Rev Fish Biol Fisheries
DOI 10.1007/s11160-006-9011-0

ORIGINAL PAPER

Video and acoustic camera techniques for studying fish under ice: a review and comparison

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Received: 27 April 2006 / Accepted: 30 June 2006

Abstract Researchers attempting to study the presence, abundance, size, and behavior of fish species in northern and arctic climates during winter face many challenges, including the presence of thick ice cover, snow cover, and, sometimes, extremely low temperatures. This paper describes and compares the use of video and acoustic cameras for determining fish presence and behavior in lakes, rivers, and streams with ice cover. Methods are provided for determining fish density and size, identifying species, and measuring swimming speed and successful applications of previous surveys of fish under the ice are described. These include drilling ice holes, selecting batteries and generators, deploying pan and tilt cameras, and using paired colored lasers to determine fish size and habitat associations. We also discuss use of infrared and white light to enhance image-capturing capabilities, deployment of digital recording systems and time-lapse techniques, and the use of imaging software. Data are presented from initial surveys with video and acoustic cameras in the Sagavanirktok River Delta, Alaska, during late winter 2004. These surveys represent the first known successful application of a dual-frequency identification sonar (DIDSON^{TM}) acoustic camera under the ice that achieved fish detection and sizing at camera ranges up to 16 m. Feasibility tests of video and acoustic cameras for determining fish size and density at various turbidity levels are also presented. Comparisons are made of the different techniques in terms of suitability for achieving various fisheries research objectives. This information is intended to assist researchers in choosing the equipment that best meets their study needs.

Keywords Acoustic camera · DIDSON · Fish surveys · Video · Ice · Sagavanirktok River · Alaska

Introduction

In northern latitudes, winter is a difficult time to study fish because of ice cover on lakes, rivers, and streams. The surface ice cover, which can be >2 m thick precludes employing observation techniques typically used in open water (e.g., snorkeling and visual observation by shoreline

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observers). Telemetry is often used to locate fish during winter but is limited to transmitter-tagged fish. In these cases, habitat and behavior are not determined, and untagged fish are not detected. When a surface ice cover is present, the only way for researchers to determine fish densities, behavior, or habitat is with specialized viewing gear lowered through holes in the ice.

Some researchers have used underwater video cameras or fish viewing tubes to examine the behavior of fish during winter (e.g., Brown 1999). In arctic sea ice, video cameras deployed through holes in the ice have been used to determine the abundance of ice-associated amphipods (Pike and Welch 1990) and the morphology of sea ice (Werner and Lindemann 1997). However, these techniques have limited applicability in waters of high turbidity.

Other specialized equipment employed in winter fish studies includes side-scan sonar systems and echo sounders. Side-scan sonar systems are used primarily in unfrozen marine waters to image structures at the sea bottom (e.g., Oliver and Kvitek 1984; Whittington et al. 1997) or under-ice to determine its physical structures (e.g., Wadhams 1988; Hop et al. 2000). The resolution they provide is much better for observing still features than for observing moving objects like fish (Fish and Carr 1990). Side-scan is not typically used for fisheries assessments, but it is possible to use in certain configurations.

Researchers have used echo sounders to determine fish density distribution below the ice (Crawford and Jorgenson 1990). Most echo sounders generally cannot determine fish size or shape, and therefore species, although splitbeam systems can determine fish size acoustically with certain assumptions regarding aspect angle, etc. Target strength distributions can be compared to fish sampled lengths for particular species and then species implied for a population provided that the population is comprised of distinct size groups (Crawford and Jorgenson 1996; Foote 1987; Hartman and Nagy 2005).

More recently, fisheries agencies have adapted a sonar-based high-definition acoustic camera to enumerate fish and determine fish presence and size at camera ranges up to approximately 20 m (Belcher 2004). The dual frequency identification sonar (DIDSON™) system, developed originally for the US Department of Defense, creates high-resolution images of its target subjects (Belcher et al. 2001, 2002).

In this paper, we summarize our collective experience with video and acoustic cameras for conducting overwintering surveys of fish under arctic and northern winter conditions. We review equipment and techniques for determining ice and water depth, deployment of camera systems, power and lighting needs, and protection of gear. We also discuss the types of video cameras suitable for working in winter conditions, along with various recording options. Methodologies for using an acoustic camera to gather data on presence, abundance, and size of fish under the ice are presented and we also compare the usefulness of video and acoustic cameras under different field conditions. New technologies as well as more traditional equipment that can be constructed with few resources are described. Our review and comparisons are intended to aid researchers and fisheries managers in choosing the appropriate equipment and techniques for conducting underwater observations of fish beneath ice cover.

Equipment and field techniques

Techniques for determining the suitability of a site for underwater fish observations, preparing ice holes, and deploying equipment are described. We also suggest techniques for protecting power sources and gear in harsh winter conditions. Viewing tools, including viewing tubes, video and acoustic cameras and recording equipment, lighting, and use of the equipment for taking measurements also are described.

Determining study site suitability

When arriving at a possible study site, researchers must first determine if ice thickness and water depth are suitable for conducting a fish survey. When ice thickness and water depth are known, the researcher can assess the likelihood of fish presence. Further, because the type of observation equipment to be used depends in large part on the water depth, the researcher can finalize the sampling strategy to include either video or acoustic cameras.

An effective method for determining ice thickness is to drill a small-diameter hole using an ice auger (as described below). The fastest method for determining water depth without drilling a hole in the ice is to use a battery-powered, digital, hand-held sonar; these are low-cost and reasonably accurate to ±2 cm, although they make no distinction between water depth and ice depth. These units generally work best in clear ice when the ice is <1 m thick; thick ice or ice layered with snow, sediments, and air pockets is difficult or impossible to penetrate with this sonar.

Preparing the ice hole

Because ice thickness varies greatly in boreal and arctic climates and can typically be >2 m by late winter, making ice holes can be challenging. Chainsaws can be used to make larger holes if the ice is not too thick. Stainless steel ice saws ($200 \times 5.5 \times 0.6$ cm, 100 cm blade with 3-cm curved and pointed teeth) are also effective for sawing between drill-holes in <1 m thick ice. For thicker ice, gas-powered ice augers are more appropriate.

A 15.2-cm-diameter auger is often adequate for drilling holes for inserting most video cameras and associated gear. The largest-diameter commercially available ice auger that the authors have found is 25.4 cm in diameter. Often it is useful to make relatively small holes in the ice to check for water presence, to get preliminary depth measurements, or to provide access for small equipment such as water quality probes. Small-diameter 5-cm stainless steel drilling (ice auger) equipment (Kovacs Enterprises, Inc., Lebanon, New Hampshire) is commonly used for this application. To power the augers, researchers typically attach them to cordless drills with a specialized adapter. The auger flights and cutting bits are connected with pushbutton connectors; these can be difficult to remove when exposed to water. A heating source, such as a small propane or butane torch, will quickly melt the ice so that extra flightings can be attached or bits removed. Alternatively, the auger can be powered by a heavy-duty electric drill (preferably rated at 550–650 rpm) or a gas-powered engine drive (Kovacs Engine Drive). When planning field trips, researchers should pack extra cutting bits as well as sharpening tools because bits quickly dull when they hit sediment in the ice or substrates in the stream or lake bed.

Deploying observation systems

Video cameras can be deployed in a relatively simple fashion to view below the ice (Carlson and Quinn 2005). We have used weighted aluminum brackets to lower video cameras into rivers with >2 m of surface ice. These brackets pivot, enabling the camera to view at different angles. For example, cameras with lasers (for measuring sizes of fish and substrate) can be pointed at various angles, depending on the types of variables to be collected (Fig. 1). We have lowered cameras into the water using 1-m sections of 2.5-cm-diameter wooden poles screwed together. The orientation of the camera can be determined by marking the top of the pole.

To maintain the position of the camera once the desired depth is achieved, a tripod with slightly larger-diameter pipe can be fitted over the pole. A set screw holds the pole at the desired position. Tripod legs can be made of thin, slightly flexible metal. The tripod can be used also to position instruments at or near the riverbed for long-term surveys or in areas where border ice is present along the edge of a water body (Fig. 2).

Selecting power sources

When conducting studies in remote areas during winter, supplying power to acoustic and video cameras can be challenging. Cold temperatures decrease the lifetime of batteries, and solar panels may receive little light (none during the arctic winter). The power requirements for all equipment, including lighting, should be given consideration, and ample battery reserves allotted. Large-capacity deep cycle batteries are the most common power source, but they are bulky and heavy and can be cracked easily. The status of batteries should be checked regularly with a voltage meter and load tester.

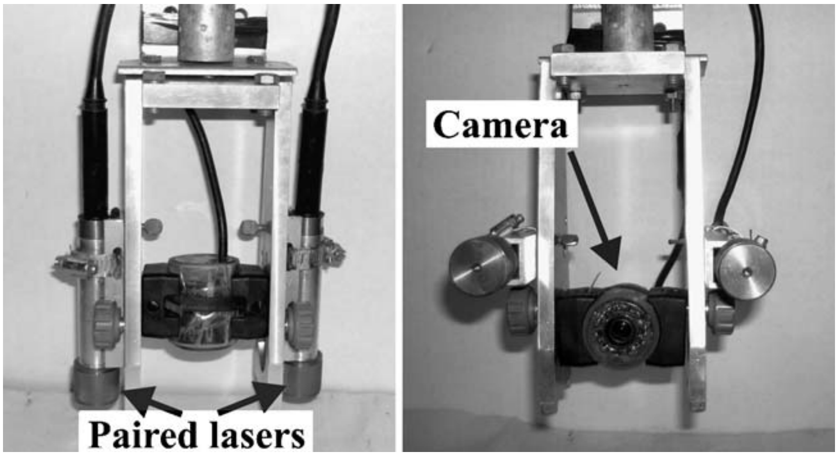

Fig. 1 Pivoting bracket used to deploy video camera and associated lasers

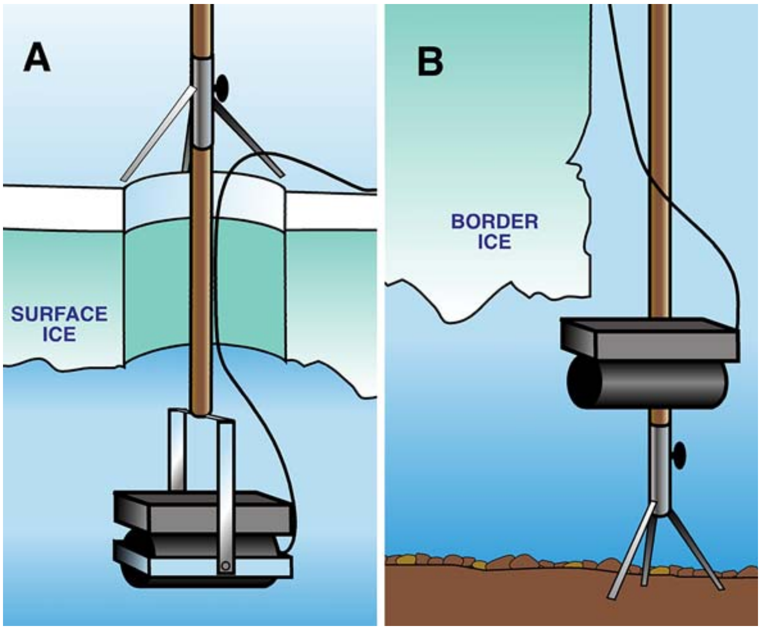

Fig. 2 Tripod and pole for positioning camera below ice or near substrate for border ice deployments along water body edge

Batteries can fulfill a variety of power requirements. Much of the camera equipment (both video and acoustic) and associated gear can be run directly off 12- or 24-V batteries. Some field gear requires 120-V AC power for which a DC-to-AC power inverter can be used to supply 120-V AC power from 12-V deep cycle batteries, although this will shorten the running time of the battery. However, these inverters can be unreliable or damaged easily, so backups and spare fuses should be kept available.

Power consumption by video survey components can be estimated by constructing a power consumption list (see example in Table 1). A key factor in battery selection is the consumption rated in ampere-hours for a given component. The ampere-hour (A h) rating is the total amount of energy that a battery can deliver for 20 h at 26°C before a 12 V battery drops to 10.5 V (i.e., a 100-A h battery can run a 10-A load for 10 h before becoming fully discharged [“going dead”]). At 0°C the A h capacity is reduced by 20%. Deep-cycle marine batteries are the preferred type because they are designed to withstand frequent cycles of deep discharge and recharge.

Table 1 Sample power consumption rate chart for video components for a 24-h period (A h = W/12(V) × 24 = 2 × W)

Component	Watt	Ampere	Ampere-hour
Camera	1.3	0.11	2.6
Lighting	200	16.7	400
Recorder	25	2.11	50
Lasers	1.4	0.12	2.8
DIDSON (24-V)	25	2.11	50
Wireless video	6.5	0.54	13
Total	259.2	21.67	518.4

External light sources added to the component list require a great deal of power. Because underwater video work often is done in remote areas, it is important to know how much effect (watt, W) and power (volt, V) the lighting equipment requires as amperage (A = W/V) for a certain duration (i.e., ampere-hours). Setting the light to the highest output can increase the current draw by a factor of 3–4. The light duration can be extended by decreasing the intensity (W) of the light bulbs, adding battery ampere-hours (e.g., keeping a larger battery at a higher temperature), changing battery type (using lithium batteries instead of lead or nickel–cadmium types), or adding a generator-powered battery charger.

For extended work, cables can be routed to a protected enclosure that contains a recording system. Solar panels can be erected to charge batteries or, if possible, a propane or gasoline generator can be run occasionally to charge batteries.

Protecting gear

Long-term monitoring can be jeopardized by wildlife or human intrusions. Mammals active during winter, such as beavers and muskrats, have chewed through our power and video cables on occasion. Cable concealment and reinforcement are two ways of avoiding data loss. Snow, if available, can be used to bury cables. If equipment is to be left for long periods of time, it should be camouflaged to conceal it from vandals. It is also a good idea to cover cables with snow or color them white, as black cables often are heated by the sun sufficiently to melt them into the surface ice cover. During temperature drops (e.g., at nighttime), the cables will freeze into the ice cover and can become very difficult to retrieve. If cables are to be put under strain, a strength member (such as Kevlar) should be incorporated.

To protect the equipment and enable optimal viewing on-site, a portable weather-resistant shelter is recommended. Heating the shelter (e.g., by propane) will enhance the operating conditions for video recorders and field computers because the recommended lower operating temperature for both equipment types is generally around 0°C. Hot water bottles or chemically based hand warmers also can be used to supply heat. They can be inserted into containers with the equipment or, in the case of hand warmers, taped directly onto gear. Sensitive electronics can be placed in polypropylene-molded plastic cases lined with foam insulation and packed with chemical hand warmers. These cases also will prevent the gear from being damaged due to water exposure or travel over rugged terrain.

Equipment options

Viewing tube

The most simple and inexpensive tool for viewing fish behavior under ice is a viewing tube (Brown 1999). The viewing tube can be constructed of a 1.5-m section of polyvinyl chloride (PVC) pipe (10–35 cm) with Plexiglas adhered to the upper end and a mirror placed at a 45° angle at the lower end. This apparatus makes it possible to view fish through a hole in the ice in clear water. However, it cannot be used for recording observations and is of little use in turbid water or darkness without the addition of lights.

Underwater video cameras

Typical underwater video systems consist of a camera in a waterproof housing attached to a recorder and a power source. The camera range of application can be expanded by adding underwater light sources and laser-based measuring systems (Fig. 3). Many underwater video cameras available today are compact and well suited for most freshwater or marine applications (~12 cm in length and 5 cm or smaller in diameter). The size of the camera is directly related to

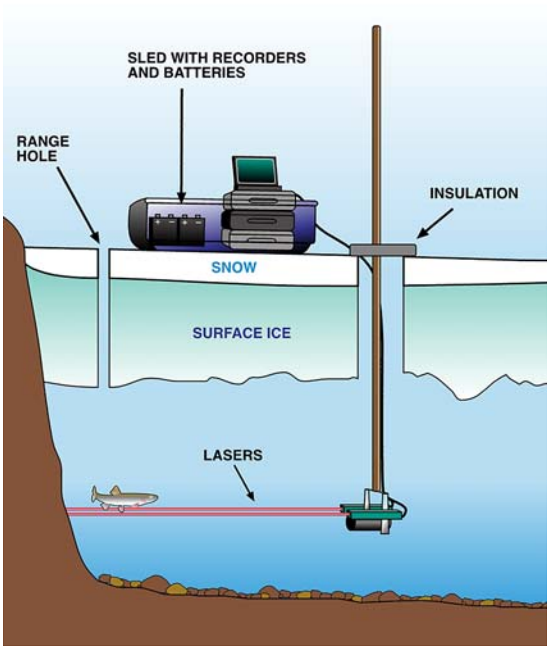

Fig. 3 Camera and lasers deployed with recording system for long-term, small-scale surveys. Camera and lasers can be pivoted to view horizontally or vertically. Bracket is lowered to desired depth using a series of wooden poles screwed together. A pivoting bracket (as shown in Fig. 1) improves camera positioning and stability

the size of the charged-coupled device (CCD) chip. A common CCD sensor size for most video cameras used for underwater surveys is 0.85 or 1.27 cm. The power requirements for underwater video cameras are 12–24 V DC at approximately 110 mA for non-lighted models.

The camera lens size is dependent on the type of survey to be conducted. A wide-angle (2–3 mm) lens can be used for fish detection close to the camera, and a 5–6 mm lens is used for objects at farther ranges. A lens with a relatively large maximum aperture or low f-stop (e.g., f/1.6) is capable of gathering more light than one with a higher F-stop (e.g., f/3.5) and smaller aperture, although the former has less depth of field. Some camera systems have zooming capability, which can be a benefit if the water is clear and sufficient lighting is present.

Monochrome video cameras are best suited for operating at low light conditions; color cameras are less sensitive with lower resolution due to the presence of a color overlay filter. The monochrome cameras are generally also more sensitive to specific wavelengths (e.g., green or red). If conditions are optimal, color cameras can be used to help distinguish species.

Cameras are rated for minimum scene illumination, also known as the lux value; the lower the specified lux value, the less light is required to obtain optimal images. Manufacturers often use different methods to determine the lux value, which is measured at a specific f-stop (normally f/1.4).

Larger scenes can be recorded by using specialized cameras, multiple camera systems, or with remotely operated vehicles (ROVs). There are commercially available video cameras that have built-in pan and tilt mechanisms, eliminating the need to rotate and reposition the camera at the surface. The units also can be programmed to search zones during long-term monitoring. Pan and tilt models are two to three times more expensive than a standard camera. Another option is to use multiple cameras and record using a multiplexer to obtain a composite image of a larger area. Alternatively, the camera can be attached to an ROV, which can be operated with cable and joystick (e.g., Bergström et al. 1992). Micro-class ROVs only weigh 3–4 kg, have a diameter of 23 cm (i.e. less than the largest ice augers), and can be supplied with 90 m of cable (e.g., http://www.rovexchange.com). However, they generally need 100–240 V AC power supply.

Instead of having a cable between the camera and recorder, an alternative option is to incorporate a wireless transmitter that can relay the video signal in air to a remotely situated recording system. These systems operate at 2.4 or 5.8 GHz and can transmit signals from several cameras from 1 to 30 km at a transmitter power output of 50 MW at 50 Ω. A clear line of sight from camera to recorder is necessary, as is a stable platform for the transmitting and receiving antenna dish. The data transfer rate is 30 frames per second (fps) with up to 500 lines of horizontal resolution for digital video. The minimum operating temperature for some units is near – 30°C. Power requirement is 10–14 V DC at 250 mA.

Underwater camera housings come in various styles and materials. Some cameras are fully potted in clear polyurethane, which prevents leakage but precludes performing maintenance and changing the lens. Camera housings typically are filled with dry air or other inert gases to prevent the lens from fogging, and a desiccant pack can be placed inside the housing if space allows. Three commonly used housing materials for freshwater applications are marine-grade aluminum, Delrin, or acrylonitrile butadiene styrene (ABS). Camera housings are generally pressure-tested to between 60 and 100 m, although marine-grade underwater cameras are placed in housings that are rated up to 300 m. Many marine-grade underwater cameras have mini connectors (pluggable underwater) for cable attachment on the camera housing.

Lighting

At northern latitudes, the incoming radiation is reduced during the winter-time and there is no sunlight for about 3 months north of the Arctic Circle. Light levels also decrease in the water column as surface ice thickens and particularly if snow covers the ice surface. A combination of 60 cm of ice and 20 cm of snow may reduce the surface radiation by as much as 99% before the light reaches the water column, and the snow layer is responsible for >95% of this reduction (Gerland et al. 1999). Other factors affecting the penetrating radiation are the properties of the ice, including trapped sediments and, to a lesser extent, air pockets.

Poor light conditions can be augmented with white or infrared (IR) lights. White light is often useful in obtaining substratum composition at low light levels or turbid conditions. The most common type of light used for underwater viewing is quartz halogen lamps, which generally have outputs of approximately 18 lux/W. Small battery-powered dive lights can be used for short-term monitoring (2–3 h).

Infrared lights operating at wavelengths longer than 800 nm can be useful for identifying fish in low light or during the nighttime; most fish species are unaffected by this IR range because it falls beyond their spectral range (Lythgoe 1988). However, IR light generally has poor penetration in open water, and absorption at 800 nm is twice that at 700 nm in fresh water. High-intensity underwater IR lights are expensive and have increased power requirements. To reduce costs, an IR filter can be placed on a white light blocking 99% of the visual spectrum and allowing only IR output. Some manufacturers now have white, colored, or IR light in the form of light-emitting diodes (LEDs) surrounding the lens of the camera. Due to the small size of the LEDs that are used, the light intensity is generally low and most applicable at close-range viewing.

An important consideration is that illuminating light has to travel twice the object distance, and objects close to the lens will be illuminated brightly. In behavior or enumeration studies, care should be taken so that the light source does not deter or attract the fish. The visual pigments of freshwater fish have optimal spectral response within the range of 510–545 nm; coastal marine fish are in the 490–510-nm range, whereas deep sea marine fish are even more blue-shifted (470–490 nm) (Lythgoe 1988; Jobling 1995). However, most freshwater fish have trichromatic vision, with the visual pigments having absorption peaks around 455 nm (blue), 530 nm (green), and 625 nm (red).

Video recorders

Depending on the duration of the recording period, either real-time video (30 fps) or time-lapse recorders can be used. Media for these systems include 8-mm digital recording tapes, 6.5-mm miniature digital video (MiniDV), Video Home System (VHS), and digital video disc (DVD). VHS has long been a standard for video archiving, but because of the size of the tapes and recorders needed, is being overtaken by the smaller 8-mm, MiniDV, CD, and DVD types of recorders. Digital recorders offer many advantages including greater recording resolution (up to 500 horizontal lines), long-term storage, and greater image reproduction capabilities. Digital video films can be stopped at a single, clear image, which can be analyzed on screen or imported to a computer via an IEEE 1394 very fast external bus (e.g., FireWire®) for editing purposes (http://www.ieee.org). DVD recorders are relatively new and have the advantage of recording directly to a DVD, which can hold up to 2 h of video on a 4.7-GB disk. However, there are continuously new versions of DVD equipment appearing on the market (e.g., http://www.dvdrecorders.ws). Digital 8-mm recording tapes are available in up to 120-min lengths for standard play (SP) mode and up to 4 h in long play (LP) mode, whereas MiniDV tapes can hold up to 80 min of video in SP mode. Another option for recording DV is to use a digital video recorder (DVR), which operates using a PC platform to record images to a hard drive. The DVR uses software to control external cameras and is very flexible in that cameras can be programmed to record at certain intervals. Many DVRs have motion detection capabilities along with many other options. DVRs also can be programmed to conduct time-lapse imaging.

VHS recorders capable of recording in time-lapse mode have long been available. Time-lapse recording VHS recorders are relatively low cost and allow for longer recording periods using a time-lapse system. The user can select the appropriate recording period based on the duration of the study, although best results are achieved with a higher recording rate at the expense of recording time. Some time-lapse systems can record up to 96 h or more depending on tape used. Standard VHS and time-lapse video or any analog video format can be transferred to a computer or DV format using analog-to-digital media converter equipment.

To maintain higher image quality during long-term monitoring, several standard non time-lapse VHS recorders can use the same camera source and be programmed to turn on and off in sequence. For example, one of the authors has used a bank of multiple VHS recorders for surveys of fish behavior. Recorders can be placed in an enclosure on a sled (similar to that shown in Fig. 3) and can run several days when timed to turn on an hour or so before sunrise and turn off an hour after sunset. A standard recording rate or 30 PPS (pictures per second) can be used to maintain image quality.

Camera range estimation

An estimate of fish density can be made by using the camera's range information. However, camera viewing range can be difficult to measure without an object of known distance from the camera. A long section of 2.5-cm-diameter white PVC (or other material) can be lowered down a 5-cm-diameter hole at measured distances from the camera. Depending on the size of the CCD array and lens used, the camera's field of view can be determined. Additional holes can be drilled in a direction away from the camera, and the range determination can be repeated until the pole is no longer visible.

Lasers

Paired lasers can be used to aid in the measurement of fish size and swimming speed (Nelson and Claireaux 2005). A typical underwater laser suited for use in shallow freshwater systems consists of a Class III B diode, with a power output of 5–20 mW at a wavelength of 635 nm and a beam size of 0.8–1 mm. The laser spot diameter or line generated laser can be adjusted and focused at a desired range. The range of the laser beams in clear water varies depending on the power output—for example, 1 m for a 5-mW laser and 8 m for a 15-mW laser. Lasers are sealed in a waterproof housing, typically aluminum or Delrin, with optically transparent Lexan windows and wet-mateable connectors. Cables lead to the surface, providing power to the lasers from a small 12-V battery. The current draw for a single 10-mW laser is approximately 50 mA.

Several types of lasers produce beams of different colors. Red (650 nm) and, to a lesser degree, green (550 nm) are commonly used colors for lasers because they fall within the higher regions of the spectral response curves of typical monochrome and color cameras. Some fish species may be repelled by colored lasers emitting in their visual spectrum. The authors have noted that red lasers (635 nm) produced avoidance reactions in broad whitefish (*Coregonus nasus*). If the spectral response of a species of interest is known, then selecting lasers that operate at the lower or higher spectrum of the wavelength is recommended.

Object size and fish swimming speed measurements

To determine fish size, two lasers typically are mounted in parallel next to the camera some distance apart. The lasers shine onto fish, substrate, or other structures and allow for scaling of these objects during later analysis. After video images are taken in conjunction with the lasers, the size of the fish and other objects can be determined using imaging software. Images from digital sources can easily be downloaded to a computer and saved as digital movie files.

Fish size and swimming speed also can be determined using stereo-video methodology. This method incorporates two cameras positioned side by side and separated by a set distance. When objects move through the camera's field of view, exact locations (x, y, z coordinates) in three-dimensional space can be ascertained and fish movements and size can be determined. Using this method requires a video multiplexer or recording directly to a computer system so that paired camera images can be stored simultaneously (Trudel and Boisclair 1996; Lines et al. 2001).

Acoustic cameras

Many lakes, rivers, and streams are too turbid for effective use of video gear to examine fish and fish habitat. Although turbidity rates often decrease in the winter, many large rivers still carry high sediment loads, and midwinter floods are common in smaller streams (Brown et al. 2001; Brown 1999; Harvey et al.1999). Acoustic cameras have been designed to substitute for lower-resolution video systems in turbid or dark waters.

The Dual frequency IDentification SONar (DIDSON) acoustic camera is a high-frequency multi-beam sonar with a unique acoustic lens system designed to focus the beam to create high-resolution images. The sonar was developed by the University of Washington Applied Physics Lab (http://www.apl.washington.edu) and is distributed by Sound Metrics Corporation (http://www.imagingsonar.com). The DIDSON has two frequency modes, which allows flexibility in resolution and range. The system's highest spatial resolution, available at shorter ranges (0 to 12 m), is achieved using 96 individual 0.3° × 12° beams operating at 1.8 MHz. At longer ranges (up to 30 m), the system uses 48 individual 0.6 by 12° beams operating at 1 MHz. The DIDSON is capable of operating at 4–21 fps and has a 29° field of view. Fishes within 1–12 m of the device are usually of sufficient resolution for size measurements, and their undulation and swimming direction can be observed. A standard NTSC (analog TV) output signal of the sonar screen can also be viewed and recorded onto any recoding device.

The DIDSON has been used for numerous fisheries investigations in both freshwater and marine environments. The freshwater applications range from salmonid smolt behavior and passage studies at hydroelectric dams (Johnson et al. 2003; Mueller et al. 2003) to adult fish counting in rivers and streams (Maxwell and Gove 2004), as well as salmon spawning surveys (Tiffan et al. 2004).

Species identification is not always possible when using the DIDSON, and this is especially true when fish species are morphologically similar (Belcher et al. 2001; Weiland and Carlson 2003). A combination of video to classify species and the DIDSON to estimate fish numbers and size proved to be effective for estimating fish occurrences during winter studies conducted by the authors. For other winter survey studies, the DIDSON may also be useful for locating fish under the ice in areas of low fish density. Smaller fish (5 cm and larger) can be detected at ranges up to 10 m.

Using the DIDSON's software measuring tool, fish length can easily be determined when the fish aspect is perpendicular to the sonar. The spatial resolution of the sonar is dependent on the range to the target. At a range of 1 m, the resolution of the measuring tool is very good (±0.5-cm accuracy in length determination) using the 1.8-MHz mode, and slightly poorer using the 1.0-MHz mode. The maximum range in the 1.8-MHz mode is 12 m. At this range, the accuracy decreases linearly to 6 cm, using the 1.8-MHz mode, and decreases linearly to 12 cm using the 1.0-MHz mode. The maximum range in the 1.0-MHz mode is 30 m, and the resolution decreases linearly to ±30 cm at this range. This is accompanied by a decrease in image resolution associated with the decreased number of beams and the increased beam width and spacing (Belcher et al. 2001; Belcher 2004). In a controlled lab test at Pacific

Northwest National Laboratory (PNNL) in 2002, three fish species ranging in length between 137 and 502 cm were measured using the DIDSON measurement tool to accuracies of 2 cm at ranges up to 6 m (Weiland and Carlson 2003).

The DIDSON's software allows the user to examine fish behavior and to enumerate fish. When post-processing, fish numbers can be determined by slowing down the frame rate and counting fish in zones as the sonar is rotated. When working in a river system where fish move from one location to another, the number of fish passing a specific site can be estimated using the fish counting option and echogram within the program. Fish behavior, such as schooling and their associations with habitat structures, can also be determined.

Due to the DIDSON's narrow field of view at close range, video cameras with a wide-angle lens are better suited for determining fish presence in the near field (<1 m). As the range to objects increases, the DIDSON coverage area also increases, optimizing detection at ranges far exceeding those of CCD cameras (Table 2).

A similar relatively new sonar system which was designed for multi-beam hull inspection is the "Proviewer 2D" imaging sonar made by BlueView Technologies$^{\text{TM}}$ (blueviewtech.com). This sonar operates at lower frequency (450 kHz) than the DIDSON and provides a wide field of view (45–50°) and a longer maximum range of 137 m, but resolution is lower than the DIDSON due to the wider beam widths. We are not aware of any published studies using this system to conduct fisheries studies although fish detection, sizing and tracking are possible at lower resolution than that of the DIDSON. The cost for this system is ~20 k.

Winter field comparison of video and acoustic cameras in an arctic river

Depending on the field setting and the types of data to be collected, a basic video system, a DIDSON or a combination of the two might be utilized. To evaluate the usefulness of the DIDSON under the ice and compare it to video cameras, the authors applied it during late winter 2004 for identifying fish-overwintering areas in the Sagavanirktok River Delta of northern Alaska and in the near-shore zone of the Beaufort Sea. Prior to this evaluation, the DIDSON had not been used under the ice. Ice thickness was about 2 m, and the water was clear (1–2 nephelometric turbidity units [NTU]). Snow cover on top of the ice ranged from 0 to 1 m. The sonar unit is sensitive to low air temperatures and must be kept above −4°C due to a saline liquid-filled lens.

The rationale for using the DIDSON in this environment was to increase the probability of detecting fish in low light environments, estimating fish abundance, and obtaining fish lengths. Video cameras were used in conjunction with the DIDSON at certain sites with larger pools and at water depths exceeding 1.5 m.

A custom bracket was used to deploy the DIDSON in a vertical orientation for lowering, which allowed the sonar to pivot once below the hole to achieve a proper aiming angle (Fig. 4). As in a video camera survey, the pole could be rotated to scan the area. We found that lowering the unit to just below the ice surface and then tilting the lens at an approximate 15° angle down from the horizontal (so that the top of the beam was near the ice water boundary) provided a good aspect for fish detections. The duration of the

Table 2 Comparative relative coverage areas and viewable area of the DIDSON and video camera calculated from standard lens characteristics

	~Coverage area (m^2)	Vertical (m)	Horizontal (m)
DIDSON HF@10 m	10.6	2.2	4.8
DIDSON LF @ 30 m	89.3	6.2	14.4
Optical camera (2.8 mm lens) clear water @ 10 m	152.3	10.5	14.5

HF = high frequency, 1.8 MHz mode

LF = low frequency, 1.0 MHz mode

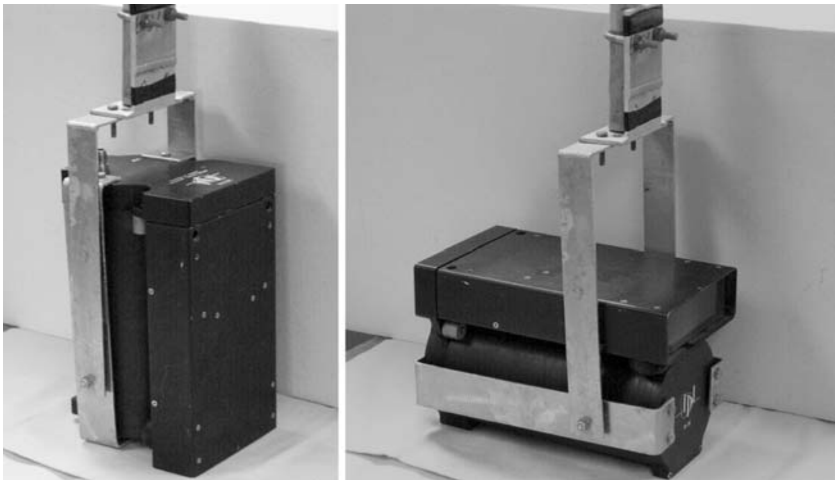

Fig. 4 Bracket used to deploy the DIDSON through the 25.4-cm-diameter ice hole. The DIDSON is placed vertically (left panel) while it is inserted through the hole in the ice. Once the sonar is below the surface ice, a rope attached near the lens is used to adjust the viewing angle (right panel)

DIDSON fish surveys was usually < 1 h due to ice formation in the hole.

During this field deployment, video cameras had an effective viewing range of approximately 10 m while the DIDSON operating in the high-frequency mode at 7 fps allowed us to enumerate fish to a range of 12 m. When we switched to the 1.0-MHz mode (~20-m effective maximum range), we detected and measured adult fish at ranges up to 16 m. The increased effective range enabled us to estimate fish abundance in large overwintering pools without the need to drill additional holes and deploy video cameras.

A combination of video and acoustic cameras were used to maximize the amount of biological information attainable during our survey. Using the video camera alone, we counted 315 adult fish, predominately broad whitefish at one site during 360° camera rotations. Using the DIDSON, we counted an additional 10 fish at a range >10 m.

Use of the acoustic camera was critical for determining the length of fish during this field survey. While the red lasers we tested to measure length produced swim avoidance responses to broad whitefish, the acoustic camera was able to obtain fish lengths without disturbing fish. A total of 145 fish were measured (Table 3) using the DIDSON in both the 1.0- and 1.8-MHz modes. For fish measured with the 1.8-MHz mode, the overall mean fish length was 42.7 cm (SD = 6.4 cm), whereas mean size using the 1.0-MHz mode was 51.8 cm (SD = 11.5 cm).

Combining both of these technologies can be valuable for determining fish length. Determining the length of individual fish with the video camera/paired laser system requires that many fish come into the path of the lasers. However, with the acoustic camera, the lengths of large numbers of fish at different ranges from the camera can be determined easily.

Laboratory comparison of acoustic and video cameras

Imaging in turbid water poses additional challenges for using video systems. To illustrate how water clarity impacts the effectiveness of detecting fish using both video and the DIDSON, a laboratory experiment was conducted at PNNL in 2004. A 4.8-m-diameter pond (0.7 m deep) was modified to guide adult rainbow trout (30–50 cm) around the periphery of the circular tank (Johnson et al. 2004). At the center of the pond, a DIDSON was positioned at mid-water depth along with a monochrome video camera. The distance of the camera to the outer part of the pond was 2.4 m. Turbidity was introduced to the clear water by adding inorganic, fine particulate matter, and the turbidity was monitored at 5-min intervals until the water reached a turbidity level of near 1 NTU. Four separate tests were run, each lasting about 3 h. Counts of fish passing through the outer region were compared for each system.

Table 3 Lengths (means ± SD) of broad whitefish measured using DIDSON during winter study at the Sagavaniktok River, 2004

Range (m)	Mean fish length (cm)				Number
	1.0 MHz	SD	1.8 MHz	SD	
0–3.0	–	–	45.7	5.8	41
3.1–4.0	–	–	39.6	6.8	43
4.1–6.0	–	–	45.7	6.7	13
0–6.0	42.6	8.0	–	–	11
6.1–7.0	53.3	7.2	–	–	16
7.1–8.0	51.8	10.8	–	–	6
8.1–9.0	45.7	15.4	–	–	9
9.1–10.0*	64.0	12.6	–	–	4
10.1–16.0*	71.6	2.1	–	–	2
Total mean	51.8	11.5	42.7	6.4	

* Length overestimated due to loss of resolution

The test concluded that the DIDSON was able to identify 100% of fish passage, even with turbidities exceeding 18 NTU, while the video camera was able to detect fish only when turbidities were below 4 NTU (Fig. 5). These tests showed that video cameras have serious limitations for fish detection in turbid environments.

Decision tables

The specific components required to complete a study will be dependent on the goals of the study as well as field constraints (Table 4). Winter surveys using video and sonar-based assessment tools need to be planned according to study area location, survey duration, size of area to be surveyed, and budget constraints. For small-scale surveys to determine fish presence or absence, a simple viewing tube may be sufficient. For fish habitat association and behavior surveys, additional components can be added (i.e., IR lighting for nighttime viewing or lasers for measuring substrate size). Additional components, such as water velocity meters, water quality probes, or color video cameras to aid in fish identification, can be deployed. All equipment should be tested prior to a winter field project (e.g., in a cold room or under realistic field conditions).

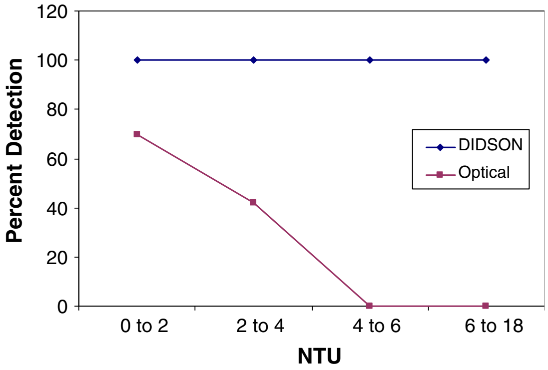

Fig. 5 Tank experiment illustrating the detection of adult rainbow trout using the DIDSON and video camera at increasing water turbidity

Adequate power supplies are essential for conducting winter surveys. It is important to review the video or acoustic camera data soon after the survey period. Often viewing the video in a controlled setting with a high-resolution monitor will reveal distant objects that were not detected while in the field.

Due to the limited experience with using the DIDSON for conducting winter surveys, we have covered the features associated with this sonar system only briefly. Although we had only a short-term deployment of the system in 2004, we found this system feasible for detecting, enumerating, and obtaining fish lengths at ranges greatly exceeding that of video cameras.

Using a combination of acoustic and video cameras may be beneficial when studying fish in moderately turbid waters. Although video cameras have limited range, they can be used to survey fish that are within the visible range of the acoustic camera. This can complement the data obtained with the acoustic camera, which is not always effective for identifying fish species. A

Table 4 Generic decision table based on type of survey to be conducted and data requirements and cost

	Viewing tube	Video camera	Wireless video system	Paired video cameras	Paired lasers	DVR/Time lapse	IR lighting	DIDSON
Fish presence	X	X						X
Long-term recording		X				X		X
Fish size				X	X			X
Fish swimming speed				X				X
Pool size estimate								X
Nighttime fish observation		X					X	X
Turbid water								X
Programmable recording		X		X		X		X
Remote location		X	X					X
Approximate cost (in 100 US$)	0.3–1	2–220	10	1.5	20–3.5	1–30	2–6	800

Table 5 Comparison (+good, – poor) of acoustic and optical cameras when conducting winter fish studies

Application	Acoustic camera	Optical camera with paired lasers
Near field use	–	+
Far field use	+	–
Identifying fish species	–	+
Ease of measuring fish	+	–
Measuring habitat	–	+
Ease of use in cold conditions	–	+
Cost	–	+
Ease of use	–	+
Extended survey period	–	+
Power consumption	–	+
Use in turbid water	+	–
Use in low visibility conditions	+	–
Data storage needs	–	+

comparison of both systems for winter use show that acoustic cameras are most efficient for measuring fish under turbid conditions or when the visibility is poor (Table 5).

This review describes many of the techniques and much of the equipment required to conduct under ice fisheries surveys during the winter. Use of the techniques detailed in this review should provide researchers with the basic background of techniques and technology needed to successfully conduct both short and long-term quantitative investigations in extreme and remote winter conditions. In addition, much of the information on video and acoustic cameras is applicable to researchers interested in observing fish during open water seasons.

Acknowledgements The research on which this paper is based was funded in part by the Minerals Management Service, US Department of Interior, Anchorage, Alaska. The authors extend their appreciation to Duane Neitzel, David Geist, Andrea Currie, and Terri Gilbride of the Pacific Northwest National Laboratory (PNNL), for helpful comments on the manuscript, and to John Stephenson, also of PNNL, for assistance with deployment systems. Pacific Northwest National Laboratory is operated by Battelle for the US Department of Energy under Contract DE-AC05-76RL01830.

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