Exxon Valdez Oil Spill
Restoration Project Final Report

Improved Salmon Escapement Enumeration Using Remote Video and Time-Lapse Recording Technology

Restoration Project 00366
Final Report

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Division of Commercial Fisheries
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Study History: A Detailed Project Description "Improved Salmon Escapement Enumeration Using Remote Video and Time-Lapse Recording Technology" was submitted to the *Exxon Valdez* Oil Spill Trustee Council in April 1998. Following review by the Trustee Council and minor revision to the Detailed Project Description, Project 99366 was approved in August 1998. In June 1999, a remote video escapement recorder was deployed on Delight Creek in East Nuka Bay, on the Outer Coast of the Kenai Peninsula. The remote video escapement recorder was operated concurrently with an adult fish weir from 23 June-5 August and from 26 August to 25 September 1999. In July 2000, the remote video escapement recorder was deployed on Port Dick Creek, at the head end of West Arm Port Dick Bay, on the Outer Coast of the Kenai Peninsula. The recorder was operated concurrently with a tidal floating weir from 9 July-2 September 2000. Our efforts focused on counting sockeye salmon at Delight Creek and chum and pink salmon at Port Dick Creek. Estimates of salmon escapement derived by the remote video escapement recorder were compared to those made by the weirs in order to evaluate the accuracy and reliability of the recorder under various escapement scenarios. An annual report was submitted in April 1999. This final report incorporates peer-review comments from the draft final report.

Abstract: We developed a remote video escapement recording system to enumerate adult salmon (*Oncorhynchus spp.*) as they enter their natal streams to spawn. The system is small, relatively lightweight, easily deployed, and operates under its own solar, wind, or hydro-generated power, depending on site characteristics. During 1999-2000 we deployed remote video escapement recorders on Delight Creek and Port Dick Creek, respectively. Our objective was to determine the reliability and accuracy of the remote video escapement recorder for estimating sockeye (*O. nerka,* Delight only), pink (O. *gorbuscha),* chum (*O. keta*, Port Dick only), and coho salmon (*O. kisutch*, Delight only) escapement into two clearwater streams, one of which was tidally influenced (Port Dick Creek). The Delight Creek remote video system underestimated the relative proportions that Dolly Varden (*Salvelinus malma*) and sockeye salmon made up of the total return by 4.8% and 15.8%, respectively. The Port Dick video system overestimated the relative proportion of pink salmon by 1% and underestimated the proportions of chum salmon and Dolly Varden by 0.8% and 0.3%, respectively. While further refinements are expected, we concluded that remote video and time-lapse recording systems are capable of collecting relatively accurate and reliable salmon escapement estimates under a variety of conditions.

Key Words: Chum salmon, coho salmon, Dolly Varden, escapement, *Exxon Valdez* oil spill, pink salmon, remote video, restoration, sockeye salmon, southcentral Alaska, time-lapse recording, weir.

Project Data: Data collected during the course of FY99 and FY00 field activities include water level, water temperature, daily escapement estimates by species, tape review statistics (e.g., # of hrs to review tape), remote video escapement recorder performance (e.g., hours of operation) and maintenance schedules (e.g., tape changes, time-lapse recording intervals). Video images are archived on 160-minute SVHS tapes. All other data are maintained in Excel spreadsheets and Word text documents (Custodian: Ted Otis, 3298 Douglas Place, Homer, Alaska 99603-8027, email: Ted_Otis@fishgame.state.ak.us)

Citation:

Otis, E.O., and M. Dickson. 2002. Improved salmon escapement enumeration using remote video and time-lapse recording technology, *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 00366), Alaska Department of Fish and Game, Division of Commercial Fisheries, Homer, Alaska.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

We evaluated the feasibility of using remote video and time-lapse recording technology to count adult sockeye (*Oncorhynchus nerka*), chum (*O. keta*), pink (*O. gorbuscha*) and coho salmon (*O. kisutch*) as they enter their natal streams to spawn. Although not a target species, Dolly Varden (*Salvelinus malma*) were also enumerated. Accurate escapement monitoring is an integral component of sustainable commercial, sport, and subsistence/personal-use fisheries management, and also for following the recovery of salmon resources injured by the *Exxon Valdez* Oil Spill. Currently, periodic, low-level aerial surveys from fixed-winged aircraft are used to monitor salmon escapements on small clearwater streams in remote areas around the state. Although this technique is fast and efficient, allowing a single observer to cover a large area in a small amount of time, surveys are frequently compromised by a number of variables that are difficult to account for (e.g., observer experience/efficiency, stream residency of target species, variable survey conditions, etc.). The resulting data often provide only a rough index of abundance that may be inappropriate for evaluating escapement goals and productivity trends, or monitoring the recovery of injured resources.

We developed a remote video escapement recording system that was small, relatively lightweight, and easily deployed. The system can operate under its own solar, wind or hydro-generated power, depending on site characteristics. The remote video escapement recorder was designed to capture time-lapse images of adult salmon as they swam over a high contrast substrate panel fixed to the stream bottom below an overhead camera. Because the camera operated continuously during daylight hours, it was potentially capable of providing near-census quality escapement data. In contrast, aerial surveys provide periodic, instantaneous estimates of fish visible to an observer travelling at 100 mph, 300 feet above the stream. Remote video escapement recorders are capable of providing a visual record of an area's environmental conditions (e.g., stream discharge and water clarity), along with the timing and abundance of the stream's salmon returns, all on a few archival videotapes.

In 1999, we deployed a remote video escapement recorder on Delight Creek, the outlet stream of a clear water lake system on the outer coast of the Kenai Peninsula. Delight Lake supports a modest sockeye salmon run (10-30 thousand fish). Five hundred meters upstream of the remote video escapement recorder we erected an adult fish weir, the most accurate means available to estimate salmon escapement. Our objective was to determine the accuracy and reliability of the remote video escapement recording system for estimating sockeye salmon escapement into a small stream. To accomplish this, we compared salmon counts derived by remote video escapement recorder, with those made at the adult fish weir and evaluated the remote video escapement recorder's performance across varying stream discharge and escapement conditions.

The remote video escapement recorder successfully operated 87% (1,095 of 1,257 hrs) of the time it was programmed to run at Delight Creek in 1999. Downtime was caused by a single incident of human error (91 hrs) and consistently poor solar generation conditions at the video site (71 hrs). During this evaluation year it was necessary to locate the video system very close to the weir to reduce migration lag time and enable daily comparisons between the two counting methods. Only 42 hrs were required to review nearly 1,100 hrs of recorded videotape for total fish passage, averaging 38 minutes to review an entire day's escapement (range 18-125 minutes).

An additional 8 hrs were required to review 294 hrs of underwater footage to estimate the species composition of the total return (mean=28 min/d; range=9-48 min/d). Generally, daily video counts tracked well with daily weir counts, particularly after mid-July when we repositioned the overhead camera and upgraded its lens to a more light-sensitive model. After these improvements, the recorder documented 85-87% of the escapement counted through the weir. The remote video escapement recorder was less successful at apportioning the species composition of the total return via an underwater camera. There was a tendency to underestimate the proportion of Dolly Varden (*Salvelinus malma*) and sockeye salmon and overestimate the proportion of pink salmon. We concluded that Dolly Varden were undercounted because they had a tendency to migrate on the stream periphery, outside the view of the underwater camera, when the main channel was occupied by sockeye salmon during the peak of their run. Conversely, we believe the underwater camera over estimated the proportion of pink salmon because they spawned within the camera's fields of view and were sometimes mistaken for new fish transiting the video site. The inflated estimate of the proportion of pink salmon necessarily caused an underestimate of the relative proportion of sockeye salmon.

In FY00, we evaluated the feasibility of using the remote video escapement recorder to count pink and chum salmon in a stream where intertidal spawning occurs. We deployed the remote video escapement recorder on Port Dick Creek, a short intertidal stream on the Outer Coast of the Kenai Peninsula. Port Dick Creek supports modest chum salmon (3,000-5,000 fish) and strong pink salmon (30,000-100,000 fish) returns. We erected the video system approximately 500 m upstream from the mouth of Port Dick Creek. One hundred meters upstream of the remote video escapement recorder we installed a floating weir that could accommodate the widely fluctuating water levels caused by large incoming tides. Using the same methods applied the previous year, we evaluated the video system's accuracy and reliability relative to the weir.

On 15 August 2000 a fire destroyed the cabin used by the Port Dick field crew. The weir was breached for 5 days while the crew was back in Homer assembling camping equipment and supplies to enable completion of this project. Unfortunately, data sheets containing the July 9-22 weir counts were lost in the fire, as were data sheets containing all the weather observations and stream survey results through August 15.

The remote video escapement recorder at Port Dick Creek successfully operated 86% (910 of 1,054 hrs) of the time it was programmed to run. No downtime resulted from insufficient battery power, however, a prematurely worn capstan brake arm in the time-lapse videocassette recorder led to 144 hrs of lost footage. Only 10 hrs were required to review nearly 782 hrs of recorded videotape for total fish passage, averaging less than 16 minutes to review an entire day's escapement. An additional 15 hrs were required to conduct a second review of 403 hrs of videotape (i.e., days with high fish passage) to estimate the species composition of the total return (mean=40 min/d). Overall, video-based escapement estimates accounted for 134,678 (92.9%) of the 144,958 fish counted through the Port Dick weir during 23 July-2 September. However, some performance limitations were discovered when we compared individual day's escapement estimates derived by the two counters. The video reviewer tended to over estimate the escapement early in the run while the daily weir passage was fewer than two-thousand fish. Conversely, later in the run when weir passage averaged 6-10 thousand fish/d, the reviewer was more likely to under count the escapement by about the same magnitude of disparity, resulting in the two accumulative escapement trend lines converging by season's end. Videotape reviewers correctly identified pink salmon as the most abundant species returning (99% video vs. 98% weir), however, they underestimated the number of chum salmon (1% video vs. 1.8% weir) and Dolly Varden (0% video vs. 0.3% weir).

We concluded that remote video and time-lapse recording technology is capable of reliably collecting good quality salmon escapement information. However, we also believe that our current video system could be improved by incorporating real-time, microwave or satellite transmission of digital images back to central locations. Such an upgrade has the potential to remove a weak link in the current system (i.e., the analog VCR), improve video image quality, preclude the need for weekly air charters to change videotapes, and facilitate more timely escapement monitoring for inseason management of commercial, sport, and subsistence fisheries. We intend to pursue these improvements and evaluate whether their cost outweighs their benefit.

INTRODUCTION

Salmon resources and services were injured by the 1989 *Exxon Valdez* oil spill (EVOS 1994, Heintz et al. 1996). Accurate, reliable estimates of spawner abundance are required to monitor the recovery of damaged salmon resources, set appropriate spawning escapement goals for individual streams, and manage commercial, sport, and subsistence/personal use fisheries inseason. Aerial surveys are frequently used to estimate salmon escapements throughout the spill area. However, these estimates are often biased by conditions (e.g., observer experience/efficiency, timing of flights, complex stream habitat, etc.) that are difficult to account for, leading to imprecise indices of spawning escapement (Bevan 1961, Cousens et al. 1982, Bue et al. 1998). Under the best circumstances, when observer efficiency is known and survey flight periodicity is linked with the streamlife of target species to facilitate area-under-the-curve estimates, aerial survey can provide a reliable index of salmon escapement (Hill 1997, Bue et. al 1998). Frequently, however, observer efficiency and streamlife are not precisely known and only one or two surveys are flown per season resulting in an uncertain index that may be inappropriate for evaluating escapement goals and salmon production.

Because accurate escapement monitoring is so important for salmon management and for documenting the recovery of salmon resources and services, the Alaska Department of Fish and Game (ADF&G), Division of Commercial Fisheries (DCF) sought to develop a reliable, cost-effective technique to improve escapement estimation where aerial survey is currently used. Fishery biologists have long considered the potential for photographic enumeration to reduce the bias and error potential inherent to instantaneous counts of salmon escapement derived from towers and aerial surveys (see Kelez 1947, Eicher 1953, and Mathisen 1962). More recently, advanced camera and recording technology has enabled considerable improvement in our ability to observe and count fish remotely (see Beach 1978, Irvine et al. 1991, Collins et al. 1991, Haro and Kynard 1997, Hatch et al. 1994, Hatch et al. 1998, Hiebert et al. 2000). However, all of the remote fish counting systems we are aware of rely on maintenance-intensive components such as fish weirs to funnel fish and internal combustion generators to produce sufficient power. These characteristics are not conducive to remote, unmanned operation along Alaska's salmon streams.

In 1997, we sought to develop a stand-alone system that would not require a weir to funnel fish and could generate its own electricity. We envisioned a system that could be easily set up, visited infrequently for maintenance and video-tape change, and would reliably collect more accurate escapement data than aerial survey indices provide. Borrowing from existing designs and making necessary additions and modifications to suit our needs, we developed a remote-video escapement recorder (RVER) in 1999. The system operates under its own, solar, wind or hydro-generated power, depending on site characteristics. Our RVER is designed to capture time-lapse images of adult salmon as they swim over a high contrast substrate panel fixed to the stream bottom below an overhead camera. Because the camera operates continuously during daylight hours, it is potentially capable of providing near-census quality escapement data. RVER's are also capable of providing a visual record of an area's environmental conditions (e.g., stream discharge and water clarity), along with the timing and abundance of the stream's salmon returns, all on a few archival videotapes.

OBJECTIVES

The detailed project description (DPD) we submitted to direct this research listed the following objectives for FY99 and FY00 activities:

> *FY99: Determine the accuracy and reliability of a remote video system for estimating sockeye salmon escapement in small streams.*
>
> *FY00: Determine the accuracy and reliability of a remote video system for estimating pink and chum salmon escapement in tidally influenced streams where intertidal spawning occurs.*

METHODS

Study Areas

Delight Creek (FY99)

We chose Delight Creek, a small clear water stream on the southern Kenai Peninsula, to evaluate RVER in FY99 (Figure 1). Delight Creek is typical of most sockeye systems where fish are sometimes visible to aerial surveyors only while ascending the outlet stream. Located in McCarty Fjord on the Outer Coast of the Kenai Peninsula (59° 34'N, 150° 15'W), Delight Lake and its outlet, Delight Creek, drain approximately 11.2 km^2 of mostly steep, forested terrain (Figure 2). However, Delight Creek is relatively low gradient, dropping only 15 m over its 3.5-km length before emptying into McCarty Lagoon. Delight Lake has a surface area of 2.8 km^2 and a mean depth of 22 m (Edmundson et al. 1998). It is relatively steep sided and has a narrow littoral zone. The summer discharge from Delight Creek ranged from 0.83 to 4.56 m^3/sec during limnological studies conducted under EVOS Project 98254 in 1997 (Edmundson et al. 1998). The area surrounding Delight Lake is a coastal temperate rainforest with annual precipitation ranging from 30 to 100 cm/yr$^-$ and a mean annual temperature of 2.7° C (Rice 1987).

Geologically speaking, the lake system is very young, having been uncovered by the rapidly receding McCarty Glacier sometime between 1920 and 1925 (York and Milner 1999). During the past 75 years, pioneering aquatic vertebrates and invertebrates have invaded so that Delight Lake has become a relatively productive system, supporting low (~102 mg m^{-2}) densities of macrozooplankton and modest returns of several anadromous fish species (Edmundson et al. 1998). The average escapement of sockeye salmon to Delight Lake in the past 20 years, as determined by aerial survey, is 10,800 fish, while the average total return for the same period is 21,200 (Hammarstrom 2000). Although some sport fishing effort occurs, virtually all of the harvest of surplus fish comes from commercial purse seine vessels operating from late June through August. Modest numbers of Dolly Varden, pink and coho salmon also return to Delight Creek, as do a few chum and king salmon. Air charter operators frequently bring sport fishermen to Delight Creek to harvest coho salmon in September.

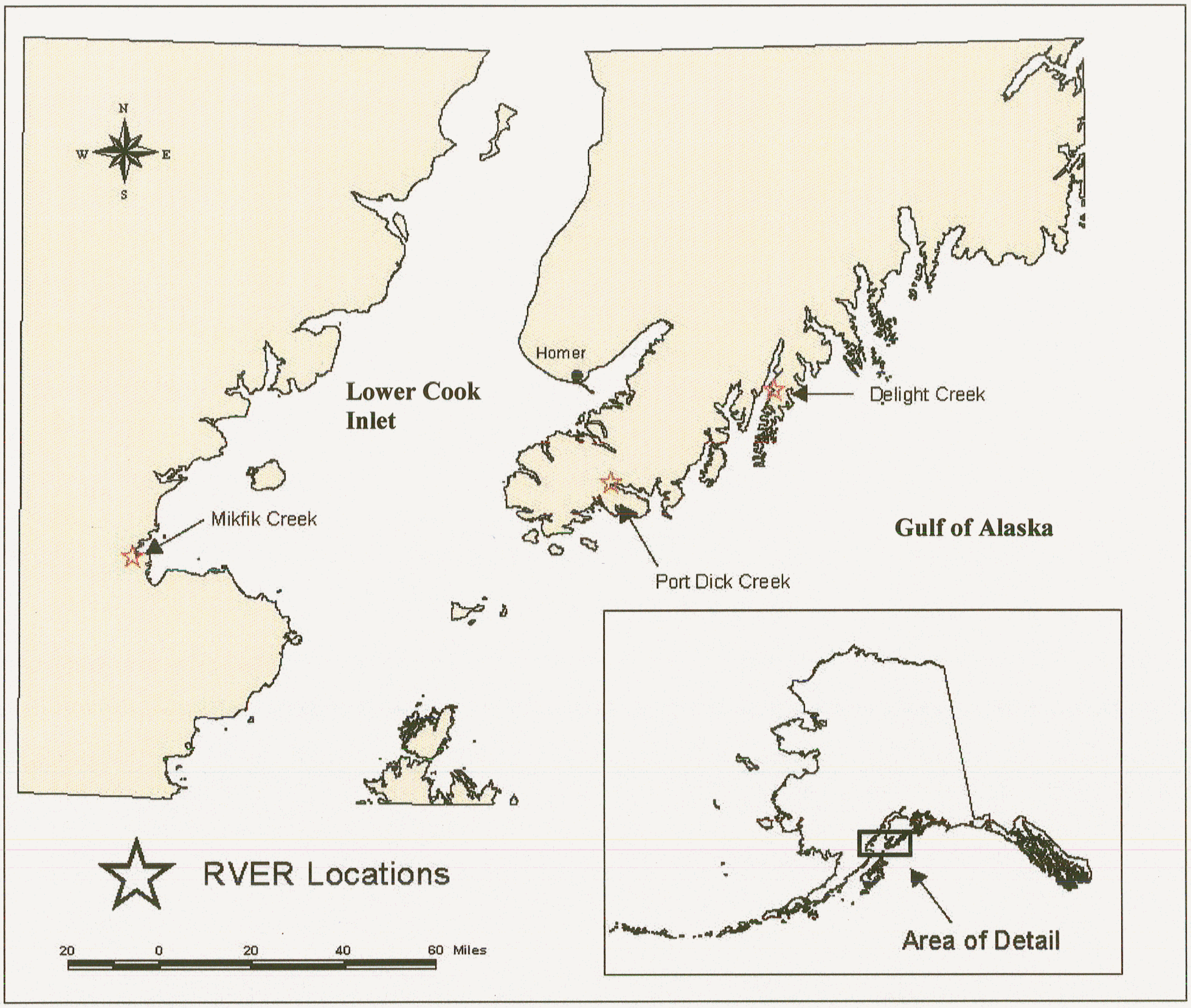

Figure 1. Map showing Lower Cook Inlet, the North Gulf of Alaska, and locations where Remote Video Escapement Recorders (RVER) were deployed during 1999-2000.

Kenai Fjords National Park (KFNP), established in 1980, protects much of the coastal mainland on the southeastern side of the Kenai Peninsula, including much of the area adjacent to our study site. The Port Graham Corporation selected areas within KFNP, including lands bordering Delight Lake and its outlet creek, under the 1971 Alaska Native Claims Settlement Act. Port Graham residents report a long history of subsistence use of the salmon resources in this area, presumably preceding the glaciated period that ended just recently. The Port Graham Corporation finally received title to these selected lands in 1995.

Port Dick Creek (FY00)

Port Dick Creek is typical of the many short, low gradient streams found along the Outer Coast of the Kenai Peninsula (Figure 1). The creek lies within Kachemak Bay State Park and borders Port Graham Corporation lands. It flows about 4.8 km through a steep valley before emptying into the west arm of Port Dick Bay on the northern edge of the Gulf of Alaska (Figure 3).

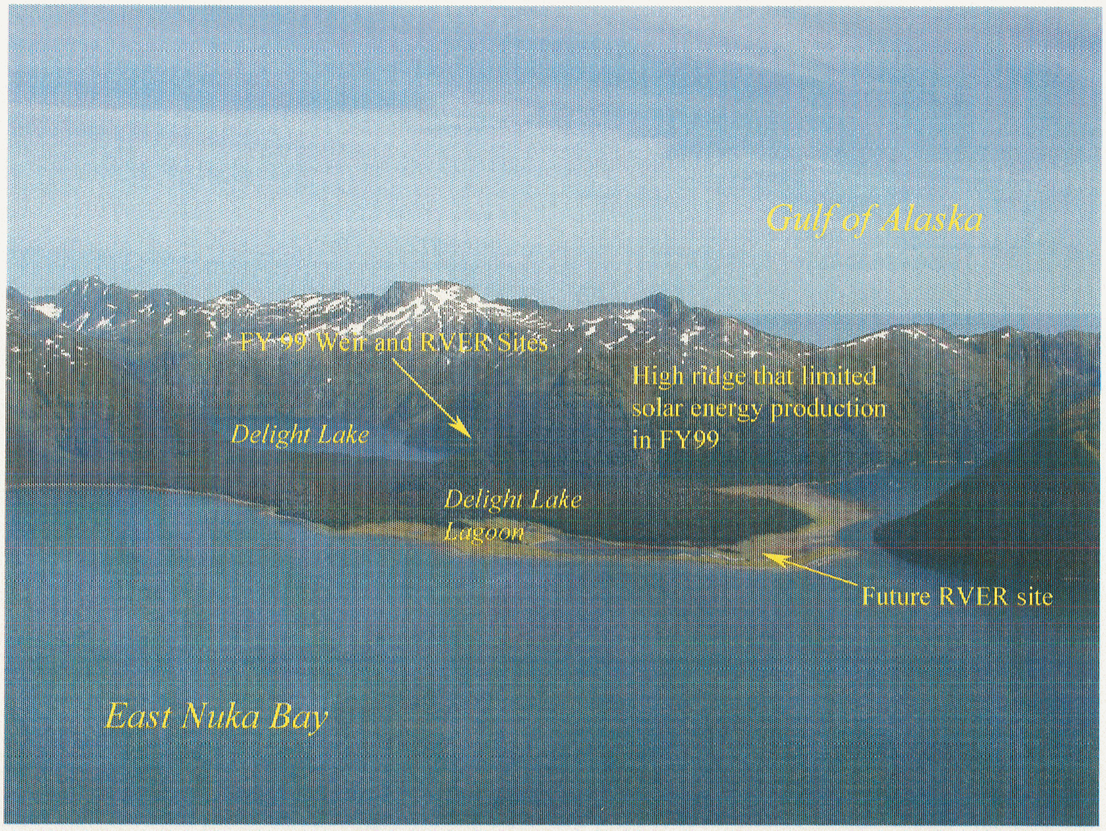

Figure 2. Aerial photograph of the Delight Creek drainage, East Nuka Bay, Alaska, 1999; illustrates relevant features and locations of the weir and video sites.

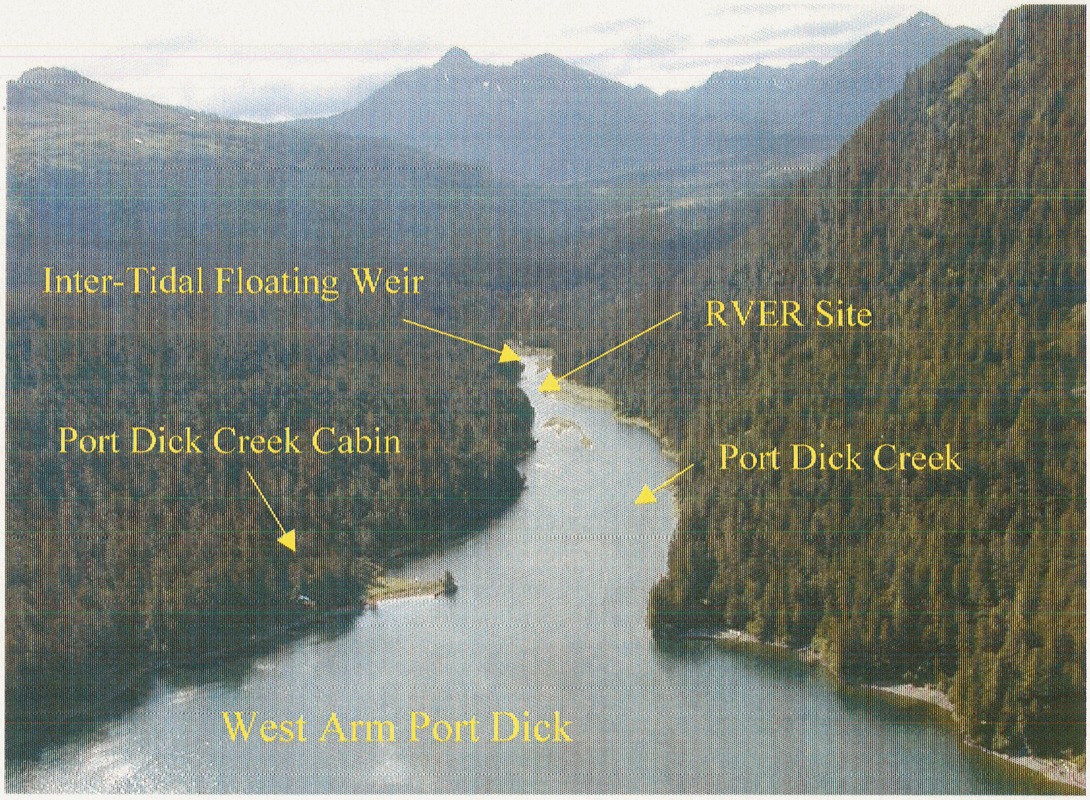

Figure 3. Aerial photograph of the Port Dick Creek drainage, West Arm Port Dick Bay, Alaska, 2000; illustrates relevant features and locations of the weir and video sites.

Annual rainfall in excess of 150 cm supports a dense forest comprised largely of Sitka spruce (ADNR 1994). Spawning habitat in two of Port Dick's tributaries was lost when the surrounding area was uplifted during the 1964 earthquake. A recent EVOS project (99139-A2) successfully restored much of the lost habitat by excavating the streambed back down to the existing water table and stabilizing the stream banks (Dickson and Coble 2000).

Port Dick Creek supports large returns of pink salmon and modest runs of chum and coho salmon. Aerial and foot survey-based indices of escapement in Port Dick Creek during the past 20-30 years have averaged 3,500 chum and 39,000 pink salmon. Coho salmon escapements have never been monitored beyond the end of the pink salmon run. Over 300,000 pink salmon have been harvested by purse seiners in Port Dick Bay during years with strong returns, making Port Dick Creek one of the most productive wild pink salmon streams in Lower Cook Inlet. Pink and chum salmon spawn throughout the lower 3 km of Port Dick Creek, including the tidally influenced portion extending 1 km upstream from the mouth. These characteristics, along with its relatively close proximity to Homer, made Port Dick Creek an ideal study site to evaluate the feasibility of using remote video to estimate pink and chum salmon escapement in an intertidal situation.

Weir

The accuracy of the video system was determined by comparing salmon escapement counts derived from time-lapse recorded videotapes to those obtained at weirs erected upstream of the video sites. Thus, we made the basic assumption that counts derived by the weir, while operational, accurately reflected the actual escapements for each species. Escapement counts derived by RVER were then calculated as percentages of the actual escapement (i.e., weir counts) to characterize the system's accuracy. System reliability (i.e., field durability) was measured by dividing the total hours of recorded videotape by the total number of hours the system was programmed to record fish passage. If the system experienced no "down time", its reliability would be 100%.

In 1999 a conventional tripod/picket weir was erected immediately below the outlet of Delight Lake, at its traditional site, to provide an accurate count of the individual escapements for each anadromous species returning to the drainage to spawn. Each day, June 23-Aug 5, and Aug 26-Sept 25, 1999, two ADF&G crewmembers identified and counted fish as they passed through the weir. In order to optimize our available field time, the weir camp was not operated for 21 days August 6-25, a period coinciding with a lull in fish activity between the sockeye and coho returns. The weir was generally operated only during daylight hours (e.g., 0600-2200, on average). The passing gate was closed each night so fish would not transit the weir unaccounted.

To facilitate counting fish in the intertidal zone of Port Dick Creek, we built a floating weir out of sealed PVC conduit, 2.5 cm in diameter and 3.3 m long (Figure 4). We maintained 2.5 cm spacing between weir pickets with a durable and flexible stringer comprised of two 3.8 cm wide strips of conveyor belt material riveted together every 80 mm along their length. The resulting 1.5-m wide weir panels were connected to one another until a continuous "fence" across the creek was formed (Figure 5). The weir panels were secured to 2.5 cm anchor chain laid across the bottom perpendicular to stream flow. The chain was secured to the bottom with duckbill

Figure 4. Assembling inter-tidal floating weir panels comprised of PVC conduit and flexible stringers. The conduit was capped to be airtight and buoyant, while the stringers maintained 2.5-cm picket spacing.

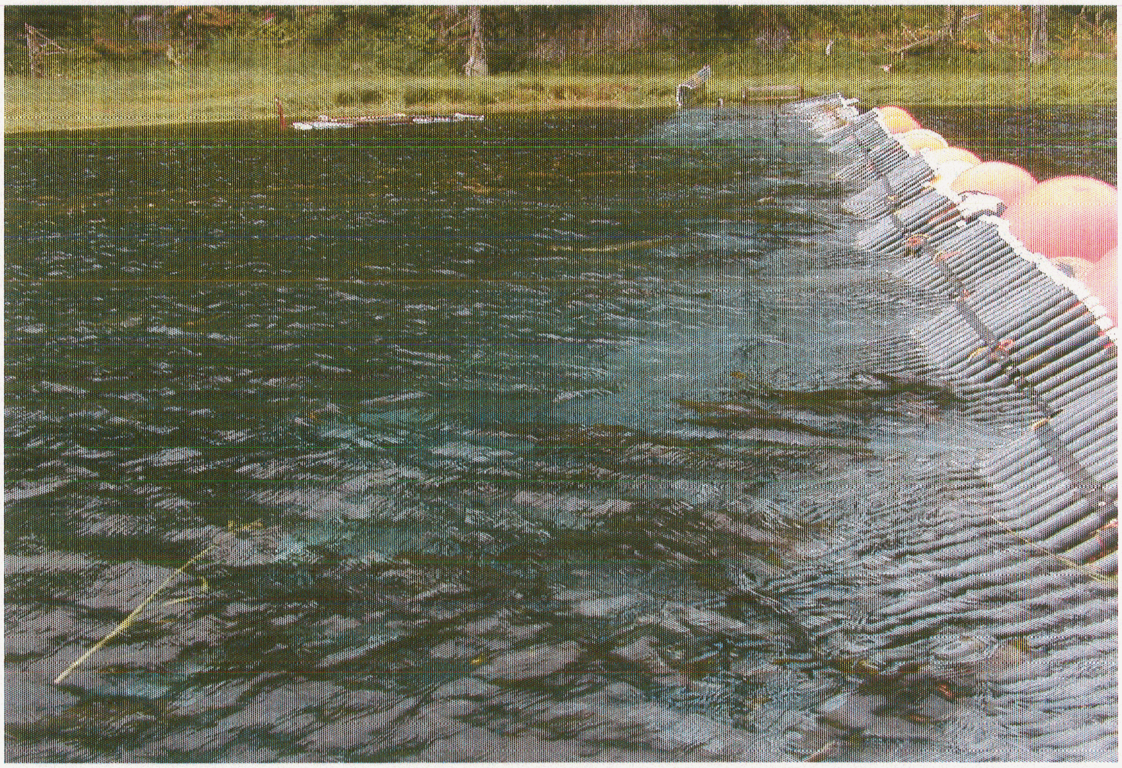

Figure 5. Photograph illustrating the inter-tidal floating weir at Port Dick Creek in 2000. Bladder buoys kept the downstream end afloat during high tides (pictured). Thousands of pink salmon darken the water in front of the weir.

anchors to resist downstream movement. We used bladder buoys to keep the downstream end of the weir afloat during high flows.

The floating weir was erected approximately 600 m upstream of the mouth of Port Dick Creek. Peak high tides raised the water level at the weir site as much as 1.3 m, increasing the maximum depth at the weir site to 2.3 m. Each day, July 9-September 2, two ADF&G crew members identified and counted fish as they passed through the weir. As at Delight Lake, the weir was operated during daylight hours (e.g., 0600-2200, on average) and the gate was closed at night.

RVER

Five hundred meters below the fish weir at Delight Creek, at the first suitable location, we erected the RVER system. Some characteristics that make a site conducive for videotaping fish passage include: 1) relatively narrow (<30 m) and shallow (<1.5 m) channel; 2) smooth, even bottom comprised of cobble-sized substrate; 3) relatively quick, but smooth current flow (>0.6 m^3/sec); and 4) good sources for wind, solar, and/or hydropower. Shallow water is particularly important if water visibility is limiting. Reductions in visibility during storm events should be considered when selecting video sites. Because lakes are effective at settling out many suspended solids, locating the video site close to the Delight Lake outlet (<0.6 km) probably helped us avoid excessive turbidity at our video site during freshets. A relatively smooth even bottom void of large boulders helps reduce surface turbulence, which can dramatically limit the ability of an above-stream camera to see fish. Quick current often helps assure that fish will transit steadily through the video site and not linger or mill around. Milling (i.e., swarming) significantly compromises the ability of video reviewers to track and count individual fish. Good exposure for solar and/or wind generators is also a key feature of a reliable video site.

The Delight Creek RVER was comprised of two high resolution, low lux capacity color cameras (Simrad[1] OE1373; Supercircuits PC33C), a four channel color multiplexer (Chugai CMX-400), a programmable, time-lapse video cassette recorder (TL-VCR) capable of recording 160-minute Super Video Home System (SVHS) tapes (GYYR TLC2100SHD-DC), five 12-V deep cycle batteries (105 Ah), two high output solar panels (BP75), and a 2-stage charge control regulator (Trace C40). Wind and/or hydrogenerators can be used in place of, or in addition to, the solar panels. The TL-VCR and multiplexer were protected inside a large, Pelican®[1] case, which was secured with the batteries inside a bear/weather proof aluminum strongbox located on a riverbank platform above floodwater stage (Figure 6). An overhead camera (sky cam), attached to a steel bracket that was secured to a tree on the riverbank, was positioned approximately 7 meters above the center of the stream. A light green colored substrate panel, comprised of 2.54-cm mesh seine material, was attached to the stream bottom beneath the sky cam to provide a high-contrast background (Figure 7). The second camera was deployed underwater adjacent to the thalweg of the stream to help apportion the species composition of escapement past the video site. Distance markers and a stream gauge were placed in the creek within view of the

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[1] The use of trade names intends only to document the methods used and does not constitute an endorsement by ADF&G.

Figure 6. Photograph illustrating the electronic components of a remote video escapement recorder (RVER) used to estimate salmon escapement in Lower Cook Inlet, Alaska, 1999-2000.

underwater camera on 17 July to document changes in water clarity and stream discharge, respectively.

A slightly modified system was deployed at Port Dick Creek in 2000. Because chum salmon are considerably larger than pink salmon, we predicted reviewers would be able to apportion species composition from the sky cam images alone. Thus, we elected to operate without an underwater camera and multiplexer at Port Dick Creek. We also added a wind generator to supplement the solar panels for the Port Dick deployment. Finally, we designed and built a 4-m tall, steel-legged quadrapod to hold the RVER system above the treeless stream bank to protect it from high tides, flood waters, and inquisitive bears (Figure 8).

Due primarily to power constraints, we did not deploy auxiliary lighting to allow the RVER to monitor nocturnal escapement at either site. Thus, nocturnal migrants could transit the video sites without being documented on video. However they could not transit the weirs, located 100-500 m upstream of the video sites, because the weirs were closed each night. To estimate nocturnal migration past the video site, weir attendants surveyed the stream between the video site and the weir twice daily. These surveys occurred prior to opening and after closing the weir for the day and generally coincided with dawn and dusk, respectively. Accordingly, we were able to estimate the number of fish that migrated during hours of darkness by subtracting the preceding day's dusk stream survey results from the present day's dawn stream survey results. The weir and RVER were operated on approximately the same daily schedules at each location.

Tape Review

At Delight Creek, the multiplexer facilitated recording images from both cameras onto a single SVHS videotape. By playing the tape back through a multiplexer, tape reviewers had the flexibility of viewing either camera full screen or both cameras simultaneously on a split screen. A multiplexer was not used at Port Dick Creek and tape reviewers viewed the single camera full screen. To enable identification of consistently active migration periods, each day was stratified into three roughly equal periods during tape review: dawn-11:59, 12:00-17:59, and 18:00-dusk. For each period, reviewers counted the total number of fish observed transiting upstream beyond the substrate panel and the total amount of time (minutes) required to review that period. They also recorded the playback mode that facilitated the most efficient review, and the hour:minute of dawn and dusk.

Once a total escapement estimate was made for all species combined, the reviewer reanalyzed days with high passage ($\geq$ 2% of the total return) to estimate the species composition of the total return. Sampling the first 15 minutes of every hour, the reviewer counted the number of individual fish of each species observed by the underwater camera at Delight Creek. Using the same video-sampling strategy, reviewers counted the number of chum salmon, identified by their larger size, from the sky cam images recorded at Port Dick Creek. The resulting composition values were used to apportion that day's combined escapement into individual escapements for each species observed. This process was also implemented for several low passage days outside the period of peak passage to account for changes in species composition across the entire run. Average species composition values from adjacent days were used to apportion the total escapement for days that were not reanalyzed for species composition.

RESULTS

Reliability

Delight Creek (FY99)

RVER successfully operated for 1,095 of the 1,257 hrs it was programmed to run in 1999, resulting in 87.1% reliability. This value would have risen to 94.4% had a human error not resulted in 91 hrs of down time. After changing a tape, the VCR was not reactivated from standby mode causing 91 hrs of lost footage. Following this incident, updated tape exchange protocols were implemented to preclude its reoccurrence. The remaining down time (71 hrs) resulted from insufficient solar power, which periodically depleted the batteries until the cameras blacked out requiring freshly charged batteries to be installed. Combining all components, the Delight Creek RVER drew about 3.5 amps/hr, less than the maximum hourly output generated

Figure 7. Photograph illustrating the key components and layout of the remote video escapement recorder (RVER) used at Delight Lake, East Nuka Bay, Alaska, 1999.

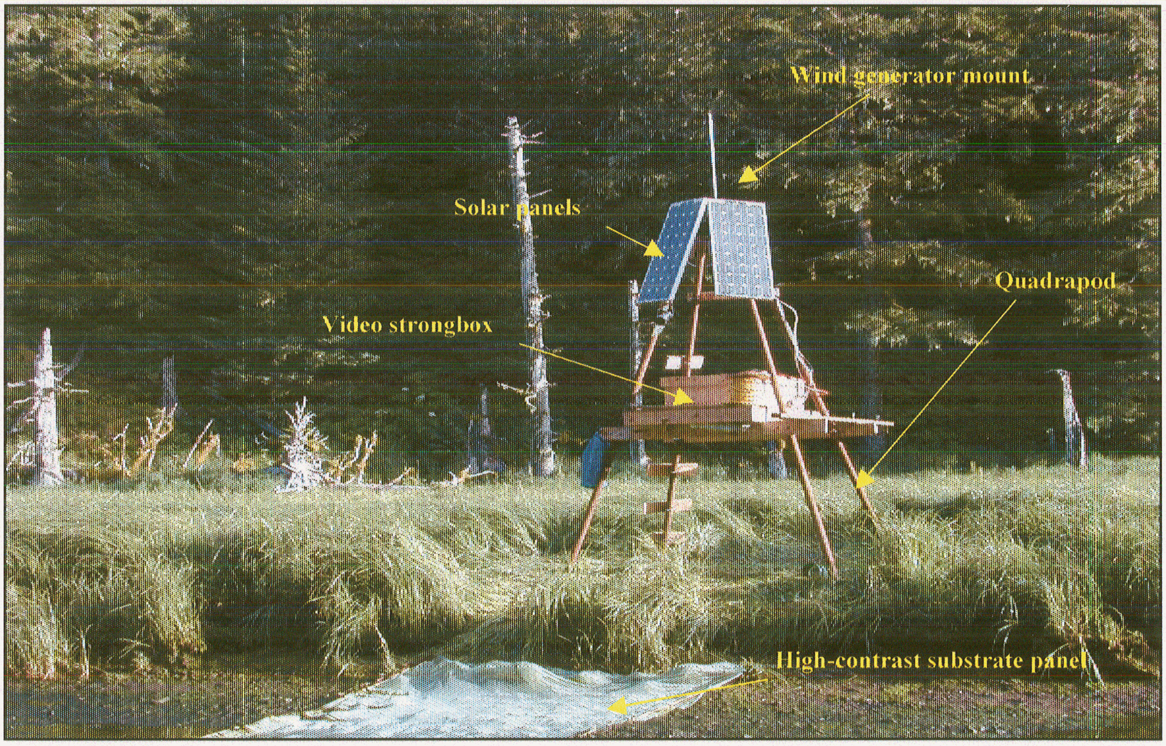

Figure 8. Photograph illustrating the key components of the remote video escapement recorder (RVER) used at Port Dick Creek, Alaska, 2000.

by a single 75 watt (4.3 amp) solar panel. We deployed two 75-watt solar panels at Delight Lake in 1999. However, a high ridge exists south of Upper Delight Creek (Figure 2) and our panels only received a maximum of 6 hrs of direct sunlight per day. A hydrogenerator we tried also was unsuccessful due to insufficient current velocity resulting from the low stream gradient. We did not try a wind generator because thick forest straddled the meandering creek and limited laminar airflow.

Port Dick Creek (FY00)

RVER successfully operated for 910 of the 1,055 hrs it was programmed to run in 2000, resulting in 86.3% reliability. However, neither human error nor inadequate power generation was responsible for the lost video footage in 2000. A prematurely worn capstan brake arm in the TL-VCR apparently led to a tape synchronization problem that rendered some video footage illegible. Because this problem was intermittent, it went unnoticed until all the tapes were reviewed in their entirety post season.

Tape Review

Review of time-lapse recorded videotapes was a somewhat monotonous, but relatively efficient process. Most often, the tape reviewer began by replaying a tape in the fastest mode while viewing both cameras (Delight Lake) simultaneously. This enabled the reviewer to hasten through long periods of blank tape while monitoring both cameras for signs of fish activity. Upon the arrival of fish, the reviewer then slowed the playback speed to enable enumeration. A total of 42 hrs was required to review 1,095 hrs of recorded tape to estimate total fish passage at Delight Creek in 1999. On average, 38 minutes were required to review a day's escapement. However, minutes of review time varied considerably with escapement activity (range 18-125 minutes); high passage days required more review time than low passage days (Table 1).

The process of reviewing videotapes to estimate species composition using the underwater camera was also relatively efficient. Only 8 hrs were required to estimate species composition from 17 days (294 hrs) of recorded videotape, an average of 28 minutes review time per day of escapement (range 9-48 minutes). Combining both reviews, 50 hrs were required to review 1,389 hrs of videotape, equating to 1 hr of review for every 28 hrs of videotape, an efficiency rate of 3.6%.

In 2-hr review mode, only 10 hrs were required to review 782 hrs of recorded videotape to estimate total fish passage at Port Dick Creek in 2000. On average, less than 16 minutes was required to review an entire day's videotape to estimate the total escapement. However, it took another 15 hrs to review 22 days (403 hrs) of videotape to estimate the species composition of the total return (40 min/d). More time was required to review the first 15 minutes of every hr to estimate species composition because a slower playback speed (18-hr mode) was required to distinguish between chum and pink salmon. Combining both reviews, 25 hrs were required to review 1,185 hrs of videotape, an efficiency rate of 2.1%.

We experimented with three different time-lapse recording modes during the 1999 season: 72, 72HD, and 120 hour. High-density mode (HD) enabled more frames/sec than normal recording, which improved tracking of individual fish while retaining extended tape duration. However, there was some accompanying loss in image resolution. Longer time-lapse recording intervals facilitated extended tape duration; however, individual fish were much harder to track across the screen during playback due to the longer interval between recorded frames. Although the multiplexer was necessary to operate two cameras, it introduced an unexpected negative effect on time-lapse recording. We discovered that in any given time lapse mode, the interval between recorded frames was longer when the multiplexer was in use (Table 1). This complicated the process of finding an optimum time-lapse interval that would enable reasonable tape duration and still retain our ability to track individual fish on the screen to avoid double counts. Of the three options we tried, we found that 72-hour, normal mode, provided the best balance between three key factors- tape duration, ability to track individual fish, and tape review efficiency.

Table 1. Time required to review one day of escapement relative to the escapement activity and time-lapse recording mode used at Delight Creek (HD denotes high-density).

Record Mode Time (hrs)	*Recording Interval (w/out multiplexer)*	*Recording Interval (using multiplexer)*	*Avg. Playback Speed*	*Avg. Time (min) to review 1 d*	*Avg. # of fish/d this rec mode*	*Comments*
			Total Fish Passage			
72	1.66 frames/ sec	1 frame every 5 sec	2 hr or A18 hr mode	29	107	fair ability to track individual fish
72 HD	5 frames/sec	1 frame every 2 sec	6 hr mode	57	442	excellent ability to track individual fish
120	1 frame/sec	1 frame every 8-9 sec	2 hr or A18 hr mode	46	299	poor ability to track individual fish (time interval too long)
			Species Apportionment			
72	1.66 frames/ sec	1 frame every 5 sec	2 hr or A18 hr mode	29	107	fair ability to track individual fish
72 HD	5 frames/sec	1 frame every 2 sec	6 hr mode	42	442	excellent ability to track individual fish
120	1 frame/sec	1 frame every 8-9 sec	2 hr or A18 hr mode	17	299	poor ability to track individual fish (time interval too long)
			Total Review Time			
72	1.66 frames/ sec	1 frame every 5 sec	2 hr or A18 hr mode	58	107	fair ability to track individual fish
72 HD	5 frames/sec	1 frame every 2 sec	6 hr mode	99	442	excellent ability to track individual fish
120	1 frame/sec	1 frame every 8-9 sec	2 hr or A18 hr mode	63	299	poor ability to track individual fish (time interval too long)

Only one camera was used to count pink and chum salmon in Port Dick Creek in 2000. This negated the need for a multiplexer and greatly simplified the selection of an appropriate recording interval. In 120-hr, normal mode, the VCR recorded one image/sec and 160-minute videocassette tapes lasted up to 8 days when recording 20 hrs/d. This recording interval enabled effective tracking of individual fish.

Video System Performance

Delight Creek (FY99)

Strong differences in video system performance existed between the early (June 23-August 5) and late (August 26-September 25) season evaluation periods, and also within the early period. Performance differences also occurred relative to the system's ability to estimate total fish passage vs. individual species' escapements through species apportionment using the underwater camera.

In general, video-based counts of total fish passage tracked very well with total weir counts, especially after July 21 when improvements were made to RVER (Figure 9). However, video down time did affect RVER's overall performance. The total escapement estimate derived by videotape was 10,909 fish, 62% of the 17,611 fish counted through the weir (Table 2). Much of

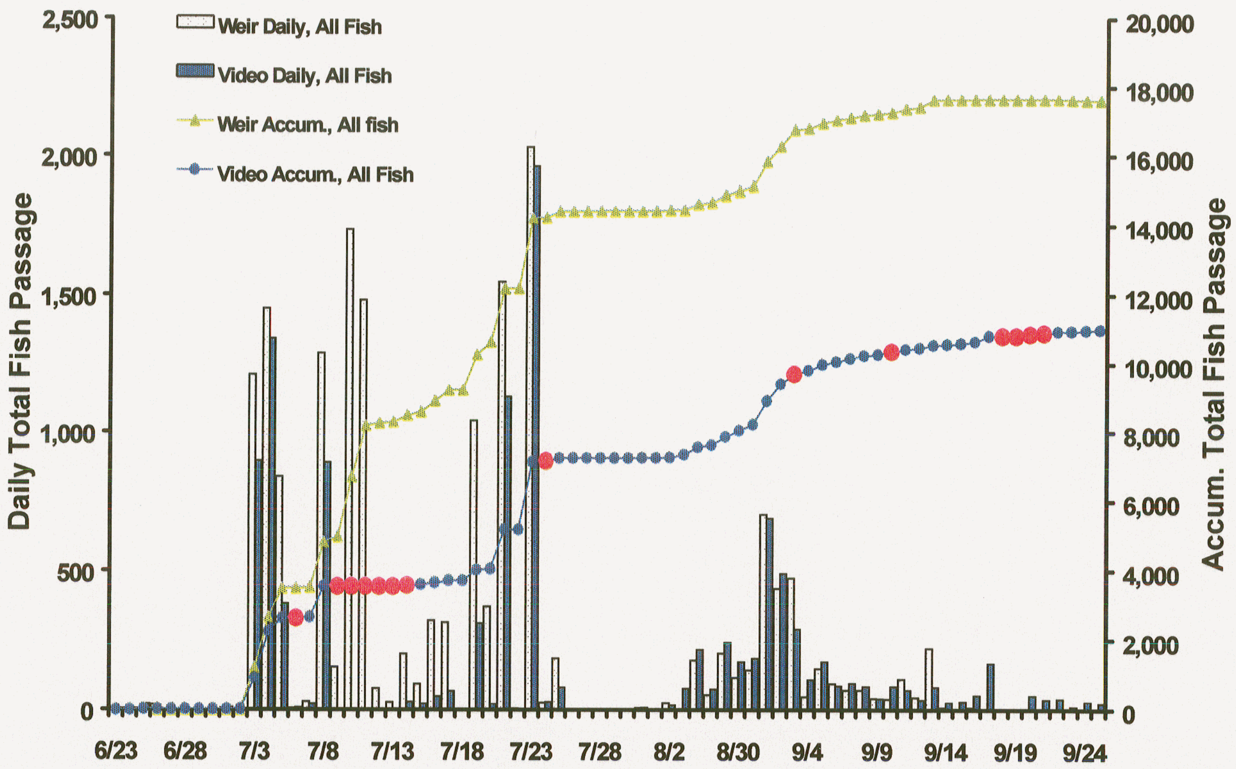

Figure 9. Daily and accumulative weir and video results from Delight Creek, 1999, where we counted sockeye salmon. Oversized data points denote periods during which RVER was "down" at least part of the day. Video counts generally tracked very well with weir counts, particularly after 19 July, when improvements were made to RVER to counteract some early season difficulties.

Table 2. Abundance and composition of anadromous fish returning to Delight Creek, East Nuka Bay, Alaska, 1999, as estimated by remote video system and weir.

	All Species Combined		Sockeye Salmon		Pink Salmon		Coho Salmon		King Salmon		Dolly Varden	
Method	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*
							ALL DAYS CONSIDERED					
							Early Season					
Video	7,260	100.0%	7,234	99.6%	0	0.0%	0	0.0%	0	0.0%	26	0.4%
Weir	14,451	100.0%	13,425	92.9%	9	0.1%	0	0.0%	4	0.0%	1,013	7.0%
Video/Weir Ratio	0.50		0.54		0.00		0.00		0.00		0.03	
							Late Season					
Video	3,649	100.0%	283	7.8%	2,956	81.0%	309	8.5%	0	0.0%	101	2.8%
Weir	3,160	100.0%	1,492	47.2%	1,243	39.3%	382	12.1%	0	0.0%	43	1.4%
Video/Weir Ratio	1.15		0.19		2.38		0.81		0.00		2.35	
							Total					
Video	10,909	100.0%	7,517	68.9%	2,956	27.1%	309	2.8%	0	0.0%	127	1.2%
Weir	17,611	100.0%	14,917	84.7%	1,252	7.1%	382	2.2%	4	0.0%	1,056	6.0%
Video/Weir Ratio	0.62		0.50		2.36		0.81		0.00		0.12	
							EXCLUDING CAMERA "DOWN-TIME"					
							Early Season					
Video	7,148	100.0%	7,122	99.6%	0	0.0%	0	0.0%	0	0.0%	26	0.4%
Weir	10,435	100.0%	9,698	92.9%	5	0.0%	0	0.0%	4	0.0%	728	7.0%
Video/Weir Ratio	0.69		0.73		0.00		0.00		0.00		0.04	
							Late Season					
Video	3,106	100.0%	244	7.9%	2,572	82.8%	225	7.2%	0	0.0%	65	2.1%
Weir	2,647	100.0%	1,233	46.6%	1,070	40.4%	314	11.9%	0	0.0%	30	1.1%
Video/Weir Ratio	1.17		0.20		2.40		0.72		0.00		2.17	
							Total					
Video	10,253	100.0%	7,366	71.8%	2,572	25.1%	225	2.2%	0	0.0%	90	0.9%
Weir	13,082	100.0%	10,931	83.6%	1,075	8.2%	314	2.4%	4	0.0%	758	5.8%
Video/Weir Ratio	0.78		0.67		2.39		0.72		0.00		0.12	

this disparity resulted from fish passage that occurred while the cameras were not functioning due to human error or power loss. Excluding days in which the cameras were down, video-based escapement accounted for 10,253 of the 13,082 fish (78%) that transited the weir (Table 2). Modifications made to the video system during the season dramatically improved its ability to document escapement. Persistent glare problems made it very difficult to effectively count fish with the sky cam until a higher contrast substrate panel was installed and the sky cam's angle of view was adjusted. On July 21st we reduced the substrate panel's mesh size from 2.54 cm to 0.32 cm. We also moved the sky cam from a direct overhead position to a location on the south bank about 3 m above the water. Other improvements included replacing the plastic lens of the underwater camera's housing with glass and installing an auto-iris lens on the sky cam to improve its ability to adjust to dramatically varying light conditions. Prior to making these changes, the video camera accounted for 3,977 of the 6,655 fish (60%) transiting the weir. Following these system improvements, video escapement totaled 3,221 fish, 85% of the 3,799 fish counted through the weir.

We also considered the potential for night passage to account for the discrepancy between video and weir counts. Although there was some upstream and downstream movement at night on a few occasions, in general nocturnal migration was negligible. Considering all days during which morning and evening stream surveys facilitated estimates of night passage, only 153 fish swam upstream past the video site during hours of darkness (about 1.5% of the total escapement). These figures all represent fish passage prior to the August 5-25 hiatus between fish runs.

Contrary to its early-season performance when video counts under-represented weir counts by an average of 31% (excluding camera "down-time"), video-based escapement counts overestimated the actual escapement during late-season efforts. Tape reviewers estimated 3,106 fish transited the video site, 17% more than the 2,647 fish counted through the weir (Table 2). However, half of this disparity is comprised of fish that transited the video site but not the weir. Accounting for the 229 fish accumulating between the video and weir sites by 25 September, the video count was 230 fish (8.7%) higher than the weir count.

Species composition differed considerably between the early and late season evaluation periods, and also between the two methods we used to estimate composition (weir and video). Between 23 June and 5 August (early season), 92.9% of the fish transiting the weir were sockeye salmon; 7.0% were Dolly Varden, and 0.1% were other species (9 pink salmon, 4 king salmon). During this same period, the underwater camera estimated these species' compositions as 99.6%, 0.4%, and 0.0% respectively (Table 2; Note: although the 4 king salmon were documented by the underwater camera, they didn't happen to occur within the first 15 minute period of each hour that we used to estimate total species composition). During the late-season evaluation period (26 August-25 September), 46.6% of the weir escapement was comprised of sockeye salmon, 40.4% was pink salmon, 11.9% was coho salmon, and 1.1% was Dolly Varden (plus 1 chum salmon). In the same period, the underwater camera estimated the contribution of these species to be 7.9%, 82.8%, 7.2%, and 2.1% respectively (Table 2).

Port Dick Creek (FY00)

Overall, RVER-based escapement estimates accounted for 134,678 (92.9%) of the 144,958 fish counted through the Port Dick weir during 23 July-2 September. However, this statistic does not accurately depict RVER's performance since it was incapacitated for 144 hrs during the season while fish continued to be counted through the weir. Likewise, the weir was breached on August 2nd and again during August 15-19, while RVER continued to record fish passage during most of that time. Accounting only for days during which both counters were operating, RVER's estimate comprised 120,803 of the 129,196 fish (93.5%) that passed through the weir (Table 3).

However, some performance limitations were discovered when we compared individual day's escapement estimates derived by the two counters. The video reviewer tended to over estimate the escapement early in the run while the daily weir passage was fewer than two-thousand fish (Figure 10). Conversely, later in the run when weir passage averaged 6-10 thousand fish/d, the reviewer was more likely to under count the escapement by about the same magnitude of disparity, resulting in the two accumulative escapement trend lines converging by season's end (Figure 10).

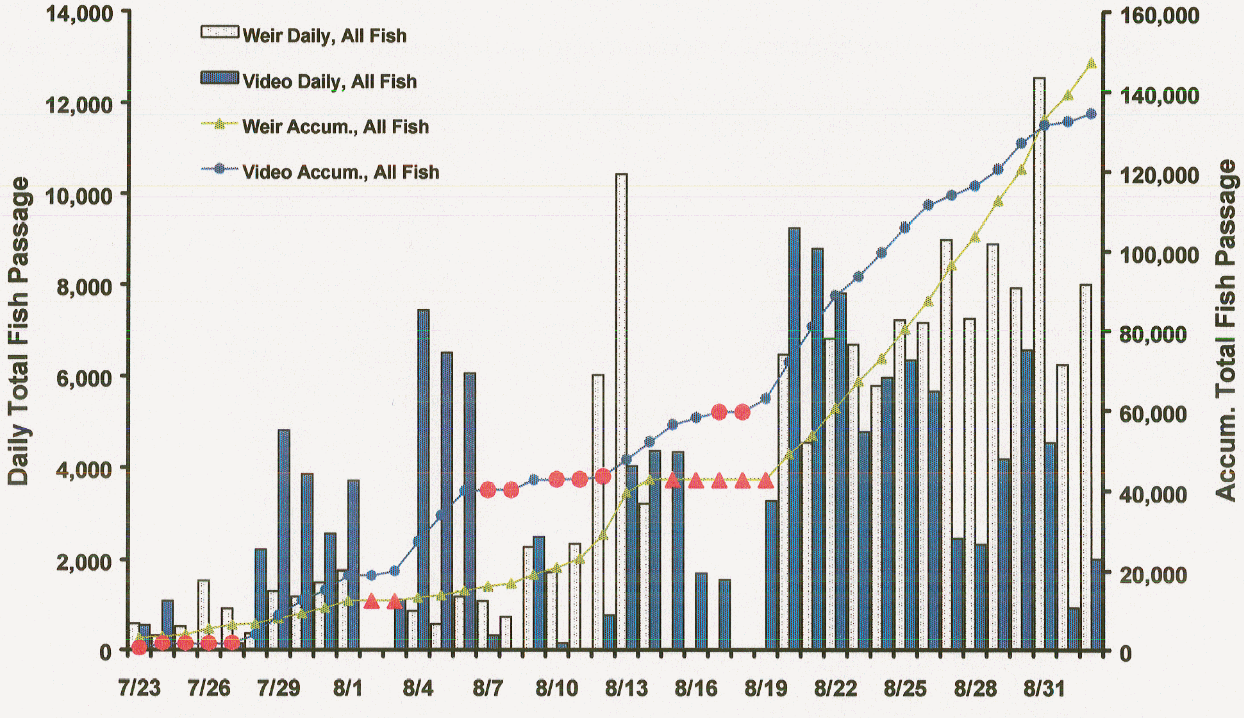

Figure 10. Daily and accumulative weir and video results from Port Dick Creek, 2000, where we attempted to count pink and chum salmon escapement in an intertidal situation. Oversized data points mark periods during which the weir or video were "down" at least part of the day. Note the video reviewer's tendency to over count the escapement while daily weir passage was low and undercount while passage was high.

Pink salmon (97.9%) dominated the escapement into Port Dick Creek in 2000, followed by chum salmon (1.8%) and Dolly Varden (0.3%). Eleven coho salmon were also passed through the weir (< 0.1%). During the same period of time, tape reviewers estimated the species composition to be 98.9% pink salmon, 1.0% chum salmon, and 0.1% coho salmon. Video reviewers did not note the passage of any Dolly Varden. These percentages did not change appreciably when weir and video "down time" was excluded from the analysis (Table 3).

Table 3. Abundance and composition of anadromous fish returning to Port Dick Creek, Port Dick Bay, Alaska, 2000, as estimated by remote video system and weir.

	All Species Combined		Chum Salmon		Pink Salmon		Coho Salmon		*Dolly Varden	
Method	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*	*Estimated Escapement*	*Relative Proportion*
					ALL DAYS CONSIDERED					
Video	134,678	100.0%	1,311	1.0%	133,203	98.9%	164	0.1%	0	0.0%
Weir	144,958	100.0%	2,551	1.8%	141,898	97.9%	11	0.0%	498	0.3%
Video/Weir Ratio	0.93		0.51		0.94		14.91		0.00	
					EXCLUDING CAMERA "DOWN-TIME"					
Video	120,803	100.0%	1,259	1.0%	119,380	98.8%	164	0.1%	0	0.0%
Weir	129,196	100.0%	969	0.8%	128,168	99.2%	11	0.0%	48	0.0%
Video/Weir Ratio	0.94		1.30		0.93		14.91		0.00	

**Although tape reviewers did not count any of the dolly varden that transited the weir, it should be noted that the camera was not operating when 90% of the dolly varden passage occured*

DISCUSSION

Reliability

Availability of an adequate energy source is critical to the overall reliability of RVER. Given the variety of available generators (e.g., solar, wind, hydro), a suitable means for producing power for RVER can likely be found at most locations it is to be deployed. Because our primary objective was to evaluate RVER's performance against the fish weir at Delight Creek, we had to locate it as close to the weir as possible to minimize migration lag effects between the two counters. Unfortunately, adequate sources of solar, wind, or hydropower did not exist close to the weir. Consequently, we experienced some difficulty in maintaining adequate reserve battery power to operate RVER without interruption.

For future deployments at Delight Creek, RVER will be located between Delight Lagoon and the terminus of the creek at McCarty Lagoon (Figure 2), where abundant solar and wind energy is available. This site change should alleviate the power generation difficulties that led to 71 hrs of the system's down time. Being much closer to the mouth of Delight Creek, the new location would also facilitate timelier escapement information. However, there are two potential disadvantages to the lagoon site- tidal influence and the potential for swarming fish. High spring tides would occasionally reverse the current at the video site and deposit marine-derived debris (e.g., algae, jellyfish) onto the substrate panel, thereby reducing its effectiveness and increasing the need for more frequent maintenance. Tidal influence at the video site may also contribute to the same swarming fish behavior we observed at Port Dick.

Although we experienced power problems at Delight Lake in 1999, RVER's ability to operate under its own power for a full season was demonstrated at Port Dick Creek in 2000. ADF&G has also operated an experimental RVER system on Mikfik Creek, within the McNeil River State Game Sanctuary, for the purpose of counting sockeye salmon returning to Mikfik Lake (Figure 1). The overall system design, components, and power draw were similar to the Delight and Port Dick RVER's, so a reliability comparison between systems is justifiable. The Mikfik RVER system was deployed on 11 June 1999 and was operated continuously until 2 August 1999 (>980 hrs). Except for a 5-day period, during which one faulty battery caused the system to fail for a total of 29 hours, the Mikfik system operated uninterrupted under power produced by a hybrid wind/solar generation system similar to the one used at Port Dick in 2000 (97% reliability). The Mikfik system never lost power during its 2000 deployment either, although freshly charged batteries were installed the last week of the season to counteract a long period of low power production brought on by overcast skies and lack of wind.

Tape Review

Reviewing videotapes to enumerate and apportion salmon escapement was a monotonous, but relatively efficient process. At Delight Creek, reviewers were able to enumerate, and apportion to species, about 28 hours of recorded videotape every hour- essentially compressing time by over 96% through time lapse recording and fast forwarding through inactive periods. By utilizing a faster recording rate and playback speed in 2000, reviewers were able to compress time by nearly 98%. These efficiency values were very similar to Hatch et al. (1994), who were able to spend 92% less time estimating escapement from time-lapse recordings than simple visual observation.

For Delight Creek recordings, we found that the time required to review videotapes to estimate total escapement appeared to be affected primarily by escapement activity- more time was required to review days with peak passage rates than those with slow passage. One would expect this given the ability reviewers had to fast-forward through periods of inactivity. However, the time lapse recording mode also affected review efficiency, particularly when recording in high-density (HD) mode. The fastest playback speed available for videotapes recorded in HD mode was 6 hrs, while only 2 hrs were required to review a video tape recorded in normal time-lapse mode. Review of both recording types can be further hastened by fast forwarding, however, the review speed remains approximately 3 times slower for tapes recorded in HD mode. Since fish activity on Port Dick Creek was virtually continuous, reviewers could not fast forward through slow periods for fear of missing fish. Instead, they were able to take advantage of the relatively fast playback speed (2-hr mode) afforded by recording in 120-hr, normal mode (1 frame/sec).

One disadvantage of analog TL-VCR's is their lack of flexibility for selecting review speeds. Although up to 13 review speeds are available to most analog TL-VCR's, only the first three or four are practical, the rest are far too slow to be efficient. Frequently, the best review rate appeared to be somewhere between the first two available speeds (2-hr and 18-hr when using normal record mode). Ideally, tape reviewers would have continuous control of playback speeds instead of the step-wise increments allowed by analog recorders in the absence of very expensive tape editing equipment.

For situations like Delight Creek, considerable review time could be saved if reviewers didn't have to waste time fast forwarding through hours of blank videotape looking for fish activity. Hatch et al. (1998) demonstrated that image-processing software could be programmed to edit out blank frames from videotapes recorded in 24, 48, and 72-hr modes, retaining only those that contained fish. The resulting tapes compressed the original recording duration by 75% and correspondingly reduced the time necessary to review them. Ours was a more challenging application than that demonstrated by Hatch et al. (1998), who were counting salmon through a glass window in narrow fish passageways at dams in the Columbia River Basin. However, with some refinement to our current RVER system, it may become possible to use image-processing techniques to further increase the efficiency of the tape review process (pers. comm., Daniel Zatz, SeeMoreWildlife Systems Inc.).

We required 50 and 25 hrs of total review time to enumerate, and apportion to species, the total returns to Delight and Port Dick creeks, respectively. While very efficient, this still represents a considerable time investment for an individual stream. However, compared to using a weir to attain an escapement estimate, 25-50 hours is negligible, especially considering the fact that at least 2 crew members are generally required to operate a weir (i.e., 2 people x ≥8 hrs/day x 7 days/wk x 10 weeks = ≥1,120 hrs). This labor investment per escapement datum contrasts sharply with aerial survey. In Lower Cook Inlet, approximately 85 hrs are flown annually to monitor salmon escapements for about 30 individual streams. Averaging for all streams then, aerial survey required only 2.8 hrs to provide an escapement "estimate" per stream- considerably more efficient than either weirs or remote video. Largely for that reason, but also because RVER's are not well suited to all streams, remote video will probably never replace aerial surveys entirely. Despite their efficiency, neither aerial survey, nor our current RVER system provide the important age, sex, and size composition data that weirs offer. However, that may change as technology continues to advance. Nez Perce Tribal biologists are planning to evaluate the feasibility of using laser and ultrasound equipment to determine the length and sex of fish directed through a small "video box" at the apex of a v-shaped weir (pers. comm., Dave Faurot, Nez Perce Tribe). Such a system would probably not lend itself to most Alaskan streams with large escapements, however, it illustrates the possibilities for remote data collection.

Video System Performance

Total Fish Passage

Several studies demonstrate that aerial survey tends to undercount true escapement, particularly when the stream lives of target species and efficiency of aerial observers are not well defined (Shardlow et al. 1987, Perrin and Irvine 1990, Bue et al. 1998). Bue et al. (1998) reported that aerial survey indices of pink salmon escapement were less than half of the corresponding weir counts, when using area-under-the-curve with a constant stream life factor of 17.5 days. Using stream-specific stream life estimates and correcting for individual observer efficiencies can dramatically improve area-under-the-curve estimates based on aerial surveys. However, these variables, especially stream life, are dynamic and can be difficult to estimate without labor intensive weir projects. This problem, along with a host of other variables that can affect aerial survey results, leads to aerial survey based indices of abundance that are of uncertain quality. Perhaps because aerial survey indices are apparently inherently conservative, this imprecise methodology has nonetheless been used successfully for many years to help manage salmon fisheries inseason. However, the level of escapement resolution necessary to manage commercial fisheries inseason is not as fine as that required by researchers seeking to evaluate biological escapement goals or to forecast future returns based on return per spawner relationships. RVER's performance, while not yet weir-quality, exhibited its potential to outperform aerial surveys.

Our initial goal was to collect better escapement data than aerial surveys provide. Two aerial surveys of the entire Delight drainage were flown in FY99; one around the historical peak of the run on 16 July, and another on 9 August when, traditionally, most of the escapement is in the lake. Only 2,600 sockeyes were counted above the weir by the 16 July aerial survey, which was conducted under good conditions. That estimate comprised only 31% of the actual weir passage of sockeyes by the same date (8,375). Similarly, the 9 August survey, flown under poor conditions, estimated 2,600 sockeyes in the lake- only 19% of the 13,445 sockeyes that had been counted through the weir. In contrast, RVER documented 73% of the sockeye escapement through 16 July, and 69% of the escapement through 5 August (when the mid-season break began). Even when considering aerial survey observations below the weir, observers documented just 8,800 fish for the season, 78.7% of the escapement estimated by videotape, and only 51.4% of the actual escapement documented by the weir up to that date.

Periodic aerial and ground surveys have been used historically to generate area-under-the-curve (AUC) estimates of the pink and chum salmon escapement into Port Dick Creek. In 2000, three ground surveys and 11 aerial surveys were conducted. Ground survey based AUC estimates for pink and chum salmon totaled 95,190 fish, 64.8% of the escapement documented by the weir. Aerial survey based AUC estimates totaled 125,036 salmon, 85.1% of the weir count. RVER's total estimate of 134,514 salmon (91.5%) was closer to the weir count than either aerial or ground survey estimates. This statistic is further enhanced by the fact that a significant number of pink salmon spawned below the weir and video sites. While the weir and video counters did not count those fish, they were included in both the ground and aerial survey estimates. Thus, the true performance of ground and aerial surveys is actually worse than their respective 64.5% and 85.1% values determined in relation to the weir.

RVER's ability to estimate total escapement varied relative to a number of factors. Early season performance at Delight Creek in 1999 was hampered by poor sky-cam image quality. After improving that situation on July 21, RVER successfully documented 85-87% of the true escapement (accounting for night passage). Contrary to the early-season undercounting, tape reviewers tended to overestimate late-season escapement relative to weir counts. The tendency for video-counts to be high during the late season was likely due to the abundance of pink salmon spawning throughout the stream. Fish that spawned in the vicinity of the video site often darted back and forth across the substrate panel as they defended their redds. During this period, we were recording in 72-hr mode, resulting in approximately 1 frame every 5 sec. It was difficult, given this time-lapse interval, to successfully track individual fish that moved back and forth across the panel and it's very likely that our over-counts were due to these video-site spawners being counted more than once.

We attempted to remedy the problem of counting "resident spawners" by using a shorter time-lapse recording interval at Port Dick Creek in 2000. We found that 1 frame/sec did indeed allow more precise tracking of individual fish so it was unlikely that video-site spawners were counted more than once. However, we encountered a new problem that affected the tape reviewer's ability to count fish at Port Dick Creek. When the tide raised the water level and reversed the current at the video site, large schools of pink salmon, in excess of 10,000 fish, would frequently swarm underneath the video camera. The density, abundance, and fast movement of these fish made it impossible for reviewers to count individuals, particularly when considering that individuals below the top layer of fish were not visible to reviewers. Reviewers had to estimate the number of fish in the swarm and keep track of its upstream and downstream movements in order to estimate the actual upstream passage. While it is likely that the relatively close proximity of the weir upstream of RVER contributed to the problem by backlogging fish that might otherwise have transited the area more quickly, the problem would have existed even without the weir. Returning salmon frequently flood in and out of river mouths with the tide before committing themselves to fresh water. Any counter placed in the intertidal zone of a creek will likely encounter this problem, particularly with pink salmon.

We feel this swarming behavior contributed to the disparity we observed between our daily video and weir counts. Interestingly, that disparity exhibited contrasting trends, relative to the actual daily escapement, such that it balanced out by season's end and the final video escapement estimate was very close to the weir estimate. However, such a trend does not lend itself to inseason management of a commercial fishery since escapement was overestimated early in the run. Further investigation is necessary to determine whether the over- and under-counting trends we observed in 2000 were due to RVER's location, the exceptionally large escapement (> 3.5 times the 30-yr average), the proximity of the weir, or a combination of these. It is possible that subtle modifications to the system, and its location, could improve RVER's performance counting pink and chum salmon in intertidal situations.

While designing RVER, we were concerned with the potential for poor water clarity to impede RVER's ability to document fish passage during high discharge events. This concern was exacerbated by the fact that salmon migration in small streams often increases with increasing discharge. Cowan (1991) reported that stream discharge and chum salmon immigration to spawning channels were positively correlated. We also observed increased daily passage rates of sockeye and coho salmon following rainstorms that led to increased discharge. Floodwaters breached the weir from 19:30 on 16 September through 10:45 on 22 September. Although fish were able to bypass the weir during this time and weir counts were not possible, the video system was able to successfully record fish passage during part of this high-water event. Beginning at approximately 15:30 on 17 September, the video system documented a surge in coho migration coincident with the rapidly rising water levels. Nearly 100 coho transited the video site in 30 minutes. Unfortunately, video was lost due to low battery power at 16:02 on 17 September and wasn't regained until charged batteries were installed at 10:45 on 20 September, when the flood receded. Had this power interruption not occurred, it is very likely that RVER would have continued to document fish passage during a period when the weir could not. Because our video site was located immediately downstream of a large settling basin (Delight Lake), increased turbidity reduced water clarity by just 40%, from ~4.0 m to 2.4 m, as discharge increased. Thus, fish were still visible to the sky cam as they swam over the high-contrast substrate panel.

During the initial design of RVER, we were also concerned with the potential for fish to migrate past the counter during darkness, while the camera was shut down. As it turned out, nocturnal migrants comprised only a very small percentage (<2.0%) of the total escapement at Delight Creek in 1999. Unfortunately, our stream survey records were lost in a fire at Port Dick Creek, however, stream surveyors recalled seeing very few new fish between the video and weir sites during their dawn surveys. Despite these observations, we recognize that nocturnal migration may be an important factor to consider for future deployments. Without adding an excessive power burden to the solar/wind generators, a super low-lux black and white camera coupled with infrared lights could be added to our current RVER system to document nocturnal migrants. Similar equipment has been used effectively by others to monitor fish activity in low light situations (Beach 1978, Collins et al 1991).

Species Apportionment

Accurately apportioning the species composition of the total return with the underwater camera at Delight Creek proved more difficult than we anticipated. Because underwater visibility was less than the width of the stream (4 m visibility vs. ~15 m stream width), we positioned the underwater camera so it would view across the stream thalweg- the main channel through which the sky cam showed most fish passage occurring. Nonetheless, RVER underestimated the proportion that Dolly Varden comprised of the total escapement in the early season evaluation (video: 0.4% vs. weir: 7.0%). In fact, the underwater camera saw very few Dolly Varden in mid-late July when their peak migration was occurring, according to weir counts. More Dolly Varden were seen in early July, when both sockeye and Dolly Varden passage were low. These data suggest that Dolly Varden may have migrated upstream closer to the stream banks, out of view of the underwater camera, while the peak sockeye migration was occurring. According to the sky cam, sockeye salmon invariably occupied the thalweg of the stream while transiting the video site. Upon subsequent review of sky cam images recorded during the peak of the Dolly Varden migration, we noted many small fish occupying the stream peripheries, outside the view of the underwater camera. This would account for RVER under apportioning Dolly Varden passage using the underwater camera. If accurate estimation of Dolly Varden escapement is an objective for future RVER deployments, more underwater cameras will be needed to view the stream peripheries along with the main channel.

We also experienced difficulties estimating the true proportion of sockeye salmon in the total late season escapement at Delight Creek. However, instead of missing sockeyes that migrated past the video site outside the view of the underwater camera, we believe we simply overestimated the proportion of pink salmon transiting the underwater camera. As discussed above, reviewers of sky cam images tended to over count pink salmon because nearby spawners constantly swam back and forth over the substrate panel. These spawners/redd defenders were frequently mistaken for "new" fish and counted as such. The same was true for pink salmon swimming in front of the underwater camera that was used for species apportionment. Thus, tape reviewers overestimated the proportion of pink salmon, which necessarily reduced the relative proportion of sockeyes.

Although fish behavior appeared to be a factor in limiting our underwater camera's ability to accurately estimate species composition at Delight Lake, our multiplexer also created problems. The four-channel multiplexer we used tripled the time interval between recorded frames, dramatically reducing the reviewer's ability to track individual fish. We believe this inability to effectively track fish contributed to the reviewer's tendency to overestimate the relative proportion of pink salmon in the total return. The multiplexer also increased RVER's total cost and power needs considerably. In our judgment, these negative characteristics outweighed the species apportionment information provided by the underwater camera/multiplexer and we would not use that same multiplexer again. However, we do feel additional cameras would be useful in some multi-species situations and we hope to find a low power multiplexer that can cycle between two or more cameras without significantly increasing the time interval between recorded frames. Until we find equipment meeting those specifications, we are not inclined to use a second camera for species apportionment.

Species apportionment was less of a problem at Port Dick Creek in 2000, despite the use of only a single overhead camera and no underwater camera. The reviewer's estimate of the composition of pink salmon was within 1% of the weir's. We had decided a priori that the size difference between pink and chum salmon would be sufficient to distinguish them with the overhead camera. This decision also accounted for the fact that the use of two cameras and a multiplexer compromised RVER's performance at Delight Creek in 1999, mainly by increasing the time-interval between images and reducing the reviewer's ability to track individual fish.

We anticipated the tendency for the Port Dick reviewer to count some large pink salmon as chums and therefore discouraged the reviewer from counting a fish as a chum salmon unless it's size was very obviously that of a chum salmon. In retrospect, we should not have set size as the only criterion, but instead included other factors such as swimming behavior. The reviewer underestimated the actual escapement of chum salmon by nearly 50% (1,311 vs. 2,551). While still larger than most pink salmon, female chum salmon are considerably smaller than male chum salmon. We suspect that the reviewer used the size of male chum salmon as her reference and therefore did not count many females. We intend to employ better "search image calibration" training in the future for reviewers who are counting chum salmon.

CONCLUSIONS

The minor reliability problems that we experienced in FY 99 highlighted the importance of an adequate energy source (wind, sun, or fast-flowing water), but they did not mask the ability of remote video escapement recorders to collect reasonably accurate escapement data. We were able to ameliorate early season visibility problems in 1999 and demonstrate that a RVER system, without the benefit of a partial weir, is capable of enumerating salmon within 15% of the actual total escapement. Not only did we improve upon that accuracy rate at Port Dick Creek in 2000, but we demonstrated that RVER's hybrid solar/wind generators were capable of sustaining it throughout a field season. The Delight Creek deployment also demonstrated that remote video escapement recorders might be able to count salmon passage during high discharge events that debilitate weirs, at least in systems not prone to excessive turbidity during floods.

We intentionally chose streams with multi-species returns in order to evaluate RVER's ability to estimate salmon escapement under challenging circumstances. Operating RVER and reviewing videotapes is much easier at locations without tidal influence and with only a single species returning, or those with little overlap in run timing between species (e.g., Mikfik Lake). The 1999 evaluation at Delight Creek demonstrated that RVER is capable of collecting reasonably accurate total escapement estimates, however, more refinements were necessary to acquire confidence in RVER's ability to accurately estimate species composition during periods of mixed species return. By reducing the interval between recorded frames, we were able to track individual fish better and improve RVER's ability to apportion escapement at Port Dick Creek in 2000.

The usefulness of our RVER system will continue to improve as further modifications to existing designs are implemented. When funding becomes available, we intend to incorporate real-time, microwave or satellite transmission of video images from streamside, back to our field office. This improvement would preclude the need to switch out videotapes in the field, enabling considerable savings in air charter costs. Real-time transmission of images would also facilitate more timely escapement monitoring, which would lead to improved inseason management of subsistence, commercial, and sport fisheries. It would also lend itself to recording digital images directly onto hard drives so we can evaluate the feasibility of using image recognition software to help automate the tape review process.

Transmitting images back to central locations and using digital media appears to have several distinct advantages over our current system. First, it removes from the field what we perceive to be the weak link in our current RVER system, the analog TL-VCR. Not only does this motor driven unit comprise the vast majority of RVER's power needs, but it is susceptible to unpredictable technical difficulties, as we experienced at Port Dick Creek in 2000. Second, digital media facilitates higher resolution images than analog is capable of. Digital recordings would also allow much greater flexibility when selecting playback speeds, something we suspect affects both the accuracy and efficiency of the tape review process. Lastly, software could be written to link the individual digital frames being reviewed to the reviewer's estimates of fish numbers. Such a feature would make an excellent training tool and facilitate detailed evaluations of within and between reader variability in escapement estimates, possibly leading to more accurate RVER-derived escapement estimates. The added cost associated with real-time transmission of digital images will have to be weighed against the enhanced performance it affords to determine whether the improvements are justified.

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