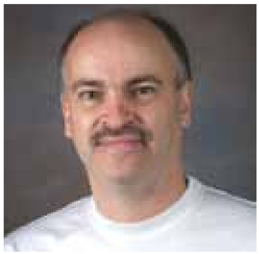
Smile, you're on HD camera

Melanie Underwood

Paul Winger



George Legge

Underwood, Winger and Legge focus in on the relative advantages of a new high definition digital video system for observing fish in a dynamic, low light fishing environment.

Who should read this paper?

Anyone with an interest in high definition (HD) video systems, particularly as a tool for observing marine flora or fauna in situ.

Why is it important?

Using underwater cameras to observe species behaviour in relation to fishing gear is becoming a common tool in the design of pre-trawl modifications. Most fish researchers have that old camera in the storeroom just needing an upgrade … but where is the bang for the buck? In upgrading the camera itself? The recording device? Both? How much would an upgrade of one or more of these system components cost, and what is the return on this investment in terms of enhanced performance? This paper establishes how even small changes in certain components of an underwater video system can go a long way towards improving the quality of the imagery, and its application to fish identification. Of particular interest are the spatial resolution of the system (i.e., its ability to distinguish fine features), performance in low light conditions, and robustness. The authors developed a simple method to test the performance of underwater camera systems in a laboratory setting and demonstrated the value of HD over traditional standard definition camera systems in the real world. Their results further show that even a relatively minor improvement, such as the addition of a solid state recording device, can improve image quality.

About the authors

Melanie Underwood is a recent graduate of the M.Sc. program at Memorial University of Newfoundland, with specialization in the field of fish capture behaviour. Paul Winger is the Director of the Centre for Sustainable Aquatic Resources at the Fisheries and Marine Institute of Memorial University. He holds a B.Sc. in Marine Biology and Oceanography from Dalhousie University, as well as an M.Sc. and PhD from Memorial University in the field of fish capture behaviour. George Legge is the Facility Supervisor at the Centre for Sustainable Aquatic Resources and developed one of the first self-contained underwater camera systems in the late 1980s.

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DEVELOPMENT AND EVALUATION OF A NEW HIGH DEFINITION SELF-CONTAINED UNDERWATER CAMERA SYSTEM TO OBSERVE FISH AND FISHING GEARS *IN SITU*

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ABSTRACT

International efforts to reduce the ecological impacts of fishing activity, including by-catch, seabed impacts, and carbon footprint, have encouraged the rapid advancement of fishing gear technology during the past few decades. However, prior to conducting gear modifications, a better understanding of animal behaviour in relation to the fishing gear is often required. The use of self-contained underwater camera systems to observe and quantify such behaviour began in the 1960s and today underwater camera systems are ubiquitous across all major research institutes, government agencies, and large fishing companies. This paper outlines the development and evaluation of a new high definition (HD 1080i/720p) digital video system for observing fish behaviour in relation to fishing gear. Under laboratory conditions, we compare the performance of the new system to four similar camera systems used during the last decade. Our laboratory study results revealed that HD video improved image quality by up to 20% and allowed characteristics of objects as thin as 4 mm to be observed underwater from 4.0 m away. We also tested the HD camera system's performance at sea attached to an offshore groundfish trawl and found that flatfish such as yellowtail flounder (*Limanda ferruginea*) could be identified to the species level with a high degree of certainty (72%), something not capable with traditional standard definition camera systems. Although HD cameras increase the image quality, they are limited to shallow environments (< 100m) when operated without the use of artificial lights. Even with the depth restrictions, the HD camera system provides digital solid state recording devices that are more adaptable to the underwater environment than traditional standard definition camera systems.

KEY WORDS

High definition video; Underwater camera; Trawl; Fish behaviour

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INTRODUCTION

Commercial fisheries in developed countries receive regular scrutiny and independent auditing to ensure sustainable harvesting practices are employed. Improvements in fishing gear technology have been widely adopted in an effort to reduce unintended ecological impacts associated with fishing activity. Significant research efforts have focused in particular on reducing by-catch (both observed and unobserved) during the past couple of decades [Graham, 2010]. While traditional species resource surveys provide valuable information on abundance, distribution, and age composition, they often are not focused on providing information on fish behaviour in the trawl zone and using this information to understand or correct abundance indices. However in modifying or designing new fishing gear to be used for resource surveys and commercially, information on the behavioural interaction between the fish and the gear, e.g., where and how animals enter and escape from the fishing gear, and how other species in the trawl zone affect these behaviours, are both necessary and vital. In commercial operations, understanding the differences in behaviour and morphology of coexisting species can lead to improved fishing gear designs that are both species and size selective [e.g., Glass, 2000; He et al., 2008; Winger, 2008]. For example, since the 1990s Atlantic cod (*Gadus morhua*) from a non-recovering stock off the eastern United States was a by-catch issue for the region's haddock (*Melanogrammus aeglefinus*) fishery, leading to a closure of the industry in 2005 and 2007 [Federal Register, 2005; 2007]. Based on previous camera observations at the entrance to the trawl [Main and Sangster, 1981; Wardle, 1993] cod were found to dive when encountering a trawl whereas haddock would rise, automatically separating the two species. These differences in behaviour led to the design of the Eliminator trawl, targeting haddock over cod and therefore resolved the by-catch problem [Beutel et al., 2008].

Various methods have been developed to gain a better understanding of finfish and shellfish behaviour during the capture process by mobile and static fishing gears. These include direct observation by SCUBA divers, manned submersibles, towed underwater vehicles, hydroacoustics, high frequency sonars, acoustic telemetry, and perhaps the most common approach, self-contained underwater camera systems [see reviews by Urquhart and Stewart, 1993; Graham et al., 2004; Winger et al., 2010]. Depending on the fishery and application, these techniques can provide critical behavioural information needed to make informed decisions about fishing gear modification. Graham et al. [2004] described the recent advances in underwater camera systems used on demersal trawls and the types of cameras required in low light environments. Depending on the application and ambient light conditions near the seabed, silicon-diode intensified target (SIT), charge-coupled cameras (CCD), and their intensified versions can all be used with good success.

Due to the unique challenges that occur when observing fish behaviour *in situ* with cameras – for example, attachment to mobile fishing gears, and the significantly lower light levels – researchers have had to trade-off image quality with the ability to see the subject. Camera resolution and pixel counts tend to be low in underwater cameras [320-700 horizontal lines: DeAlteris et al., 1992; Milliken et al., 1992; Bublitz, 1996; Olla et al., 2000; Albert et al.,

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2003; Yanase et al., 2009], limiting research on some individual species which have low contrast with their background; for example, morphologically similar fish species such as flatfish. On rare occasions, observations can be made when a flatfish species is geographically isolated from other flatfish species [e.g., Godø et al., 1999]. However, in most cases, identification of flatfish to the species level has been difficult, forcing researchers to lump several species into a single 'flatfish' category [see research from Beamish, 1966; 1969; Walsh and Hickey, 1993; Bublitz, 1996; Kim and Wardle, 2003; Chosid et al., 2011], or drop a considerable number of observations because of uncertainty [e.g., Albert et al., 2003].

High definition (HD 1080i/720p) cameras are now widely used in both the film industry and consumer electronics. Due to their generally poor performance at low light intensities, their application in underwater use has been limited; however, advances in recent years have opened up the opportunity to develop their potential use for studying fish behaviour and fishing gear [Favaro et al., 2011]. The purpose of this study was to 1) develop a full HD camera system that could be easily mounted on a trawl during commercial operations and be capable of separating morphologically similar species in low contrast situations; 2) evaluate the camera system under laboratory conditions with previously used camera systems; and 3) identify via video footage yellowtail flounder during commercial trawling operations.

MATERIALS AND METHODS

Camera System and Operation

The new camera system was built upon the

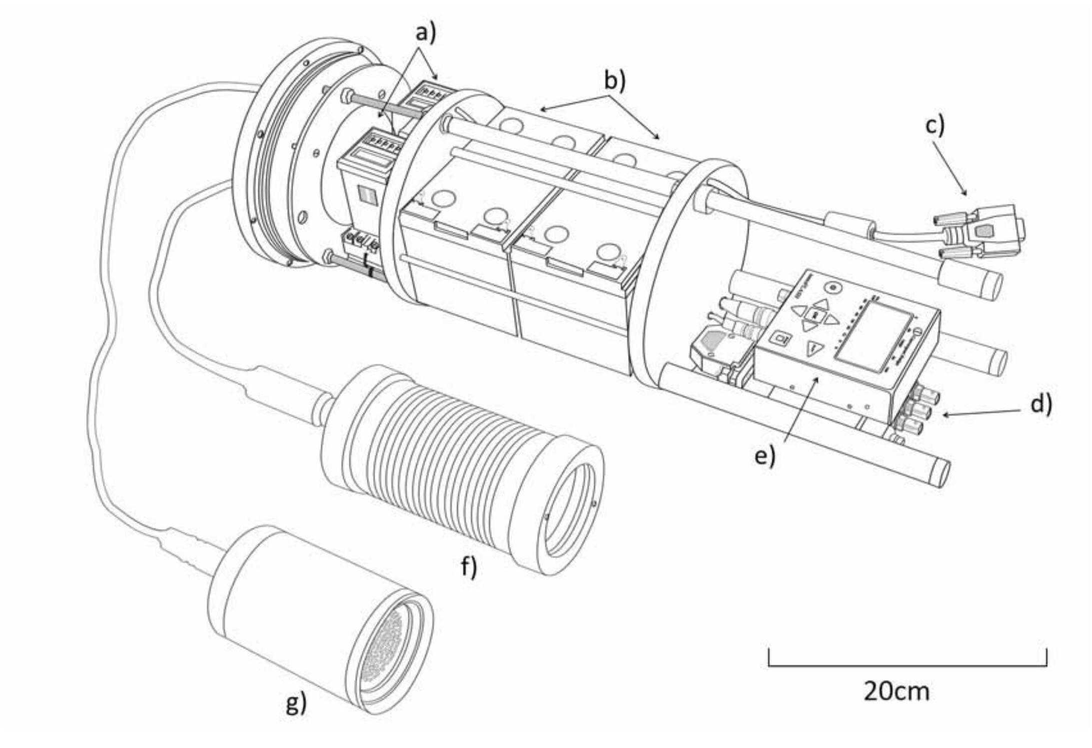

Figure 1: The individual components of the high definition (HD) self-contained underwater camera system developed at the Fisheries and Marine Institute of Memorial University. The inside of the instrument housing (depth-rated to 1500 m) consists of a) the programmable relay system; b) two 12-volt batteries; c) RS-232 connection; d) SD/HD converter; and e) a nanoFlash digital recorder. Also illustrated are f) the HD Splashcam Seatrex camera head and g) the interchangeable LED lights (red, infrared and white).

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working principles of traditional self-contained underwater camera systems used in fishing gear research [e.g., Milliken et al., 1992; Legge, 1998; Olla et al., 2000]. The basic system is separated into two parts: the instrument housing, which contains the electronics, and the peripherals, which include the camera head and lighting fixture (Figure 1). An interchangeable umbilical allows for different camera heads and lights to work with the same electronics setup. Inside the housing, the inner frame consists of a relay system (Potter & Brumfield CNT Series) and two 12-volt batteries. The original system used a standard definition (SD) Kongsberg Osprey CCD camera head and a Hi8 Sony CCD-TR81 8 mm camcorder for recording video. The new system incorporates modern technology, including a HD Splashcam Seatrex camera head, nanoFlash HD/SD recorder (convergent-design.com), and an AJA HD10C2 HD-SDI to analog HD converter (www.aja.com).

The relay system delays the start of recording and cuts the power to the electronics after the assigned time. The converter can be used with both the SD and HD, allowing multiple kinds of cameras to be used. The nanoFlash records up to 280 mbps and identifies the correct mbps needed by the video source. The nanoFlash records digitally onto two 64 Gb compact flash disks allowing 164 minutes at the highest mbps. An internal clock allows for synchronization of the video's time stamp with other onboard instrumentation, such as hydroacoustic gear monitoring sensors. The focus and mode of the camera head is controlled by external software via a RS-232 connection.

The camera head and lighting fixture are mounted in a protective cage (53.0 x 53.0 x 28.5 cm aluminium frame) with a multi-angle camera mount enabling the camera to be rotated 360 degrees, angled every 10 degrees (± 3 degrees) depending on the desired field of view. Lighting fixtures can also be mounted in the cage if needed. The cage is masked with black tape to reduce light reflection on the camera lens.

Laboratory Trials

Controlled evaluations of the old and new camera systems were conducted in September 2010 at the Fisheries and Marine Institute's 22 m long flume tank in St. John's [see Winger et al., 2006 for more details]. A 3.0 m long Camera Resolution and Imagery Board (CRIB) adapted from the 1951 USAF resolution test chart [Department of Defense, 1959] was developed, consisting of a total of 72 bars ranging in width from 0.1 to 8.0 cm with each width repeated three times (Figure 2). The CRIB was used to compare the quality of the footage from five different combinations of cameras and recording devices which progressively increase with technology. These included a standard definition camera and two moving state recording devices (Hi8 and MiniDV); standard definition camera and two solid state recording devices (SD and HD); and the high definition camera with the

Figure 2: The Camera Resolution and Imagery Board (CRIB) adapted from the 1951 USAF resolution test chart [Department of Defense, 1959] consisting of 72 black bars ranging in width from 0.1-8.0 cm to test the image quality of the underwater camera systems.

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Set-up	Pixel size	Camera	Converter	Recording Device	Recording Device Model
Original	640x480	Kongsberg	none	Hi8 Handycam	Sony CCD-TR81
Experimental 1	640x480	Kongsberg	none	MiniDV Handycam	Sony DCR-HC42
Experimental 2	640x480	Kongsberg	none	SD digital solid state	µAVR H.264x4
Experimental 3	1280x720	Kongsberg	AJA HD10C2	HD digital solid state	Convergent Design nanoFlash
Experimental 4	1280x720	Splashcam	AJA HD10C2	HD digital solid state	Convergent Design nanoFlash

Table 1: Description of the original and new experimental camera systems evaluated under laboratory conditions in the Marine Institute flume tank. Kongsberg is the Kongsberg OE 1367 CCD model and Splashcam is the Splashcam SeaTrex HD.

high definition solid state recording device (Table 1). The intent of this comparison was not to include all brands of products available on the market; it was, however, meant to be representative of the typical equipment used in this field of research.

Each experimental setup involved placing the respective camera underwater at a distance of 4.0 m vertically above the CRIB and recording the footage onto one of the recording devices. Video footage was recorded for two minutes at night with only the flume tank overhead lights on to reduce and standardize ambient light levels and shadows. After each camera was placed in the water, the system was left for 30 minutes to reduce water movement and help with water clarity. Four frames were randomly captured from each experimental setup. The total number of bars observed and the thinnest group of bars (all bars of the same width that could be identified) were recorded.

Field Trials

Sea trials were conducted on board the commercial Ocean Choice International groundfish trawler, *F/V Aqviq*, on the southern part of Grand Bank off eastern Newfoundland in May and June 2010. The system was evaluated using both the SD Kongsberg Osprey CCD camera head and the HD Splashcam Seatrex camera head, both installed in the protective cage with the video signal transferred via the umbilical to the recording housing where data were recorded onto the nanoFlash digital video recorder. Five successful tows were completed in May using the SD Kongsberg Osprey CCD camera, placing the cage and camera A) on the trawl's headline looking toward the lower belly and footgear, B) on the wing looking across the mouth of the trawl to the other wing, and C) straight down at the footgear. In June, five additional tows were completed with the HD Splashcam Seatrex camera, where it was placed only on the trawl's headline looking directly down at the footgear. In all cases, the camera systems were placed on the first tow of the afternoon in depths of 60-80 m to optimize the natural light.

Prior to mounting the camera on the trawl, the instrument housing was opened and the batteries were connected. At this time there was power to the camera head and the relay only. The camera was set to the infinite focus, 280 mbps (allowing a recording time of 164 min) and ICR (Infrared Cut-Filter) mode. The relays were set to the required start and stop times. The electronics were then placed into the recording housing and it was sealed. The camera head was secured inside the protective cage to prevent collision and damage. The recording housing containing the electronics was secured to the trawl in a tightly fitting bag made of polyethylene netting, 1.5 m from the camera

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and its protective cage. Four 20.3 cm diameter trawl floats were tied to the cage and housing to achieve neutral buoyancy and avoid any negative effect on the geometry of the trawl.

Analysis of the video footage was later conducted at the laboratory using Noldus Information Technology, Observer XT 10.1 software (www.noldus.com). The footage was divided into a grid of 100 squares in the manner similar to Albert et al. [2003]. Only footage looking at the footgear from the headline was used to determine identification. A grid square was selected from a list of randomly generated numbers and while the footage was playing, the first individual fish in that square observed rising from the seafloor until the individual interacted with the trawl was used. After the observation (when the individual interacted with the trawl) the next grid square was selected from the list of randomly generated numbers and the process was repeated until the footage ended or it was impossible to identify individuals on or in the substrate from the video. Yellowtail have fine morphological differences compared to other flatfish and can be visually identified by their protruding mouths. A total of 150 individuals were observed and subjectively identified as yellowtail or unidentified flatfish depending on the presence or absence of the protruding mouth.

RESULTS AND DISCUSSION

Camera System and Operation

Upon initial powering, many underwater cameras are set to auto-focus as the default setting by the manufacturers. In underwater environments, this feature can cause the camera to routinely go out of focus as it tries to focus on particles in the water column moving between the fishing gear and the camera. Out of focus footage increases the difficulty in identifying individual fish, requiring extended time at sea to compensate for the loss in usable footage. In contrast, the focus of the HD Splashcam Seatrex camera used in this study was ideal given that it could be set to infinite prior to deployment, thus stopping the camera from focusing solely on particles in the water and increasing the probability of getting valuable footage.

Laboratory Trials

Analysis of the flume tank video recordings of the CRIB showed variations in performance level among the five camera systems evaluated. The number of bars observed was greater for cameras with higher image resolution and solid state recording devices (Figure 3). The original

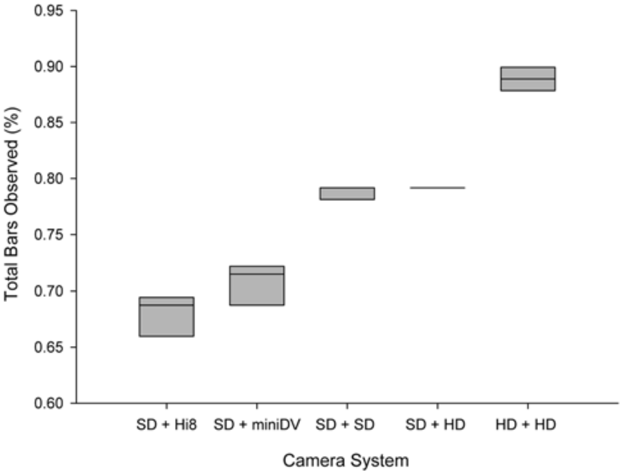

Figure 3: The median percentage of total bars observed (out of 72) for the four frames of each camera system (camera + recording device). The five camera systems include: the standard definition (SD) camera and a Hi8 recording device, SD camera and a MiniDV recording device, SD camera and a SD solid state recording device, a SD camera and a high definition (HD) solid state recording device, and a HD camera plus a HD solid state recording device. The boxes represent the range of percentages observed, with the median indicated by a black line.

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system (standard definition Kongsberg Osprey CCD camera with a Hi8 recording device) observed an average of 68% of the bars (49 out of 72 bars). Using the same standard definition (SD) camera with a newer recording device (MiniDV) produced a modest improvement in the percentage of bars observed (71%; 51 out of 72 bars). The conversion to digital solid state recording devices improved image quality to 79% of bars observed (56.75 out of 72 bars); however, the use of an SD or HD solid state recording device did not influence image quality (79% for both). The HD camera system outperformed the other camera systems and was the only camera system to observe over 80% of the bars (89%; 64 out of 72 bars). The high definition camera with the HD digital solid state recording device observed 10% more bars than the SD camera with either of the solid state recording devices (89% and 79%, respectively) and over 20% more bars than the original system (89% and 68%, respectively).

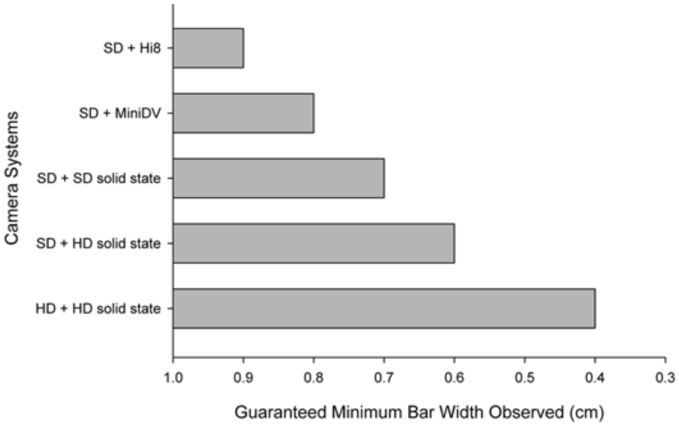

Figure 4: Guaranteed minimum bar widths (all frames observed three bars) each camera system observed when the CRIB was 4.0 m underwater from the camera. The five camera systems include: the standard definition (SD) camera and a Hi8 recording device, SD camera and a MiniDV recording device, SD camera and a SD solid state recording device, a SD camera and a high definition (HD) solid state recording device, and a HD camera plus a HD solid state recording device.

The minimum bar width observed also improved with recent advances in image resolution and solid state recording devices (Figure 4). The original camera system (SD + Hi8) as well as its immediate successor (SD + MiniDV) were able to detect bar widths of 0.9 cm whereas the solid state recording devices with the same camera were able to detect smaller widths (SD solid state recording device = 0.7 cm; HD recording device = 0.6 cm). The high definition camera system (HD + HD) by comparison was consistently able to detect bar widths of 0.4 cm, outperforming all other systems. However these results occurred under optimum conditions and were not subjected to low light levels and moving water as found in underwater environments.

Field Trials

The original camera system, using a Hi8 camcorder, consisted of moving parts (Hi8 tapes, tape tracks). The underwater environment in which this camera system was used is not entirely compatible with this type of technology. While deploying the system, the recording housing can often come into contact with the stern of the vessel causing any components inside the system to be bumped. The high definition camera system developed in this study uses a recording device that is solid state, using a memory card rather than a tape, to digitally record the observations. Solid state reduces the chance of the recording device stopping unexpectedly when bumped and eliminates the requirement to ‘digitize’ footage upon return to the laboratory.

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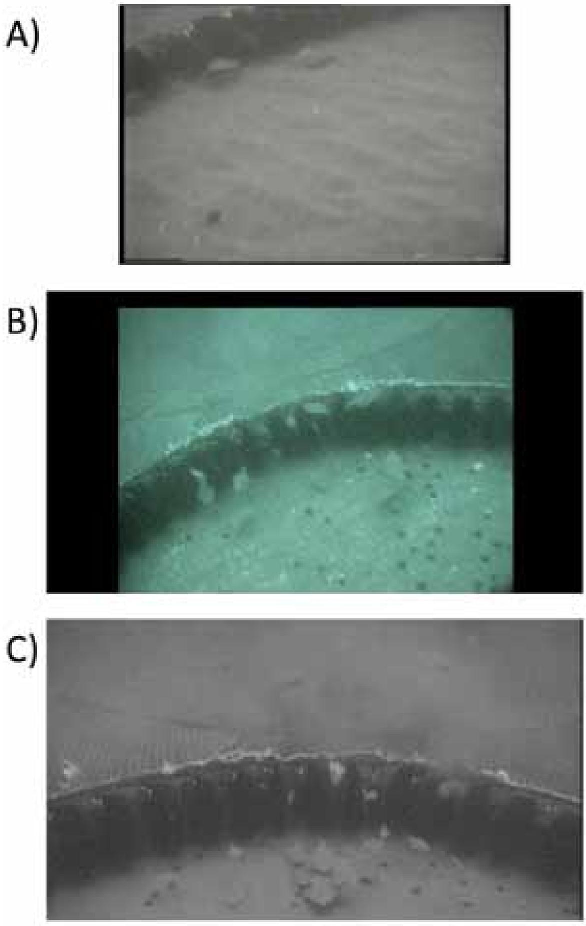

Figure 5: Still frames collected from three different camera systems used on the Grand Banks of Newfoundland. Frame A was collected from the SD camera and Hi8 recording device in 1998 [Legge, 1998]. Frame B was from the SD camera and Frame C from the new HD camera, both recorded using the HD recording device in 2010.

Noticeable differences in image quality were observed among the video camera systems when mounted on the headline of a bottom trawl (Figure 5). Frame A shows a still frame from video collected using the SD Kongsberg Osprey CCD camera and Hi8 recording device (SD + Hi8) collected more than a decade ago [Legge, 1998]. Frames B and C show still frames collected during this study, including the same SD Kongsberg Osprey CCD camera connected to the HD solid state recording device (SD + HD; Frame B), and finally the HD Splashcam Seatrex camera connected to the HD solid state recording device (HD + HD; Frame C). Caution is advised when comparing the frames as the images were collected from different tows and in one case a different year (i.e., Frame A). Nonetheless, the comparison illustrates the evolution in image quality with technological improvements over time and supports the empirical observations from the lab trials. Successful identification of yellowtail (to the species level) was accomplished 72% of the time (72 out of 100 fish) when using footage from the HD solid state camera system compared to only 46% of the time (23 out of 50 fish) when using footage from the SD solid state camera system, representing a significant improvement in underwater camera systems. A small amount of observations were recorded for the SD solid state camera system because only 50 individuals were observed rising from the seafloor due to footage being out of focus.

As a result of these improvements, high definition (HD) cameras can now be used in the field of fish capture research due to technical advances in their minimum illumination levels. Several of the more common types of self-contained underwater camera systems [as used in Castro et al., 1992; Weinberg and Munro, 1999; Albert et al., 2003] have lower minimum illumination levels than the high definition camera system described here, and are currently better alternatives for very low light environments and night observations (Figure 6). It is anticipated that in the next few years the technological improvements seen in CCD cameras from 1993-2004 [Graham et al., 2004; Figure 6], such as increasing minimum illumination levels from 1 lux (the same as the high definition camera) to 10-4 lux, will also occur in HD camera systems. However, until these developments occur and permit high

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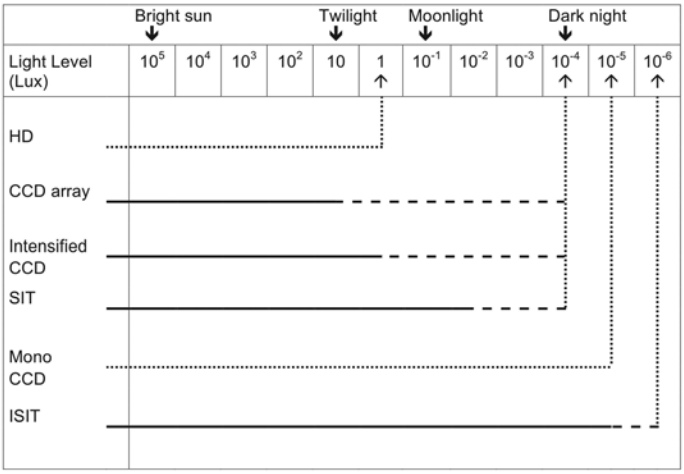

Figure 6: Minimum illumination levels for various camera types. Updated from Graham et al. [2004] to include high definition cameras. The solid lines are the camera minimum illumination in 1993; dashed lines indicate minimum illumination in 2004; and the dotted lines indicate the current minimum illumination. (CCD: charge-coupled camera; SIT: silicon-diode intensified target; ISIT: intensified SIT)

definition technology to be used in very low light observations, current high definition camera systems will still require independent illumination for dark underwater environments.

CONCLUSION

This study developed a simple method to test the performance of underwater camera systems in a laboratory setting and demonstrated the value of HD over traditional SD camera systems. While HD may not be suitable for all fish capture studies, this study documented its ability to discriminate flatfish to the species level with a high degree of certainty, something not previously capable of SD systems. The study also indicates that small improvements in the upgrade of a camera system (i.e., upgrade to a solid state recording device) will significantly improve the image quality. Even with the challenges of real time footage, it is expected that the high definition camera system should outperform the original camera system and that using a solid state recording device would be an improvement for *in situ* measurements of fish and fishing gears. It is hoped that the findings of this study will help guide the upgrade of future camera systems and whether HD is worth the upgrade or just upgrading the recording device is sufficient. Although developed for behavioural research on bottom trawls, the camera system is highly flexible and can be applied to stationary gear, such as pots or traps, and other forms of mobile gear.

ACKNOWLEDGEMENTS

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