# *Exxon Valdez* Oil Spill
Restoration Project Annual Report

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

Restoration Project 99366
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

Edward O. Otis
Mark Dickson

Alaska Department of Fish and Game
Division of Commercial Fisheries
3298 Douglas Place
Homer, AK 99603

April 2000

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

Restoration Project 99366
Annual Report

**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. Estimates of salmon escapement derived by the remote video escapement recorder were compared to those made by the weir in order to evaluate the accuracy and reliability of the recorder. This is the first annual report to be submitted.

**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. In 1999 we deployed a remote video escapement recorder on Delight Creek, the outlet of a clear water lake system on the Outer Coast of the Kenai Peninsula that supports a modest sockeye salmon run (10,000-30,000 fish). Our objective was to determine the reliability and accuracy of the remote video escapement recorder for estimating sockeye salmon escapement into a small stream. The recorder successfully operated 87% of the time it was programmed to run. Daily video counts of total fish passage tracked very well with daily weir counts of the same, particularly after mid-July when subtle modifications to the video system dramatically improved image quality. After these improvements, the remote video escapement recorder documented 85-87% of the total fish passage counted through the weir. While further refinements are expected, we concluded that remote video and time-lapse recording systems are capable of collecting relatively accurate and reliable sockeye salmon escapement estimates.

**Key Words:** Chum salmon, coho salmon, Dolly Varden trout, 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 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. 2000. Improved salmon escapement enumeration using remote video and time-lapse recording technology, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 99366), Alaska Department of Fish and Game, Division of Commercial Fisheries, Homer, Alaska.

# TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## EXECUTIVE SUMMARY

We are evaluating the feasibility of using remote video and time-lapse recording technology to count adult sockeye (*Oncorhynchus nerka*), chum (*O. keta*), coho (*O. kisutch*) and pink salmon (*O. gorbuscha*) as they enter their natal streams to spawn. 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 rigorous analyses such as evaluating escapement goals and productivity trends, or monitoring the recovery of injured resources.

We developed a remote video escapement recording system that is small, relatively lightweight, and easily deployed. The system operates under its own, solar, wind or hydro-generated power, depending on site characteristics. The remote video escapement recorder 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, it is 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 hrs) of the time it was programmed to run. Most of the down time resulted from insufficient solar energy being available at the site the remote video escapement recorder was deployed. 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 41.7 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 8.0 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 subtle modifications to the remote video escapement recorder dramatically improved image quality. The overhead camera, used to enumerate the total escapement, was upgraded to a more light-sensitive model and then repositioned. 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 char (*Salvelinus malma*) and overestimate the proportion of pink salmon. We concluded that dolly varden char 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. Pink salmon were over counted by both the overhead and underwater cameras because they spawned within the camera's fields of view and were sometimes mistaken for new fish transiting the video site. This problem can be remedied in the future by recording at a faster time-lapse interval to increase the tape reviewer's ability to track individual fish on the screen. While further refinements are expected, we concluded that remote video escapement recording systems are capable of collecting relatively accurate and reliable sockeye salmon escapement estimates. There are hundreds of clear water streams throughout the spill area, and the rest of Alaska, whose salmon escapement monitoring could be improved with the use of remote video and time-lapse recording technology.

In FY00, we intend to evaluate the feasibility of using a remote video escapement recorder to count pink and chum salmon in a stream where intertidal spawning occurs. If this application can be developed, a new technology will be available to monitor the recovery of injured resources in many of the small, remote streams throughout the spill area. Once we demonstrate the feasibility of these applications, in the future we'd like to explore real-time, microwave transmission of images back to central locations. This single step would dramatically reduce the remote video escapement recorder's power consumption, preclude the need for weekly air charters to change video tapes, and allow more timely escapement monitoring for inseason management of commercial, sport, and subsistence/personal use fisheries.

## 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 survey estimates of spawning escapement 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, salmon production, etc.

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 (Irvine et. al 1991, Hatch et. al 1994, Hatch et. al 1998). 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 to change tapes, 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, 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.

We chose Delight Creek, a small clear water stream on the southern Kenai Peninsula, to evaluate RVER. Delight Creek is typical of most sockeye systems where fish are sometimes visible to aerial surveyors only while they're ascending the outlet stream. Because fish often disappear upon entering the lake, area-under-the-curve estimates of spawning escapement are problematic. During two periods between June and October, 1999, we operated RVER concurrently with an adult fish weir to evaluate its performance. RVER successfully operated 87% (1,095 hrs) of the time it was programmed to run. Only 41.7 hrs were required to review nearly 1,100 hrs of recorded videotape, averaging 38 minutes to review an entire day's escapement (range 18-125 minutes). An additional 8.0 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 subtle modifications to the remote video escapement recorder dramatically improved image quality. After these improvements, the recorder documented 85-87% of the total escapement counted through the weir. RVER was less successful at estimating the species composition during mixed-species return periods. It had a tendency to underestimate the relative proportion of dolly varden char (0.9% vs. 5.8%) and overestimate the relative proportion of pink salmon (25.1% vs. 8.2%).

## OBJECTIVES

The detailed project description (DPD) we submitted to direct this research listed the following objective for FY 99 activities:

> *Determine the accuracy and reliability of a remote video system for estimating sockeye salmon escapement in small streams.*

## METHODS

*Study Area*

Located in McCarty Fjord on the Outer Coast of the Kenai Peninsula (59° 34'N, 150° 15'W), Delight Lake and its outlet creek drain approximately 11.2 $km^2$ of mostly steep, forested terrain (Figure 1). However, Delight Creek itself 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 its outlet, Delight Creek, ranged from 0.83 to 4.56 $m^3$ $sec^{-1}$ 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 $yr^{-1}$ 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

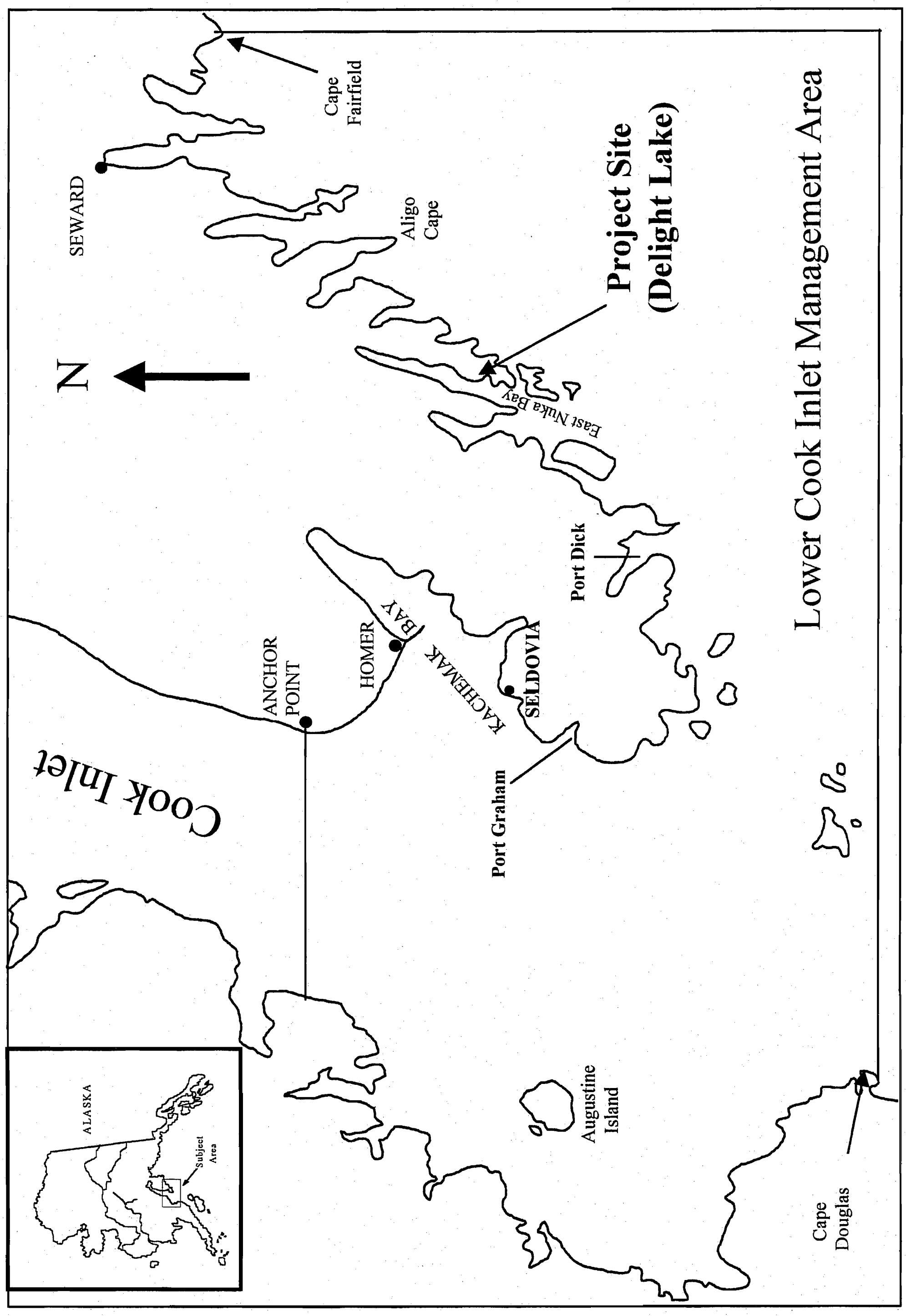


Figure 1. Map showing Lower Cook Inlet, Alaska and the location of our remote video escapement project (not drawn to scale).

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 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 char, 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.

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.

*Weir*

The accuracy of the video system was determined by comparing salmon escapement counts derived from time-lapse recorded videotapes to those made by an adult weir erected upstream of the video site. System reliability (i.e., field durability) was measured by dividing the total hours of recorded video tape 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%.

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 from June 23-Aug 5, and from Aug 26- Sept 25 two ADF&G crew members 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 in late August, a period coinciding with a lull in fish activity between the sockeye and coho returns.

*RVER*

Five hundred meters below the fish weir, at the first suitable location, we erected the RVER system. RVER is 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 (VCR) capable of recording 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 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 2). An overhead camera (sky cam), attached to a steel bracket that was

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

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

The weir crew made daily weather observations relevant to video system performance (e.g., percent overcast during peak solar generating hours, wind speed and direction that may affect the camera's ability to see fish due to surface turbulence). They also kept daily logs documenting the charging performance and reserve status of the solar panels and batteries, respectively. Their logs also included the vital statistics of the recording process (e.g., the time-lapse mode each tape was recorded in, tape duration, etc.)

*Stream Surveys*
To optimize our ability to evaluate video performance across varying stream discharge and run conditions (e.g., the peak vs. tail of the run) we developed a sampling protocol that enabled daily comparisons between the two enumeration methods. Twice daily, a crewmember surveyed the 500 meters of stream between the video site and the weir to count fish that may have transited the video site but not the weir. 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 also able to independently 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.

*Tape Review*
The multiplexer facilitated recording images from both cameras onto a single SVHS tape. 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. 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, the hour:minute of dawn and dusk, and the number of fish transiting the video site prior to and after the morning and evening stream surveys, respectively. These last data were used to help estimate true night passage as opposed to fish passage occurring between an evening stream survey and the following morning's stream survey.

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. Focusing on the first 15 minutes of every hour, the reviewer counted the number of individual fish of each species observed by the underwater camera. The resulting composition values were used to apportion that day's combined escapement into individual escapements for

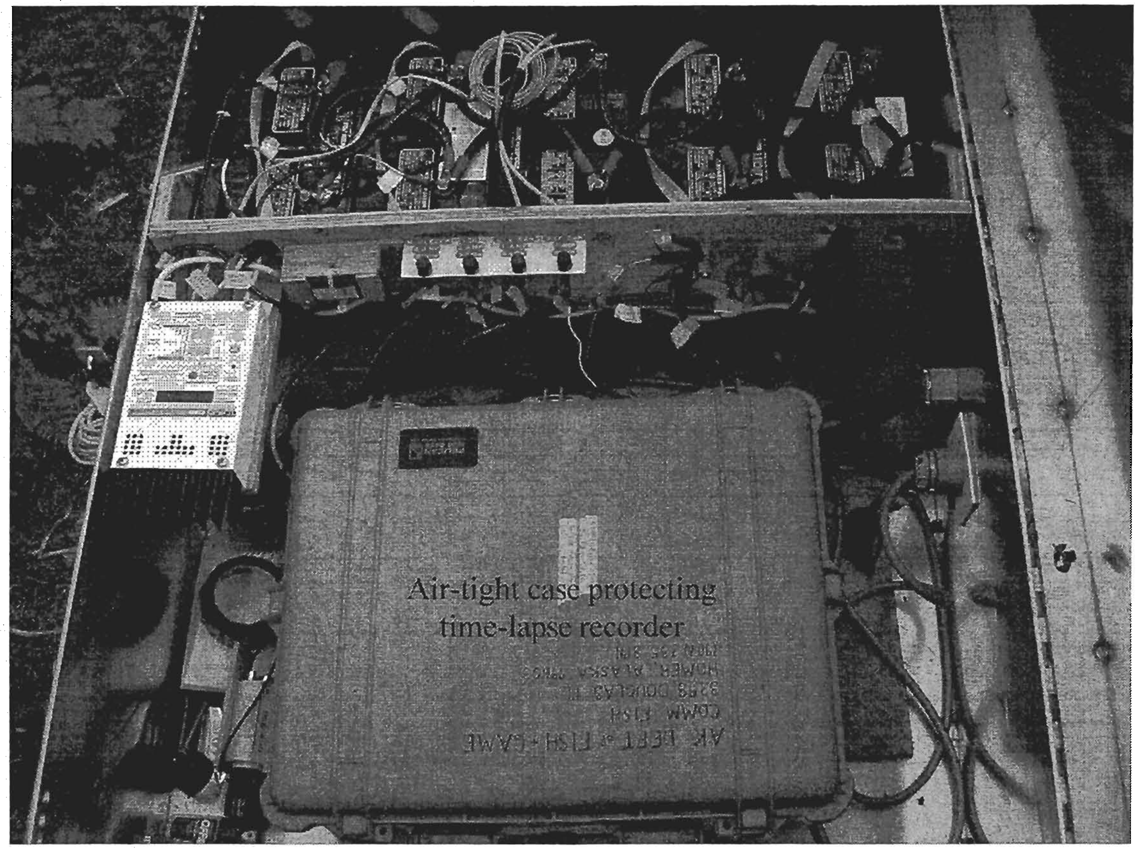


Figure 2. Photograph illustrating the electronic components of a video system used to count salmon escapement at Delight Creek, East Nuka Bay Alaska, in 1999.


Figure 3. Photograph illustrating the key components and layout of a remote video system used to count salmon escapement at Delight Creek, East Nuka Bay, Alaska in 1999.

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*

RVER successfully operated for 1095.4 of the 1257.2 hrs it was programmed to run, resulting in 87.1% reliability. This value would have risen to 94.4% had a human error not resulted in 90.9 hrs of down time. The remaining down time resulted from insufficient solar power, which periodically depleted the batteries until the cameras blacked out requiring freshly charged batteries to be installed. All components combined, the Delight Creek RVER drew about 3.5 amps/hr, less than the maximum hourly output generated 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 4) 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.

*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 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 41.7 hours was required to review 1,095.4 hrs of recorded tape to estimate total fish passage. On average, 38 minutes were required to review a day's escapement. However, minutes of review time varied considerably with escapement activity (review time: max = 125, min = 18, SD =24); high passage days predictably required more review time (Table 1).

The process of reviewing videotapes to estimate species composition with the underwater camera was also relatively efficient. Only 8.0 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, SD =14). Combining both reviews, 49.7 hrs were required to review 1389.4 hrs of videotape. That equates to 1 hr of review for every 28 hrs of videotape, an efficiency rate of 3.6%.

We experimented with three different time-lapse recording modes during the 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

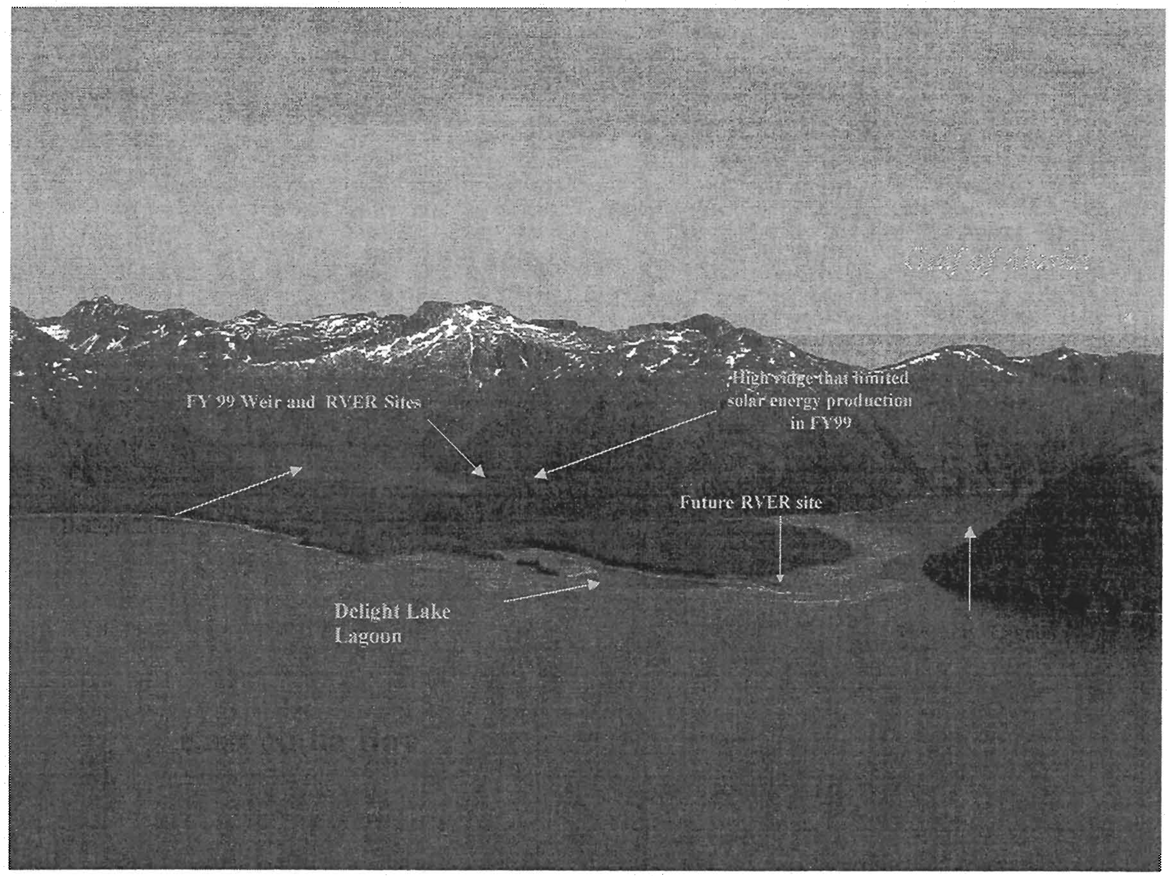


Figure 4. Aerial photograph of the Delight Lake drainage, East Nuka Bay, Alaska, 1999; illustrates relevant features and locations of the FY 99 weir and video sites.

Table 1. Time required to review a day's escapement relative to the escapement activity and time-lapse recording mode used (HD denotes high-density mode).

| *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) |

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).

*Video System Performance*
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.

**Total Fish Passage**

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 5). 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 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). Subtle changes 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 21$^{st}$ 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 can be explained by fish that transited the video site but not the weir.

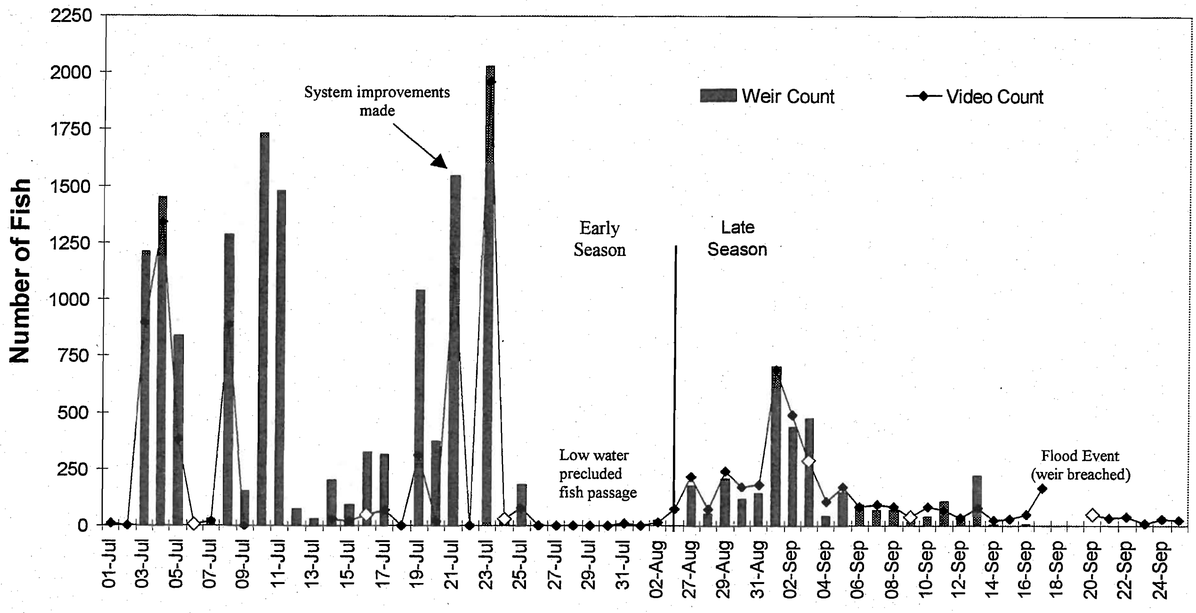


Figure 5. Total daily escapement past the video and weir sites at Delight Lake, East Nuka Bay, Alaska in 1999. Open data markers indicate the video was down for part of the day.

Table 2. Abundance and composition of anadromous species returning to Delight Creek, East Nuka Bay, Alaska in 1999, as estimated by a remote video system and adult weir. Values are stratified by escapement period within each of two evaluation criteria.

| | 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 | |

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 Apportionment

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, 92.9% of the fish transiting the weir were sockeye salmon; 7.0% were dolly varden char, 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 H20 cam, 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 char (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).

## 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. 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 use at Delight Creek, RVER will be located between Delight Lagoon and the terminus of the creek at McCarty Lagoon (Figure 4), where abundant solar and wind energy is available.

Another option for low gradient sites lacking solar and wind energy may be a low-RPM, high-output water wheel. It would be similar in design to a traditional fish wheel, except the baskets would be replaced by large surface area paddles that rotate on an axis. A generator could be attached to the floating platform supporting the structure, which would be secured to the stream bank near the video strongbox. The slow moving, water-driven paddles could be geared down to spin a higher RPM generator to charge the battery bank in the strongbox.

Although we experienced power problems at Delight Lake, RVER's ability to operate under its own power for a full season was demonstrated at another location in 1999. ADF&G operated a second experimental RVER system on Mikfik Creek, within the McNeil River State Game Sanctuary, for the purpose of counting sockeye salmon returning to Mikfik Lake. Because only a single species returns to Mikfik Creek only one camera and no multiplexer was used there. Nonetheless, the overall system design, components, and power draw were similar to the Delight RVER, so a reliability comparison 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 flawlessly under power generated by a hybrid wind/solar generation system (97% reliability).

*Tape Review*

Reviewing videotapes to enumerate and apportion salmon escapement was a monotonous, but relatively efficient process. Reviewers were able to enumerate, and apportion to species, nearly 28 hours of recorded videotape every hour- essentially compressing time by over 96% through time lapse recording and fast forwarding through inactive periods. This efficiency value was 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. 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 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.

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 situation than 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, we may be able to use image-processing techniques to further increase the efficiency of the tape review process in the future.

We required just under 50 hrs of total review time to enumerate, and apportion to species, the total return to Delight Creek (nearly 1,390 hrs of videotape). 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, 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 were flown last year to monitor salmon escapements on 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.

*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 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 the 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 video tape, and only 51.4% of the actual escapement documented by the weir up to that date. Although these preliminary results represent only one field season of data, they demonstrate the potential for RVER systems to outperform aerial surveys.

RVER's ability to estimate total escapement varied relative to a number of factors. Early season performance 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. This problem of counting "resident spawners" should be readily overcome by a more frequent time-lapse recording interval that allows more precise tracking of individual fish. Our future efforts will investigate this solution.

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.

## Species Apportionment

Accurately apportioning the species composition of the total return with the underwater camera 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 char 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 char 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 char 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 char passage using the underwater camera. If accurate estimation of dolly varden char 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. 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 area 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.

## CONCLUSIONS

The minor setbacks that we experienced in FY 99 highlight the importance of a reliable energy source (wind, sun, or water), but they do not mask the ability of remote video escapement recorders to collect reasonably accurate escapement data. We were able to ameliorate early season visibility problems 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; an accuracy rate we expect to improve upon in the future. Furthermore, we demonstrated that remote video escapement recorders might be able to count salmon passage during floods when weirs are washed out, at least in systems not prone to excessive turbidity during high discharge events.

We intentionally chose a stream with multi-species returns in order to evaluate RVER's ability to estimate salmon escapement under challenging circumstances. Streams with overlapping sockeye and pink salmon escapements are difficult because pink salmon often spawn in the area around the video counter while sockeye salmon invariably move right through to the lake. Operating RVER and reviewing videotapes is easiest for streams with only a single species returning, or those with little overlap in run timing between species. This first year evaluation demonstrated that RVER is capable of collecting reasonably accurate total escapement estimates, however, more refinements are 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 should be able track individual fish better and improve RVER's ability to apportion escapement in the future.

The usefulness of our RVER system will continue to improve as further modifications to existing designs are implemented. In the near future, we hope to incorporate real-time, microwave transmission of video images from streamside, back to field offices. This improvement would preclude the need to switch out videotapes in the field, enabling considerable savings in air charter costs. It would also lend itself to recording digital images directly onto hard drives for subsequent analyses by image recognition software that can help automate the tape review process. Real-time transmission of images would also facilitate greater flexibility in selection of time-lapse recording intervals and more timely monitoring of escapement conditions which would lead to improved inseason management of subsistence, commercial, and sport fisheries.

## ACKNOWLEDGMENTS

The authors wish to thank the dedicated field staff who assisted during various stages of this project: Josephine Ryan, Carla Milburn, Janice Higby, Greg Demers, and Tom Sigurdsson. We'd also like to extend our appreciation to John Berryman, Jose DeCreeft, and Ken Day for safely transporting crews and equipment to and from the field site.

## LITERATURE CITED

Bevan, D.E. 1961. Variability in aerial counts of spawning salmon. Journal of the Fisheries Research Board of Canada 18(3):337-348.

Hammarstrom, L.F. 2000. 1999 Lower Cook Inlet annual finfish management report. Alaska Department of Fish and Game, Division of Commercial Fisheries Regional Information Report 2A00-17. 147 pp.

Bue, B.G., S.M. Fried, S. Sharr, D.G. Sharp, J. Wilcock, and H.J. Geiger. 1998. Estimating salmon escapement using area-under-the-curve, aerial observer efficiency and stream-life estimates: the Prince William Sound pink salmon example. North Pacific Anadromous Fisheries Commission Bulletin 1:240-250.

Cousens, N.B.F., G.A. Thomas, C.G. Swann, and M.C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1108.

Cowan, Larry. 1991. Physical characteristics and intragravel survival of chum salmon in developed and natural groundwater channels in Washington. American Fisheries Society Symposium 10:125-131.

Eicher, G.J. 1953. Aerial methods of assessing red salmon populations in western Alaska. Journal of Wildlife Management 17(4):521-527.

Edmundson, J.A., M.S. Dickson, and W.A. Bucher. 1998. Limnological and fishery investigations concerning sockeye salmon production in Delight and Desire lakes. Alaska Department of Fish and Game, Division of Commercial Fisheries Regional Information Report No. 2A98-15. 57 pp.

*Exxon Valdez* Oil Spill Trustee Council. 1994. Final Environmental Impact Statement for the Exxon Valdez Restoration Plan.

Hatch, Douglas R., M. Schwartzberg, and P.R. Mundy. 1994. Estimation of pacific salmon escapement with a time-lapse video recording technique. North American Journal of Fisheries Management 4:626-635.

Hatch, D. R., J.K. Fryer, M. Schwartzberg, D.R. Pederson, and A. Wand. 1998. A computerized editing system for video monitoring of fish passage. North American Journal of Fisheries Management 18: 694-699.

Heintz,R.A., S. Rice, and B. Bue. 1996. Field and laboratory evidence for reduced fitness in pink salmon that incubate in oiled gravel in B. Barton and D.D. MacKinlay, eds. Proceedings of Contaminant Effects on Fish Symposium. International Congress on the Biology of Fishes. San Francisco State University.

Hill, R.A. 1997. Optimizing aerial survey count frequency for the area-under-the-curve method of estimating escapement. North American Journal of Fisheries Management 17:461-466.

Irvine, J.R., B.R. Ward, P.A. Teti, N.B.F. Cousens. 1991. Evaluation of a method to count and measure live salmonids in the field with a video camera and computer. North American Journal of Fisheries Management 11:20-26.

Kelez, G.B. 1947. Measurement of salmon spawning by means of aerial photography. Pacific Fisherman 45:46-51.

Mathisen, O.A. 1962. Photographic enumeration of red salmon escapement. Pages 349-372 in Koo, T.S.Y (ed.) Studies of Alaska Red Salmon. Univ. of Wash. Publ. In Fish. New Ser. 1: 449 pp.

Perrin, C.J. and J.R. Irvine 1990. A review of survey life estimates as they apply to the area-under-the-curve method for estimating the spawning escapement of pacific salmon. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1733.

Rice, B. 1987. Changes in the Harding Ice Field, Kenai Peninsula, Alaska: with implications for Kenai Fjords National Park, Alaska. M.S. thesis, School of Agriculture and Land Resources Management, University of Alaska Fairbanks.

Shardlow, T., R. Hilborn, and D. Lightly. 1987. Components analysis of instream escapement methods for pacific salmon (*Oncorhynchus spp.*). Canadian Journal of Fisheries and Aquatic Sciences 44:1031-1037.

York, G. and A. Milner. 1999. Colonization and community development of salmonids and benthic macroinvertebrates in a new stream within Kenai Fjords National Park, Alaska. Final Report to the National Park Service, Cooperative Agreement No. CA 9700-2-9021. 57 pp plus appendices.