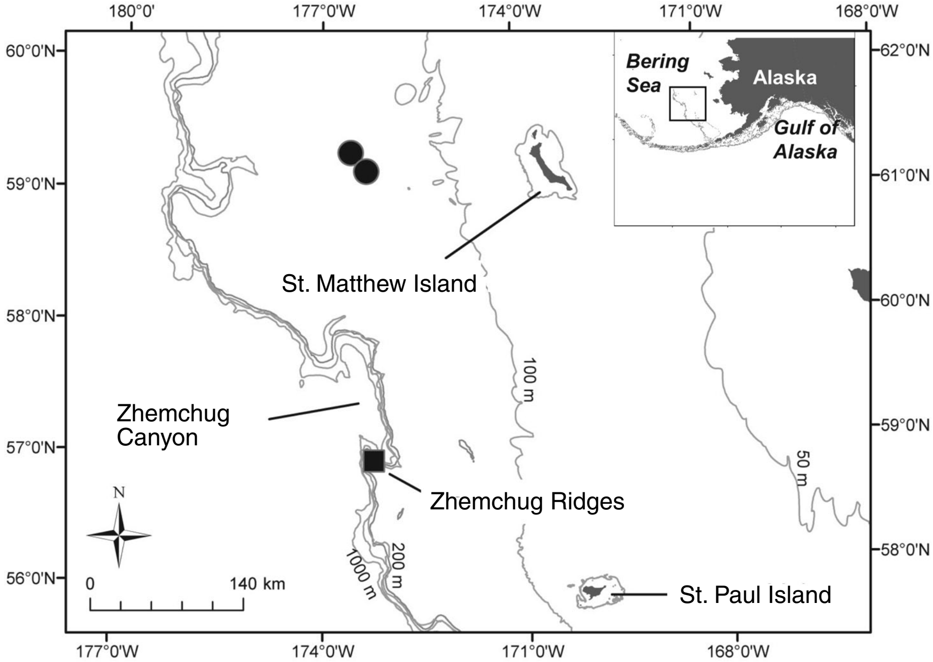


Figure 6

Map of study areas in the eastern Bering Sea showing the location of field tests of the drop stereo video cameras for sampling untrawlable areas (black square) in July 2008 and for sampling fish behavior in a trawl (circles) with a still-frame stereo camera in July 2007.

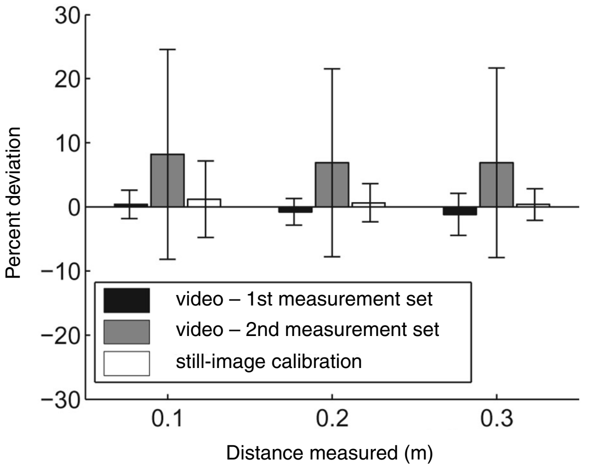


Figure 7

Results of measuring known distances on the checkerboard (see Fig. 2) during the first and second calibrations of the drop stereo video-camera system and a still-frame stereo-camera system used for estimating fish length and studying behavior. Calibration is a necessary step in the use of stereo cameras to allow measurements to be made from images. Values represent the percent deviation in measurements in relation to known values, including 95% confidence intervals based on five measurements.

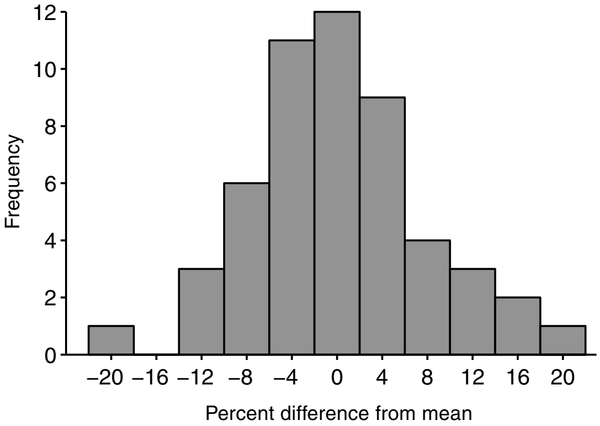


Figure 8

Frequency of percent differences from multiple length measurements of $n=20$ rockfish and the mean length of the fish. Individual fish were measured multiple times from a series of images extracted from video taken by a drop stereo-video camera. Measurements from each image were then compared to the mean measurement for that individual to estimate potential measurement error. Rockfish observations were collected at Zhemchug Ridges, eastern Bering Sea in July 2008.

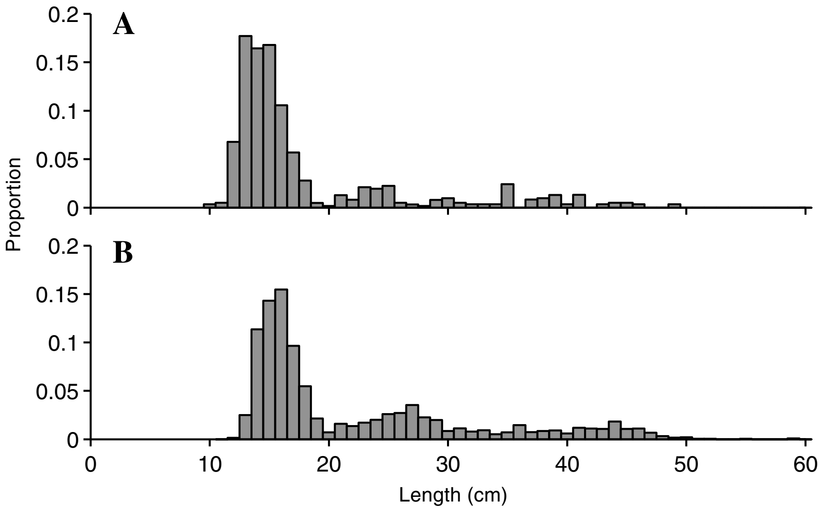


Figure 9

Comparison between length frequencies of walleye pollock (*Theragra chalcogramma*) estimated from (**A**) the images from a still-frame stereo camera (n=360) within a midwater trawl, and length frequencies obtained from (**B**) fish captured in the codend and directly measured (n=1260). The smaller camera-based sample results are similar to the direct measurements in their overall size distribution, but there was less definition for larger fish (>20 cm). Data were pooled from three trawl samples taken in the eastern Bering Sea in July 2007.

ined. Northern rockfish lengths from stereo-video images taken along transects at Zhemchug Ridges ranged from 9 to 41 cm (mean length=30.0 cm). In three bottom-trawl surveys near the Aleutian Islands, Clausen and Heifetz (2002) found that the mean size of northern rockfish was 29.9 cm and ranged from 15 to 38 cm. Juvenile Pacific ocean perch lengths (2.6 cm to 25.0 cm) were similar but ranged to smaller sizes than those found for the Aleutian Islands (8.3cm to 24.9 cm; Boldt and Rooper, 2009). Lengths of juvenile Pacific ocean perch obtained from stereo video were also similar to those in three experimental tows in the Zhemchug Ridges area in 2004 and 2007 (juveniles ranged from 10 cm to 25 cm). However, these lengths were measured from fish captured during bottom trawl hauls, where the incidence of smaller fish may have been due to reduced catchability of smaller individuals. Although these observations are not meant to serve as a quantitative comparison of trawl- and stereo-camera–derived size estimates, they demonstrate the similarities in information supplied by the two methods and the potential for stereo cameras to overcome some problems with the catchability of juvenile fish.

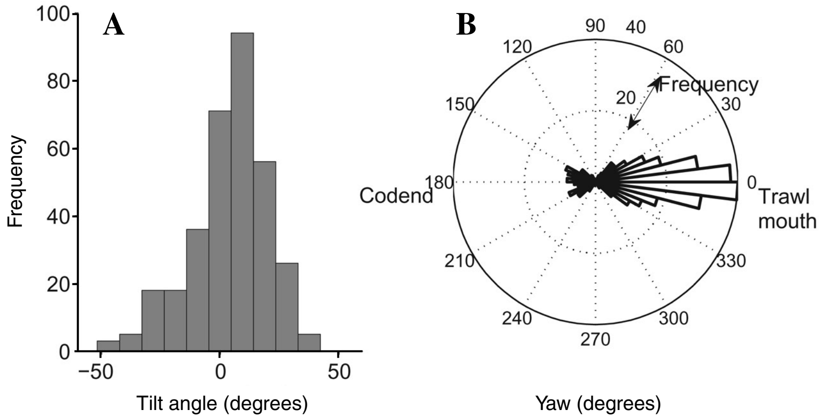


Figure 10

Orientiation of walleye pollock (*Theragra chalcogramma*) within a midwater trawl. A still-frame stereo camera was used to determine (**A**) the distribution of individual fish tilt angle (deviation of snout-tail axis from the horizontal), and (**B**) the yaw (angle of fish heading in the horizontal plane). Most fish were oriented horizontally and facing toward the trawl opening. Image data were collected in the eastern Bering Sea in July 2007 as part of a study of fish behavior within the trawl.

The stereo camera was very useful for studying behavior of pollock in the trawl. The data show the possibility of performing a length-based analysis of behavior which will directly contribute to studies of gear selectivity and future designs of scientific trawl gear. Although a postsurvey calibration was not performed with the still-frame system, the cameras were securely fastened in the housings and were not removed during the entire data collection, thus maintaining intercamera spacing and angles. The agreement between the catch-based length measurements and the stereo-derived lengths provides direct validation of the stereo-derived measurements. The low sampling frequency of 1 frame per 5 s ensured minimal influence of the artificial lighting from the cameras on behavior because the fish photographed had not been previously exposed to the light source.

Recent development of high-resolution digital imaging devices and an increased access to custom designed, freely available software tools have made stereo-camera methods easy to implement by research groups without direct expertise in the subject. The camera calibration toolbox (Bouguet, 2008) provided the basis for software development. Although the current analysis approach is still fairly time intensive, the volumes of data analyzed were not very large. In a routine application of stereo-video cameras in untrawlable areas, additional levels of automated processing would likely be required because the quantity of video footage would substantial. For some aspects of the analysis, such as the matching of targets on the stereo cameras and the extraction of fish lengths, automation may be attainable, whereas automating more difficult tasks of isolating and identifying fish targets may not be feasible.

Stereo photography will continue to be developed as survey tools are developed for monitoring fish stocks and thereby improving the quality of stock assessments of fishery resources in Alaska. Some challenges remain; for instance, the challenge of institutionalizing image-based sampling as a routine survey method for untrawlable habitats. As a method of studying fish behavior in trawls, stereo cameras provide promising results by allowing three-dimensional reconstructions of the trawl environment.

Acknowledgments

The development and deployment of the camera and winch system was possible only through the assistance of G. McMurrin, G. Mundell, B. Lauth, G. Hoff, and especially S. McEntire. T. Cosgrove, K. Sjong, L. Mavar, and M. Booth of the FV *Vesteraalen* were instrumental in conducting the field tests. Calibration and deployment of the still-frame camera system were significantly aided by D. Jones and A. McCarthy. This manuscript was reviewed by D. Somerton, G. Hoff, R. Lauth, and M. Wilkins.

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