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[Article]

Monitoring Fish Wheel Catch Using Event-Triggered Video Technology

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Abstract.—In large, turbid rivers, fish wheels are often used as a live-capture technique for monitoring migratory fish runs. After capture in the wheel's rotating baskets, fish are lifted out of the water, slid down a chute, collected in a live-box, and then sampled. To eliminate the handling and holding of fish associated with fish wheel live-boxes, an event-triggered video system was developed so that fish were video recorded during capture and then immediately released back into the river. A magnetic switch, connected to an exit door installed in the fish wheel chute, signaled a computer to videotape passing fish. Periods of no fish capture were not recorded. Reliability and accuracy were evaluated over a 3-year period, 2001–2003. In over 14,000 h of operation and 262,000 recorded fish images, the system failed only once (due to a malfunction of the exit door). Fish counts from the video system were 4% higher than counts from fish wheel live-boxes, mostly because fish were jumping out of the live-box before counting began. Compared with continuous time-lapse recordings, the video system missed 1% of captured fish, mostly small *Coregonus* spp. that passed under the exit door without activating the switch. Subsequent adjustments to the door and software capture settings eliminated undercounting. The advantages of the switch-triggered video system over traditional fish wheels with live-boxes were reduced handling and holding time for captured fish; improved counting accuracy; unattended operation; and lower labor costs. Future developments in image recognition and motion detection software should increase the use of event-triggered video in fishery science.

Fish wheels are commonly used as a live-capture method for fishery management and research in large, turbid Alaskan and Canadian rivers (Meehan 1961; Milligan et al. 1985, 1986; Merritt and Roberson 1986; Link and English 1996). A fish wheel has two or more large baskets (attached to an axle) that are spun by the river's current (Underwood et al. 2004b). Fish are captured in the fish wheel's rotating basket, lifted out of the water, and deposited into a live-box for later handling and processing. Catch statistics on run timing and relative abundance are gathered with fish wheels and used mainly for in-season management of Pacific salmon *Oncorhynchus* spp. Also, fish wheels facilitate fish capture for mark–recapture population estimation (Cappiello and Bromaghin 1997; Cleary and Hamazaki 2003; Kerkvliet and Hamazaki 2003; Underwood et al. 2004a) and radiotelemetry experiments (Milligan et al. 1985, 1986; Eiler 1990). Studies have documented the negative effects from fish wheel capture and holding in live-boxes. Bromaghin and Underwood (2003) found that fish held in live-boxes experienced slower upstream swimming speeds and a decreased probability of recapture at distant upstream locations than immediately released fish. Cleary (2003) concluded that fish captured by a fish wheel showed a measurable physiological effect from handling and tagging. The cumulative negative impact to fish populations from management and research fish wheel projects could be significant. In 2003 alone, approximately 150,000 salmon were caught and released from fish wheel projects in the Yukon River drainage (Tanana and Kantishna rivers: B. Borba and P. Cleary, Alaska Department of Fish and Game, personal communication; Yukon River main stem: P. Milligan, Canadian Department of Fisheries and Oceans, personal communication).

To reduce stress on fish wheel−captured fish, an event-triggered video system was envisioned that would remotely (i.e., with no user present) collect catch data without the need to handle or hold fish in live-boxes. Event triggering is routinely incorporated into photographic systems for wildlife studies (Cutler and Swann 1999) but is rarely applied in fishery research. Event triggers require a mechanism to signal the taking or recording of still pictures or video segments. The triggering device can be (1) a mechanical switch activated by pressure, magnet, tripwire, or sound (Moruzzi et al. 2002; Liebezeit and George 2003); (2) a light beam, infrared, or white-light trans-

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FIGURE 1.—Switch-triggered video system installed on a Yukon River fish wheel. The magnet and switch are shown enlarged in the inset. The enclosure housed a notebook computer, time-lapse videocassette recorder, fuse box, and 12-V battery bank.

mitter–receiver (Koerth and Kroll 2000); (3) a passive infrared sensor (Hughes and Shorrock 1998); or (4) a computerized motion detector (Irvine et al. 1991; Hatch et al. 1998). Triggered systems are most advantageous when the organism to be studied is infrequently present, long-term monitoring is required, or when condensing the amount of recorded material for review and storage is desirable.

In fishery studies, photographic triggering devices are difficult to implement and have been limited in scope. Irvine et al. (1991) used computer software with optical tripwires to generate numerical estimates of coho salmon *O. kisutch* smolts passing through illuminated transparent tunnels. Hatch et al. (1998) used image processing software to edit time-lapse video recordings of underwater, migrating adult salmon passing through fish ladders at hydroelectric dams. These methods use differences in pixel luminescence values between constant background and fish-present video frames to extract fish images from continuous recordings, and require background light levels to be fairly constant and contrasting with the fish's image. Luminescence triggers operate best in situations where background lighting can be controlled (e.g., underwater or enclosed tunnels or boxes). Due to this environmental limitation, a different method was needed to reliably use event-triggered video for monitoring fish wheel catch. This paper describes the design and evaluation of a computerized video system that used a mechanical trigger to digitally record fish passing through a fish wheel chute.

Methods

An event-triggered videorecording system for monitoring fish wheel catch was designed, installed, and evaluated on fish wheels in Alaska's Yukon River drainage from 2001 to 2003 (Figure 1). Fish captured by the fish wheels were passed through a chute, video recorded, and then deposited back into the river. The system was designed to operate in remote areas using 12-V portable power supplies. By 2003, four fish wheels were equipped with the video system. Two wheels monitored the daily catch of fish swimming upstream during the summer and fall seasons (Zuray 2002, 2003; Fliris 2004), and two wheels were part of mark–recapture experiments estimating population sizes for adult migrating salmon (Cleary and Hamazaki 2003; Underwood et al. 2004a).

The video system consisted of an analog camera, computer, magnetic switch, time-lapse videocassette recorder (VCR), lights, and 12-V power supply (Figure 2). A color, charge-coupled-device

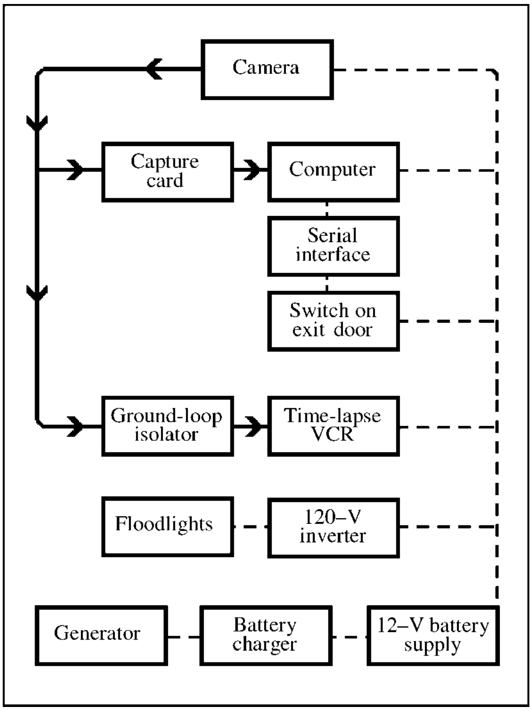

FIGURE 2.—Schematic of the switch-triggered video system. The solid line represents the path of the video signal, and the dashed line shows the electrical power connections. All electrical components were fused between the battery supply and the individual component.

chipset (CCD), closed-circuit-television (CCTV) camera was enclosed in a waterproof housing and aimed into the fish wheel chute from above. The camera had 480 lines resolution, adjustable shutter speed, and external varifocus and auto-iris lens. To provide a contrasting background to the fish's image, the fish wheel chute was lined with 0.3-cm-thick, white, ultra-high molecular weight polyethylene. The camera's shutter speed was set at 1/1,000 s, which produced clear images of sliding fish traveling roughly 2 m/s. The analog video signal from the camera was fed into a universal serial bus (USB) capture card installed in a notebook computer by either a direct coaxial cable connection or a wireless 5.8-GHz transmitter–receiver for distant application; both produced clear images. The capture card digitized the analog video signal into audio–video interleaved (AVI) format, with an image size of 320 $\times$ 240 pixels. The notebook computer had a 700-MHz processor, 256 kilobytes of random access memory, a video card with 8 Mbytes of memory, and 20 Gbytes of hard drive storage. At times, the analog video signal from the camera was also connected to a time-lapse VCR, producing video recordings for system evaluation purposes. A 75-Ω ground loop isolator was needed between the VCR and computer capture card to eliminate noise interference in the video signal. All components were powered by a 12-V, deep-cycle battery bank with a 500 A/h storage capacity. The battery bank was charged using water current and gasoline-powered generators. Two 90-W floodlights, equipped with on–off light sensors, illuminated the video chute during nighttime operation. The entire system required approximately 2.6 A/h (12 V) to operate during daylight hours and 18 A/h to operate during the night.

A triggering device was incorporated into the video system so that only video frames containing fish images were recorded onto the computer's hard drive. Live video from the camera would stream into the computer's memory but would only be recorded if triggered by a magnetic switch. The magnetic switch was attached to an exit door installed in the fish wheel chute (Figure 1, inset). When a fish exited the chute, the exit door would open, activating the switch and sending an electrical signal to the notebook computer through a serial interface (Figure 2). A direct electrical connection or the wireless video transmitter/receiver would send the switch signal to the interface. Salmonsoft FishCap software, a video capture program, was modified to accept the electronic switch signal. Through buffering, video frames held in computer memory before the trigger event could be accessed and recorded by the software. This allowed more flexibility in switch placement (e.g., the magnetic switch could be placed at the exit to the chute and the entire path of the fish through the chute could be recorded; Figure 3). The digitized video recordings of passing fish were compiled in files on the computer's hard drive for later review. To reduce the file size of the digitized recordings but collect sufficient video frames of each passing fish for review, the frame rate of recording, numbers of frames recorded before and after each trigger event, and video compression quality were adjusted using the capture software. A counterweight damper system was installed on the exit door, which slowed the door's descent and prevented multiple switch signals caused by the door bouncing when shut (Figure 4). Adding or subtracting counterweights adjusted the ease with which the door was opened by passing fish.

The video system was evaluated for reliability and accuracy during three summer–fall seasons, 2001–2003. Data were collected on total operation time, number of fish captured by species, and type

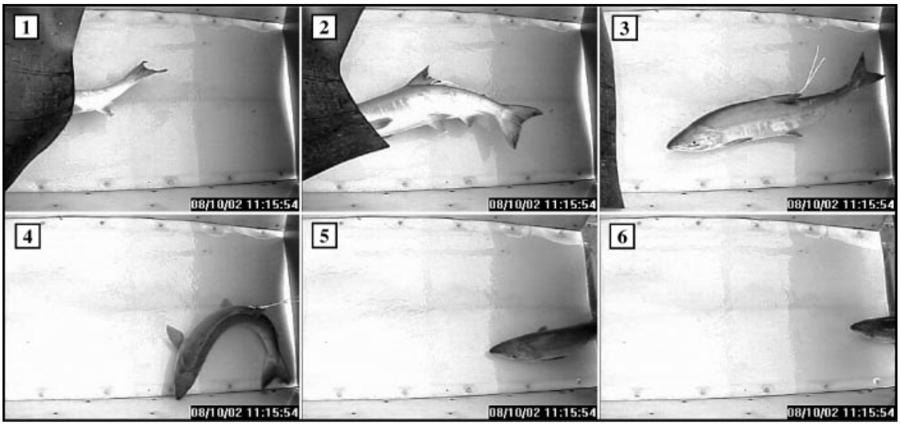

FIGURE 3.—Switch-triggered video recording of a tagged chum salmon sliding down the video chute. Frames 1–4 were recorded before the fish hit the exit door, frame 5 when the fish activated the switch by opening the door, and frame 6 when the fish exited the chute.

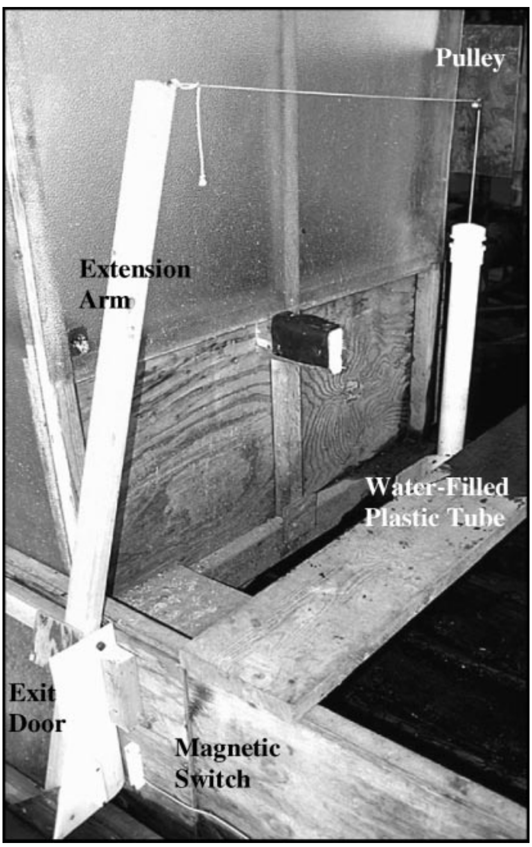

FIGURE 4.—Counterweight damper system installed on the exit door of the fish wheel chute. Nylon line is attached to the exit door extension arm and run through a pulley. The line's other end is weighted with a pill bottle containing lead shot and inserted into a water-filled tube.

and number of system failures. Throughout the testing period, comparisons were made between the number of fish recorded by the switch-triggered video system with (1) fish collected in the fish wheel live-box or (2) fish recorded on continuous time-lapse videotape. A video review program, Salmonsoft FishRev, was used to tally fish by species from the digitized video files produced by the video system. Live-box-captured and time-lapse-recorded fish were tallied manually. Videotapes from the time-lapse VCR were reviewed with an editing VCR equipped with a jog–shuttle for playback. Digitized and time-lapse recordings were synchronized, and each frame was time stamped so corresponding time segments were comparable.

Results

The switch-triggered video system proved to be very reliable for the entire 3-year testing period. Combining data from the four fish wheel projects, the video system operated for over 14,000 h and recorded over 262,000 fish images (Table 1). Salmon species (Chinook, chum, and coho salmon) were the most common species recorded (235,962), followed by Bering cisco, least cisco (14,746), and inconnu (7,145). The magnetic switch failed only once during the entire testing period. The exit door became detached from the video chute from a broken hinge pin, causing the switch to be left on for an extended period of time and consequently burning out the switch.

During data comparison periods, the number of fish recorded from the triggered video system was within 4% of the number of fish counted from fish wheel live-boxes and 1% of fish recorded on time-

TABLE 1.—Catch statistics from fish wheel projects using the switch-triggered video system, Yukon River drainage, Alaska, 2001–2003.

Project[a]	Year	Season	Sample time (h)	Catch			
				Salmon[b]	Cisco[c]	Inconnu[d]	Other[e]
Rampart Rapids catch monitoring	2001–2003	Summer–fall	5,036	93,883	10,183	4,874	2,898
Tanana River catch monitoring	2001–2003	Summer–fall	5,089	46,791	190	12	158
Rampart Rapids tag–recapture	2002–2003	Fall	2,380	51,093	4,320	2,258	1,542
Nenana River tag–recapture	2003	Fall	1,570	44,195	53	1	335
Total			14,075	235,962	14,746	7,145	4,933

[a] Sources are as follows: Rampart Rapids catch monitoring, Zuray (2002, 2003); Tanana River catch monitoring, Fliris (2004); Rampart Rapids tag–recapture, Underwood et al. (2004a); and Nenana River tag–recapture, Cleary and Hamazaki (2003).
[b] Salmon species include Chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, and coho salmon.
[c] Cisco species include Bering *Coregonus laurettae* and least cisco *C. sardinella*.
[d] *Stenodus leucichthys*.
[e] Other fish species (listed from most to least abundant) include broad whitefish *C. nasus*, humpback whitefish *C. pidschian*, longnose sucker *Catostomus catostomus*, burbot *Lota lota*, round whitefish *Prosopium cylindraceum*, northern pike *Esox lucius*, Arctic grayling *Thymallus arcticus*, and Arctic lamprey *Lampetra camtschatica*.

lapse videotape (Table 2). During 1,794 h of live-box capture, the triggered video system recorded 660 additional fish (i.e., of the 19,499 fish recorded using the switch program, 18,839 were counted from the live-box). On occasion, fish were observed jumping out of the live-box before counting began. This, along with a few data recording errors explained the difference between video and live-box counts. Compared with 357 h of time-lapse recordings, the video system missed 34 out of 3,462 fish that passed down the chute. Of the 34 missed fish, 22 were small cisco species that passed under the exit door without triggering the switch. Additionally, 12 salmon were missed because a capture setting in the software—the number of video frames captured after the trigger event—needed to be increased to allow for multiple fish recordings (i.e., more than one fish sliding down the chute at once). Subsequent adjustments to the door and software capture settings eliminated undercounting by the video system.

Discussion

The advantages of enumerating fish wheel catch using the switch-triggered video system over traditional wheels equipped with live-boxes were (1) improved fish counting accuracy, (2) reduced handling and holding times for captured fish, (3) unattended operation for extended periods of time, (4) reduced data recording errors, and (5) lowered labor costs. Also, mark–recapture population experiments successfully incorporated the triggered-video system into tag recovery data collection (Underwood et al. 2004a; B. Borba, Alaska De-

TABLE 2.—Comparison testing of the triggered video system with time-lapse video recordings and fish wheel live-box captures, 2001–2003. See Table 1 for details on projects and fish species.

Project	Sample time (h)	Method	Counts			Comment
			Salmon	Cisco	Total	
Rampart Rapids catch monitoring	152	Trigger	1,344	352	1,696	1 salmon and 22 cisco missed; exit door adjusted
		Videotape	1,345	374	1,719	
Tanana River catch monitoring	205	Trigger	1,732	0	1,732	11 salmon missed; software setting adjusted for multiple fish
		Videotape	1,743	0	1,743	
Rampart Rapids tag–recapture	1,086	Trigger	15,571	0	15,571	Trigger recorded 633 more fish
		Live-box	14,938	0	14,938	Salmon jumped from live-box
Nenana River tag–recapture	708	Trigger	3,928	0	3,928	Trigger recorded 27 more fish; data recording errors
		Live-box	3,901	0	3,901	

partment of Fish and Game, personal communications). Observer error from counting bias (Cousens et al. 1982; Hatch et al. 1998; Jones et al. 1998) and species identification (Haas et al. 2001) is a common problem in fishery enumeration studies. The video system can reduce observer error by digitally storing images of all captured fish in permanent records that can be reviewed, recounted, and checked for accuracy at a later date. Unlike continuous time-lapse recording, switch-triggered video files only contain the images of captured fish. This condensed data set allows fish species to be quickly tallied, especially during periods of low fish passage. The portability of the video system (i.e., running off a portable 12-V power source) gives the application additional flexibility during site selection.

Despite the advantages of the video system, the reliance on technology comes with a price. Some technical knowledge of computer operations and software, electrical circuitry, and video equipment is needed to install and troubleshoot system components. Training employees to operate and maintain the equipment is required. Routine testing of the switch, exit door, and video software should be done to ensure the system operates correctly throughout the sampling period. Fish counts from switch-triggered video files should be compared periodically with visual counts or continuous video recordings to ensure accuracy of the system.

Event-triggered video technology has the potential to improve and widen the scope of fishery research and management studies. Future developments in event-triggering devices and techniques should increase the applicability of this technology. The present limitations are, in large part, due to the aquatic environment, where traditional mechanical triggering devices have limited underwater use. As image recognition and motion detection software improves and filters are developed to exclude erroneous triggering from, for example, reflected light or passing debris, the use of this technology should expand. The reduction in handling and holding time of captured fish using triggered video should reduce stress effects and give added impetus for researchers to develop new and improved video methods. Mark–recapture experiments could integrate an event-triggered video system with passive integrated transponder tag detectors (Prentice et al. 1990), automating the collection of recapture data. Resistivity (Cousens et al. 1982) and infrared (Shardlow and Hyatt 2004) counters, coupled with triggered video, could be used for species apportionment and multiple-target assessments. Studies where fish are channeled through a confined space (e.g., counting fences; Cousens et al. 1982), fish traps (Schmetterling and McEvoy 2000; Harmon 2003), or fish ladders (Hiebert et al. 2000; Schmetterling et al. 2002) may benefit from using a triggered video system over more traditional counting methods.

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