THE FEASIBILITY OF DOCUMENTING AND ESTIMATING ADULT FISH PASSAGE AT LARGE HYDROELECTRIC FACILITIES IN THE SNAKE RIVER USING VIDEO TECHNOLOGY

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Prepared by:

Douglas R. Hatch
David R. Pederson
Jeffrey K. Fryer
Matthew Schwartzberg
Andrew Wand

Columbia River Inter-Tribal Fish Commission
Portland, Oregon

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EXECUTIVE SUMMARY

A field study was conducted at Lower Granite Dam on the Snake River in 1992 and 1993 to evaluate the feasibility of using video technology to document and estimate fish ladder passage of chinook salmon *Oncorhynchus tshawytscha,* sockeye salmon *0. nerka,* and steelhead *0. mykiss.*

Through the two years of study, a video system was developed and used that produced video images during salmon passage periods. A technician identified and counted fish images from the video record. Fish ladder passage estimates of target species made from the video record were similar to estimates made by on-site counters during daytime periods, indicating that the two methods were relatively precise. We also found that at Lower Granite Dam, a significant percentage (6.4% and 8.3%) of target salmonids migrated during nighttime periods when on-site counts were not typically made during the two years of study. Analysis of the video record permitted verification of individual sockeye salmon identified and counted by on-site count personnel, and provided data useful to managers of this ESA-listed stock. For example, in 1993, 31.3% of sockeye specimens were counted using video at times when on-site counts were not made, i.e. during the 10 minute-per-hour break periods and at nighttime. Analysis of the video record also permitted collection of additional data such as length measurements of individual specimens, which was used to regulate a fishery located upstream.

Direct cost comparisons indicated that counts of target species made using the video system were substantially lower to obtain than those based on on-site counting methods. The video method annually cost approximately 1/3 that of on-site counting. The estimate included all equipment costs annualized over a two year period.

A computer software demonstration program was developed that graphically illustrated the possibilities of obtaining accurate fish counts using a completely automated, machine-vision fish counting and identification system.

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INTRODUCTION

Project Background and Justification

This project was established to test the feasibility of using video technology to estimate and evaluate steelhead *(Oncorhynchus mykiss)*, sockeye salmon (0. *nerka),* and chinook salmon (0. *tshawytscha)* passage at Lower Granite Dam on the lower Snake River. The Snake River is the largest tributary of the Columbia River. Lower Granite Dam is a key fisheries monitoring location used by managers to assess the status of Snake River salmon stocks. Several of these stocks are in low abundance and have been listed as threatened or endangered under the federal Endangered Species Act (ESA 1973). Fisheries managers were interested in investigating “the feasibility and benefits of using video-based or other automatic counting and species recognition systems for monitoring adult fish passage at mainstem Columbia and Snake river dams” (NPPC 1993).

The standardized fish counting method now used at all U.S. Army Corps of Engineers (COE) dams including Lower Granite is based on “on-site” visual observations of migrating adult salmon at viewing windows in hydroelectric dam fish ladders. Fish passage is monitored generally between 1 March and 15 December and, during this time period, fish are counted for 8, 10, or 16 hours per day. Fish are counted for the first 50 minutes of each hour. These 50

minute counts for each day are totaled and then expanded to account for "break periods". Fish-ladder passage estimates made using the on-site method now employed are treated as absolute estimates, but because they are not repeatable, they are not subjected to tests for accuracy. Review for individual specimen identification is also not possible. Tests of counting precision are performed on a monthly basis, although due to the small size and configurations of the counting stations "blind" tests are difficult to perform. In the few times that blind tests have been performed, no difference was found between different observers' counts (Dan Rawding, WDFW personal communication).

Time-lapse video systems have been used to record salmon passage at various fish viewing stations throughout the Columbia River Basin (Hatch et al. 1994). This technique provides the opportunity to calculate variance and place confidence bounds on fish passage estimates. Video technology provides a permanent record of fish passage that can be reviewed multiple times by different readers to obtain accurate specimen and population abundance estimates. Time-lapse video also permits 24 h uninterrupted monitoring of fish ladder passage. In other studies of this methodology (Hatch et al. 1994), a significant proportion (approximately 8.5%) of the entire sockeye and chinook salmon runs in the Wenatchee River, Washington, were found to have migrated during the eight hours of the day when fish counting is not typically conducted at COE hydroelectric projects. Previous studies also reported that nighttime

passage ranged from 14.2% to 1.9% for chinook, 9.1% to 3.5% for steelhead, and 14.0% to 5.0% for sockeye at Bonneville, The Dalles, and John Day dams (Calvin 1975). In this study we evaluate the significance and composition of nighttime passage at Lower Granite Dam using the video fish counting system.

Video fish counting at Lower Granite Dam can also reduce data gathering costs by approximately 80% and increase the amount of data collected by 33% compared with on-site counting (Hatch et al. 1993). Video fish counting costs are site specific and may increase or decrease depending on the type of data collected or fish passage numbers .

Video fish counting requires the tedious task of reviewing a number of videotapes to count and identify specimens. To eliminate this task, we also investigated the potential to fully automate the fish counting procedure using machine vision technology.

Project Goal, Objectives, and Tasks

The goal of this project was to develop a video-technology based method to accurately, economically, and efficiently assess salmonid passage at Lower Granite Dam and to compare results to currently employed “on-site” visual count methods. The six tasks associated with this project were to:

1. Install a time-lapse video system to record adult fish passage at the fish counting station in Lower Granite Dam;
2. Document and calculate fish-ladder passage estimates for sockeye salmon, chinook salmon, and steelhead at Lower Granite Dam using time-lapse video technology;
3. Test the precision of fish counts of target species generated from time-lapse video recordings relative to on-site counts;
4. Compare the costs of producing annual fish ladder passage estimates from on-site and video counting;
5. Record, analyze, and archive individual passage events, particularly for sockeye and chinook salmon stocks that have been listed as endangered or threatened under the Endangered Species Act; and,
6. Investigate image processing techniques that may permit computerized counting and species identification from videotape records.

DESCRIPTION OF PROJECT AREA

Lower Granite Dam is located at river kilometer (rkm) 107 on the Snake River, Washington (Figure 1). Completed in 1975, the dam is part of the Lower Snake River Project of the COE, and provides navigation and electrical power generation throughout the year. It is 32 m high and 206 m long, and contains an adult fish passage facility. All upstream migrating fish must pass a single fish counting station (Figure 2). This station includes a counting room, with a 116 by 122 mm glass viewing window separating the counting room from the fish ladder. An adjustable crowder varies the width of the counting slot in the fish ladder from 45.7 to 91.4 cm. Fluorescent bulbs behind a glass diffuser located on the crowder provided backlighting in 1992. An encased front lighting system was installed and used in 1993.

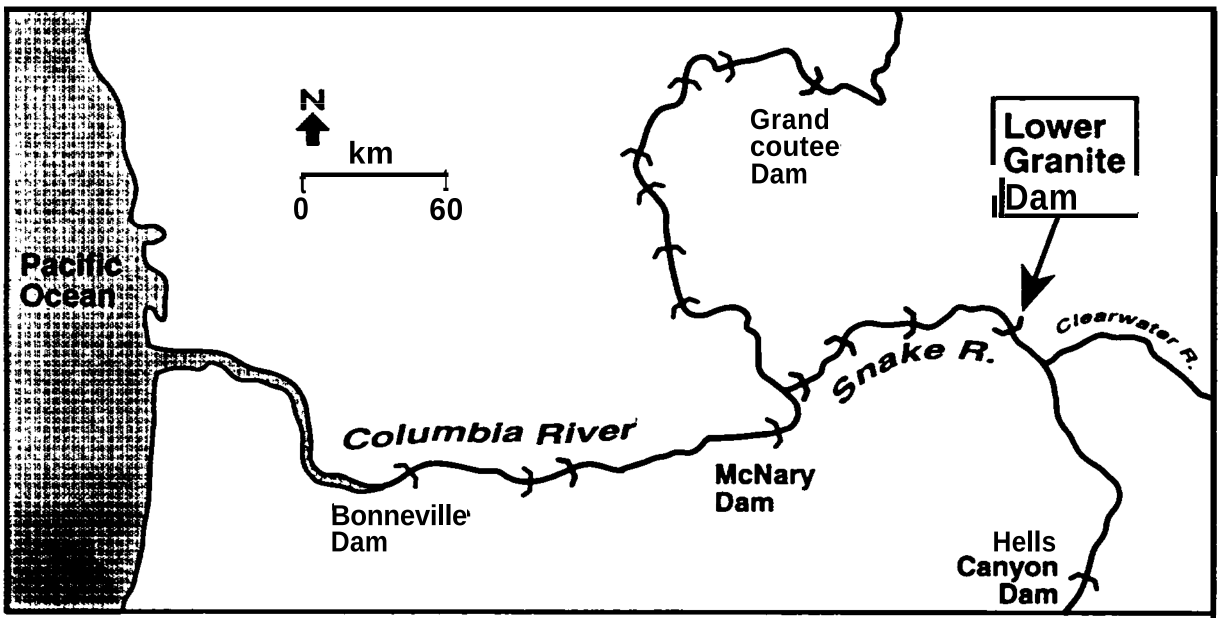


Figure 1. Map showing the location of Lower Granite Dam.

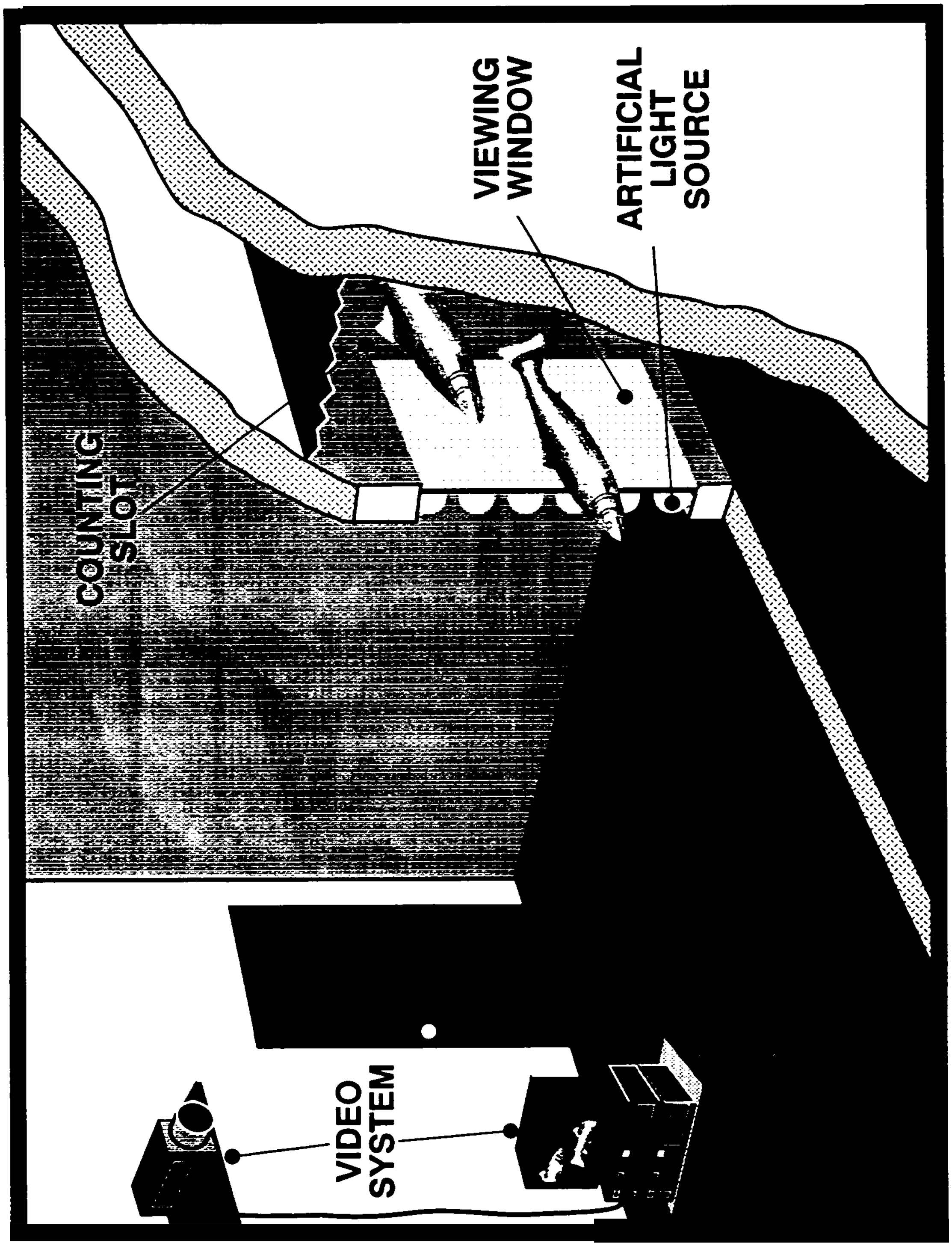


Figure 2. Diagram of a video fish-passage counting system similar to the one installed at Lower Granite Dam.

METHODS

Task 1. Recording Adult Fish Passage

A color-charged coupling device (CCD) camera (Panasonic WV-D51 00) was secured to the back wall of the counting room 2.2 m off the floor (Figure 2). The camera was aimed at the fish viewing window 3.3 m away. The camera was connected to a Panasonic AG-6720 time-lapse Super Video Home System (S-VHS) videotape recorder (VTR). Fish passage was recorded in 72 h time-lapse mode, a VTR setting that yields 1.66 video records per second. Studies made at Lower Granite and Tumwater dams, reported that this recording speed maximizes the amount of fish passage that can be captured on a given videotape cassette without missing fish passage during VTR frame advance (Hatch and Schwartzberg 1990; Hatch and Schwartzberg 1991; Hatch et al. 1993). During recording, the VTR imprinted the time and date on each frame of videotape, providing a record of the exact time each fish passed through the counting slot.

In the first study year, recording took place continuously from 1 April 1992, through 15 December 1992. Videotapes were changed five times each week (Monday through Friday) and mailed to our laboratory in Portland, Oregon for analysis. A few non-recorded time periods in the 1992 video record occurred, ranging from 10 minutes (6 September 1992) to 70 h (8-1 1 May

1992). No data loss representing greater than 10 minutes occurred between 1 June 1992 and 15 December 1992 when the majority of the data analyzed in this report was collected.

In the second study year, recording took place from 4 February 1993 through 31 December 1993. Lights were installed on 9 February 1993, at which time night counts were initiated. One tape was not changed on schedule and, therefore, ended recording on 13:59 on 18 April. Recording began again on 19 April at 10:OO. Power to the VTR was turned off by the on-site counter at the dam from 13:14 on 6 April, and continuous recording was restored by the CRITFC at 12:02 on 7 April. Estimates of fish passage during non-recording periods were made by interpolation using an average of the previous and following days' hourly counts.

During this study, several modifications were made to the counting room to improve videotape image quality. In early 1992, the videotape images were of relatively poor quality because lighting was insufficient. On 17 May 1992, six 90 watt halogen flood lights were placed around the viewing window inside the counting room. On 12 August 1992, four more lights were added. In addition, strips of black velvet were affixed to the shelf around the viewing window to reduce incidental glare caused by this extra lighting. Backlighting was turned down, and the crowder was adjusted to narrow the depth of the

counting slot to 45.7 cm. These adjustments provided lighting conditions that produced good-quality videotape images and were compatible with on-site counting procedures.

In 1993, a lighting engineer was consulted to provide technical advice regarding light modifications needed to provide optimal video picture quality in the fish viewing area. To further enhance video images and fjsh counting accuracy, the CRITFC, the COE, and the Washington Department of Fish and Wildlife (WDFW), [formerly the Washington Department of Wildlife (WOW)], discussed and agreed on the following modifications: installation of a ramp in the counting slot to direct fish off the bottom, extension of the window cleaning brush's length to clean the full width of the window, encasement of the side window lights, and elimination of back lighting and replacement with a white reflective background.

The initial entry ramp was extended 5.1 cm in an attempt to move fish off the bottom of the fish counting slot. The extended window cleaning brush increased the usable horizontal viewing window space by 38.1 cm. Encased light structures were placed in this increased viewing space. Both light structures contained an LT-4 track, seven CTL 602 light fixtures, and seven 90 watt halogen-IR bulbs. This light system was encased in a 106.7 cm by 25.4 cm by 22.9 cm metal box, with bulbs 15.2 cm away from the fish passage

window. Each light box was vented and installed with a fan to dissipate heat within the boxed area. An LT-4 track, two T442 fixtures, and two 60 watt halogen bulbs were placed along the outer sides of the upper viewing area. Also, one L651 track, two L2770 lampholders, and two 65MR16 50 watt bulbs were placed at the bottom viewing area. The total wattage for the lighting system was 1,480. The lamp angles were adjusted to provide the best illumination when the crowder was 91.4 cm from the viewing window. On 7 April 1993, the number of lights in the boxed system was reduced from seven to six lights each, and the lights on the bottom sill (the 65MR16s) were removed. On 17 June 1993, all 90 watt bulbs were replaced with 60 watt halogen-IR (Par 38) lamps, reducing the total wattage to 840.

In 1992, the video camera was originally placed in its upright position, and captured a 115.6 by 78.6 cm section of the viewing window. This field of view encompassed the entire width of the window, but did not include the top 43.3 cm. In an attempt to reduce the vertical area missed, the camera was readjusted on 9 July 1992 to capture a 115.6 by 86.1 cm section of the viewing window. The camera was readjusted on 12 August 1992 by orienting it vertically (turning it on its side) to eliminate the possibility of fish avoiding the upper limit of the camera's field of view. This modification allowed the camera to capture the entire height of the viewing window and 86.4 cm of the window's width. In 1993, the camera remained vertically orientated, giving a

88.9 cm horizontal by 122.0 cm vertical camera view of the fish counting window.

Task 2. Fish Ladder Passage Estimates Using Time-Lapse Video

Tapes from 1992 and 1993 were reviewed by an experienced fish counter using a special VTR (Panasonic AG-1960) equipped with a jog/shuttle dial. This dial allows precise control of tape movement, in forward or reverse, at speeds ranging from freeze frame to 7X normal speed. Steelhead, chinook adult and chinook jack (<55.9 cm) salmon, and sockeye salmon counts were tallied for the first 50 min. of each hour and for the entire hour. All hourly counts were summed to produce daily counts, which were distributed to several agencies within one week after recording.

The mean dates of migratory timing and their associated standard deviations were calculated (Mundy 1982) for steelhead, sockeye, and chinook salmon.

Nighttime counts for each species were calculated. Nighttime hours, in both 1992 and 1993, were considered to be those hours when on-site counts were not made. In 1992, this period included 2100 to 0500 (from 1 June to 24 October), 2000 to 0400 (from 25 October to 31 October), and 1600 to 0600 (from 1 November to 15 December). In 1993, nighttime periods included

1600 to 0800 (from 1 March to 30 March), 1600 to 0400 (on 31 March), 2000 to 0400 (on l-2 April), 2000 to 0500 (on 3 April), 2100 to 0500 (from 4 April to 29 October), 2100 to 0400 (on 30 October), 2000 to 0600 (on 31 October), and 1600 to 0600 (from 1 November to 15 December).

Particular attention was paid to observations of sockeye salmon because of the importance placed by fishery managers on conservation of this stock and the relatively small number of fish in this population. Whenever a sockeye salmon was observed, its fork length was measured and recorded. The length estimate was determined by measuring the fish image in each frame and using the maximum length recorded. Water magnifies the size of the fish, and the further from the glass the fish was in the viewing chamber, the smaller the fish would appear on the video record. Measurements were calibrated to a standard of known length via Bioscan's OPTIMAS (BioScan 1990) image processing program. Fork length measurements were also taken on weekly samples of chinook and steelhead between 28 February and 18 August 1993.

Task 3. Precision of Video Relative to On-Site Fish Counting

Three tests were performed to investigate the precision of video-based fish passage estimates relative to on-site fish counting. Data from 1992 and 1993 was tested independently and combined. Paired t-tests (Mendenhall 1983) were used to compare video-based and on-site fish counts. For all tests

a, the probability of a Type I error, was set at 0.05. Test 1 compared daily fish passage estimates for steelhead, chinook salmon total (combined adults and jacks), chinook salmon adults, and chinook salmon jacks. On-site counts were provided by the COE, whose estimates were made by counting for 50 min. per hour for 8, 10, or 16 hours per day. These counts were taken from the COE maintained Columbia River Hydro-Management System (CROHMS) database on 6 January 1993 for the 1992 data and 16 March 1994 for the 1993 data. At the end of each day, the counts were expanded by a factor of 1.2 to account for the 10 min. break periods taken each hour by on-site fish counters. Depending on the time of year, on-site counts were made for either 8, 10, or 16 hours in a given day. Our video-based fish counts were made for the entire 8, 10, or 16 hour period corresponding to COE's counting-day length. Test 2 used the same COE data described above, but the video data consisted of 24 hour fish passage estimates.

To investigate the potential error that the 1.2 expansion factor, used to adjust 50 min. counts to estimate hourly fish passage, had on fish passage estimates, we conducted a paired t-test on video data. This third test used daily fish passage estimates generated from 60 min. counts compared with estimates generated from 50 min. counts expanded by 1.2.

In addition to the tests of hypothesis mentioned above, correlations between each variable were made using Pearson's Correlation (Hays 1988) and Spearman's Rank Correlation methods (Conover 1980).

A potential source of counting error attributed to video counting is the possibility of a fish swimming past the viewing window at a velocity great enough to exclude the capture of the fish image on time-lapse videotape. Since there was no published data about fish swimming speeds at the Lower Granite Dam fish counting slot, an experiment to calculate the average amount of time that fish spend in the viewing window was conducted. The video signal from the camera was routed to a second VTR recording simultaneously with the primary VTR used in this study. This second VTR recorded in 6 h time-lapse mode, a speed that generates 60 video records per second. In contrast, the primary VTR, recording in 72 h mode, generated 1.66 video records per second. The 6 h recordings were made on 7 randomly selected days in 1992 and on 14 days in 1993. The number of frames were counted that each individual fish appeared on each 6 h tape. From these data, the probability of a fish appearing in X number of 72 h time-lapse recorded video frames was calculated.

Task 4. Video and On-Site Counting Cost Comparisons

Comparisons were made between the estimated costs of video fish counting at Lower Granite Dam and a comparable on-site fish counting

methodology. We did not use financial information from the COE or WDFW who currently perform on-site counting at Lower Granite Dam. On-site counting costs were estimated by calculating the total number of hours during which counting was performed and multiplying by $12, the approximate hourly wage of on-site fish counters. On-site counting generally takes place for 8 h/day (1 March to 31 March), 16 h/day (1 March to 31 October), or 10 h/day (1 November to 15 December), and is performed 7 days per week. No additional costs including administrative and indirect costs were included in the estimate. Note that this comparison is based on producing counts of target salmonids and does not include any additional tasks that may be carried out by on-site counters.

In the cost estimation comparison, we estimated the cost of a video system based on the cost required to count the same number of hours as the present on-site counting program. In addition to salary costs, for the video system, equipment, videotape, and mailing expenses were also included. Equipment costs were based on the purchase price of new equipment and the entire equipment cost was included in the video count cost estimated, although this equipment is estimated to be serviceable beyond the two years of this study. As in the on-site count cost estimate, administrative, and indirect costs were not included in the video count cost estimate.

Task 5. Record, Analyze, and Archive Individual Passage Events

The permanent videotape record was used throughout the two counting seasons to verify the passage of individual sockeye salmon. The majority of the time that on-site counters observed a sockeye salmon, the time and date of passage was noted in 1992, all times and dates were noted in 1993. Coincidence of observation between the two methods helped to verify individual specimen identification. On occasions when on-site counters identified a sockeye salmon but video counting originally did not, the video record was reviewed additional times for specimen confirmation. On occasions when sockeye salmon were identified by video counters but not by on-site counters, no further analysis of on-site counts could be made, although these specific video records were reviewed repeatedly for positive confirmation.

Task 6. Computerized Counting and Species Identification from Videotape Records

Tardis Systems Inc., an image processing consulting group based in Los Alamos, New Mexico, was consulted to undertake a proof-of-principle study to examine computerized fish counting from videotape records. A software demonstration program was created that uses a number of advanced image processing techniques to count and speciate fish on several digitized sequences of video frames.

This machine vision problem was partitioned into five primary processing steps to be performed on the videotape frames being analyzed. These steps were to:

a. Determine whether a fish is present in the current frame;
b. Remove the background from the frame if a fish is present;
c. Locate each discrete object, or *blob,* and extract relevant features;
d. Analyze each blob to determine the number and species of fish present in the frame;
e. Count fish passage by keeping track of when fish entered and exited the counting slot.

A complete report on this task is attached as Appendix (A). The demonstration program was tested on eight different frame sequences that contained a total of 70 fish images.

RESULTS

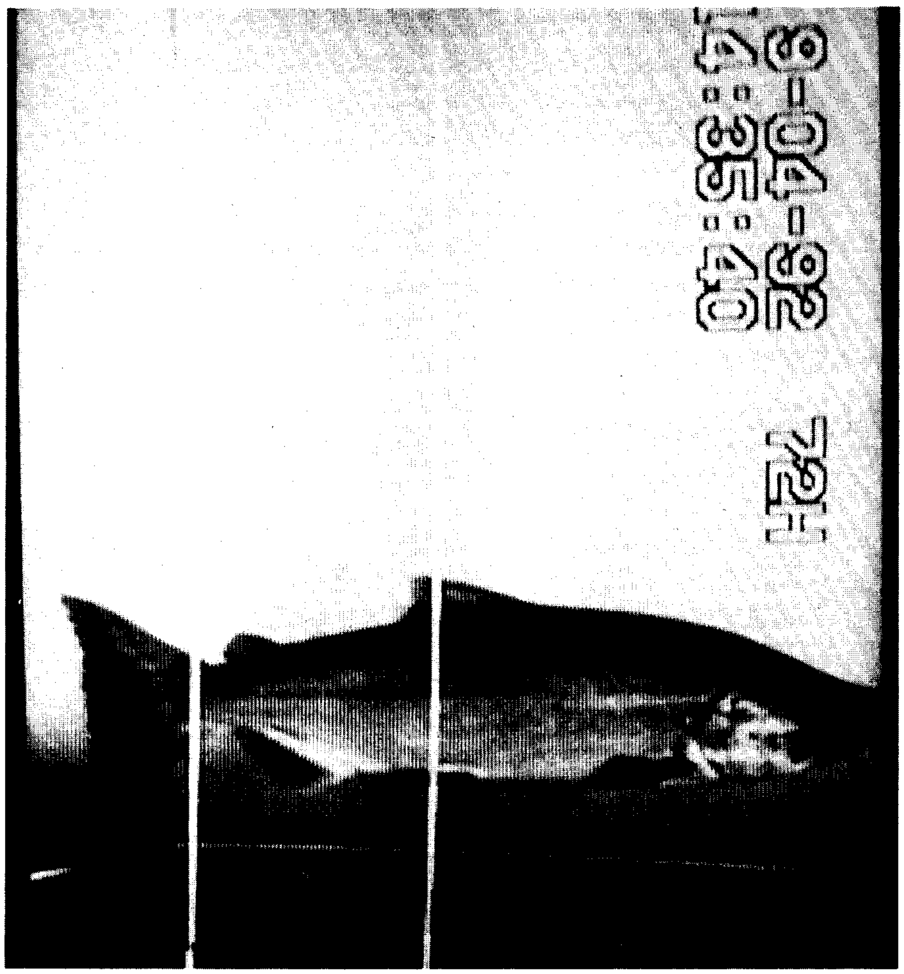
Task 1. Recording Adult Fish Passage

In 1992, a total of 123 videotapes were recorded, changed, and mailed during the period from 1 June to 15 December. One tape was lost in the mail and not received for review. In 1993, a total of 184 videotapes were recorded, changed, and mailed during the period 1 March to 15 December. Data was also collected from 4 February through 28 February, and from 16 December through 31 December 1993. Image quality was good to excellent in 1992, especially after lighting modifications were made. During 1993, picture quality declined after 1 March because of light angle modifications, irregular window cleaning schedules, and adjustments made to the back crowder (Figure 3).

Task 2. Fish Ladder Passage Estimates Using Time-Lapse Video

1992 Fish Counts

Adult chinook and jack salmon, steelhead, and sockeye salmon fish passage estimates derived from videotape records from 1 June through 15 December 1992 were 7,020, 666, 125,599, and 15; respectively (Appendices A, B, C). Since the video feasibility project did not begin until 1 June 1992, there is not enough data to provide spring fish counts. Summer chinook adult and jack counts were 2,924 and 359. Fall chinook salmon adult and jack counts were 858 and 164. The mean dates of passage at Lower Granite Dam



-Figure 3. Fish image photographed from the video monitor screen.

were 28 July, 29 September, 7 October, and 22 July, for summer chinook, fall chinook, steelhead, and sockeye; respectively, with associated standard deviations of 7.1, 20.8, 20.2, and 21.4. Adult chinook salmon passage distribution showed a peak on 2 July and passage counts dropped to near zero from approximately 30 July through 3 September (Figure 4). Jack chinook salmon passage distribution generally followed that of adults. Steelhead passage generally showed a normal distribution with the bulk of passage occurring between mid-September through October (Figure 5). The maximum daily count of sockeye salmon was two (Figure 6).

1993 Fish Counts

Video-based adult chinook and jack salmon, steelhead, and sockeye salmon fish passage estimates for the entire 1993 season (1 March through 15 December, 1993) were 31,022, 339, 72,916, and 11; respectively (Appendices E, F, G). Spring chinook adult and jack counts were 22,146 and 166. Summer chinook adult and jack counts were 7,629 and 133. Fall chinook adult and jack counts were 1,247 and 40. The mean dates of passage at Lower Granite Dam were 29 May, 21 September, 29 August, and 14 July, for spring/summer chinook, fall chinook, steelhead, and sockeye; respectively, with associated standard deviations of 22.4, 17.2, 73.6, and 10.5. In 1993, adult chinook salmon distribution showed three major modes during the majority of the migration occurring between 19 April and 17 July (Figure 4). Counts of

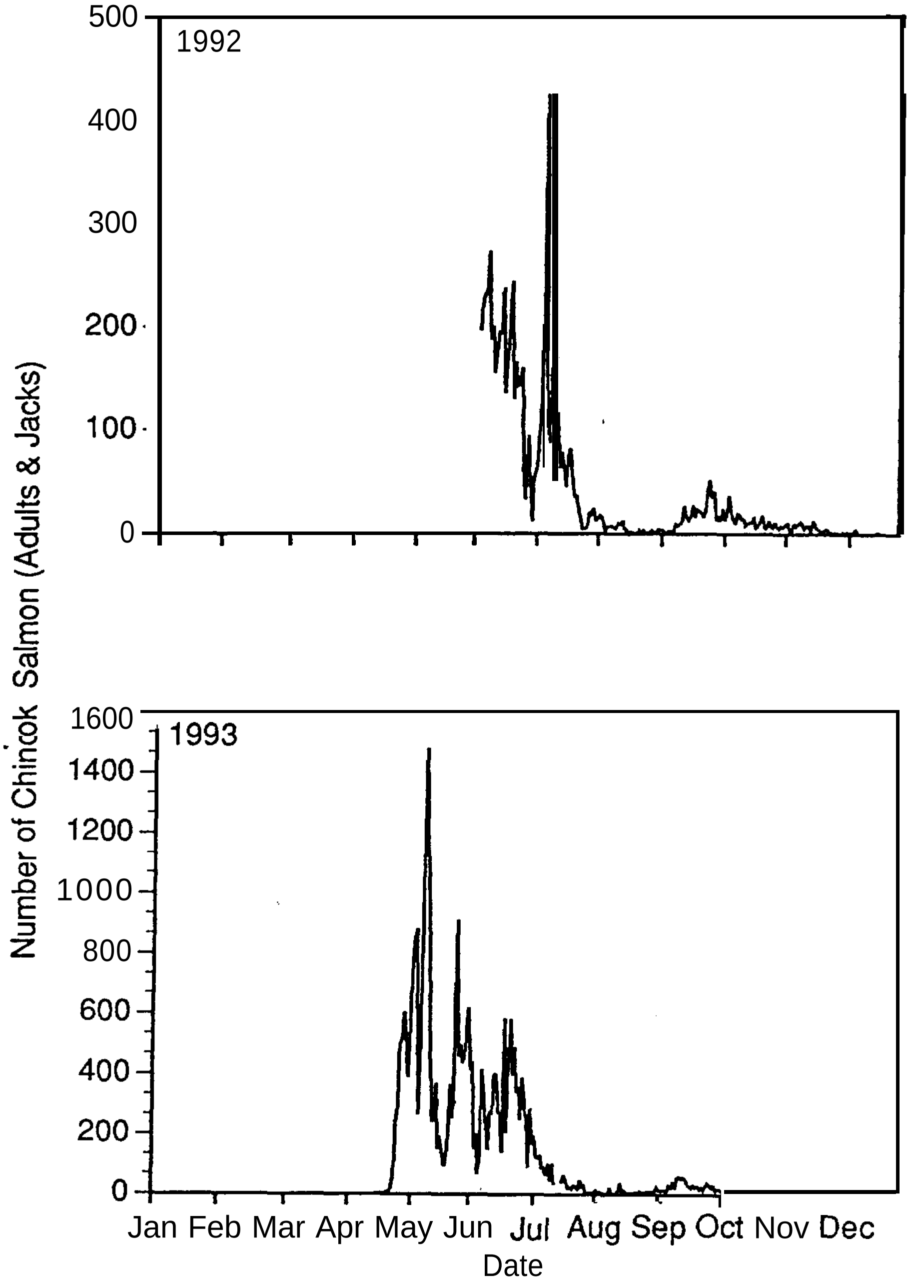


Figure 4. Snake River chinook salmon fish ladder counts made at Lower Granite Dam using video technology in 1992 and 1993.

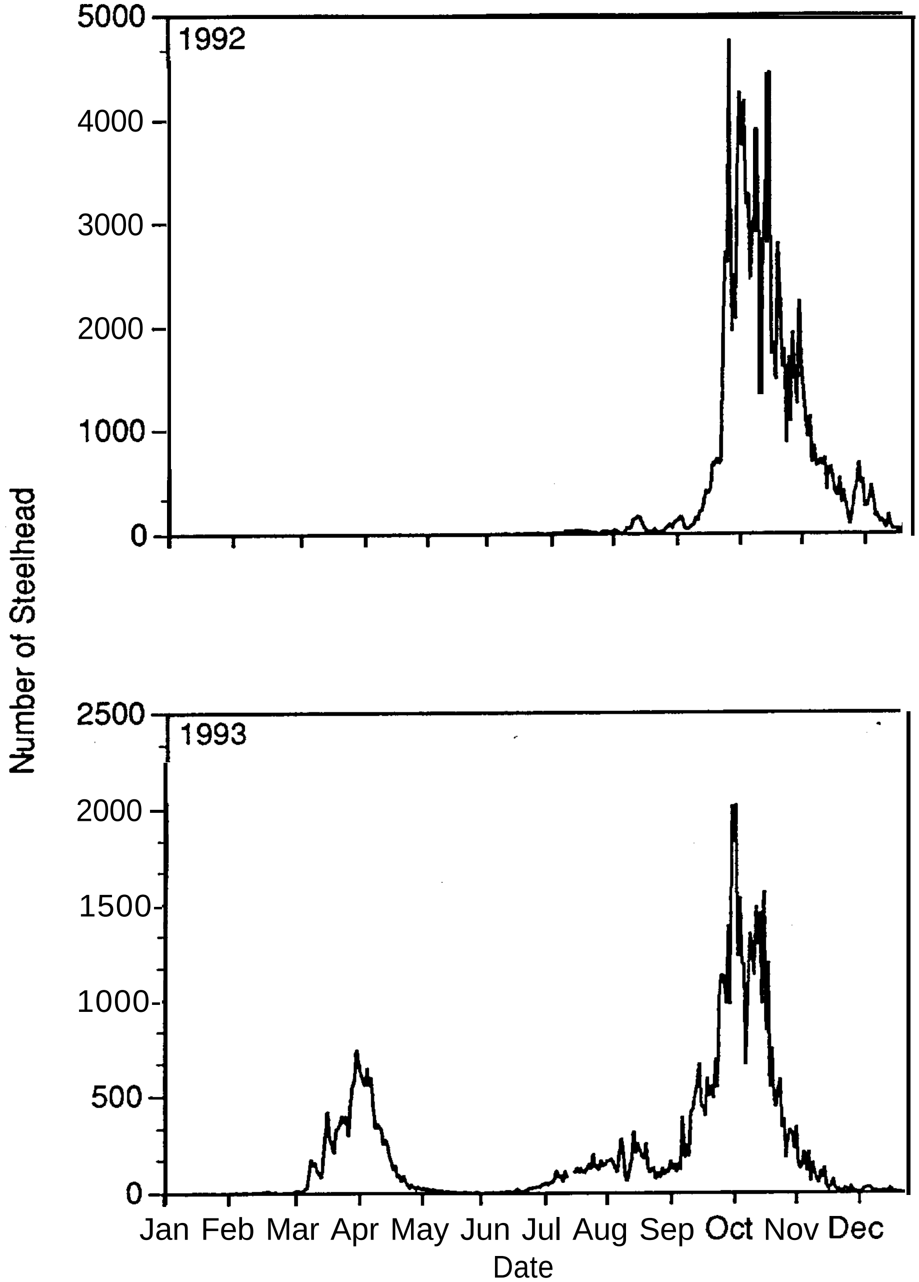


Figure 5. Snake River steelhead fish ladder counts made at Lower Granite Dam using video technology in 1992 and 1993.

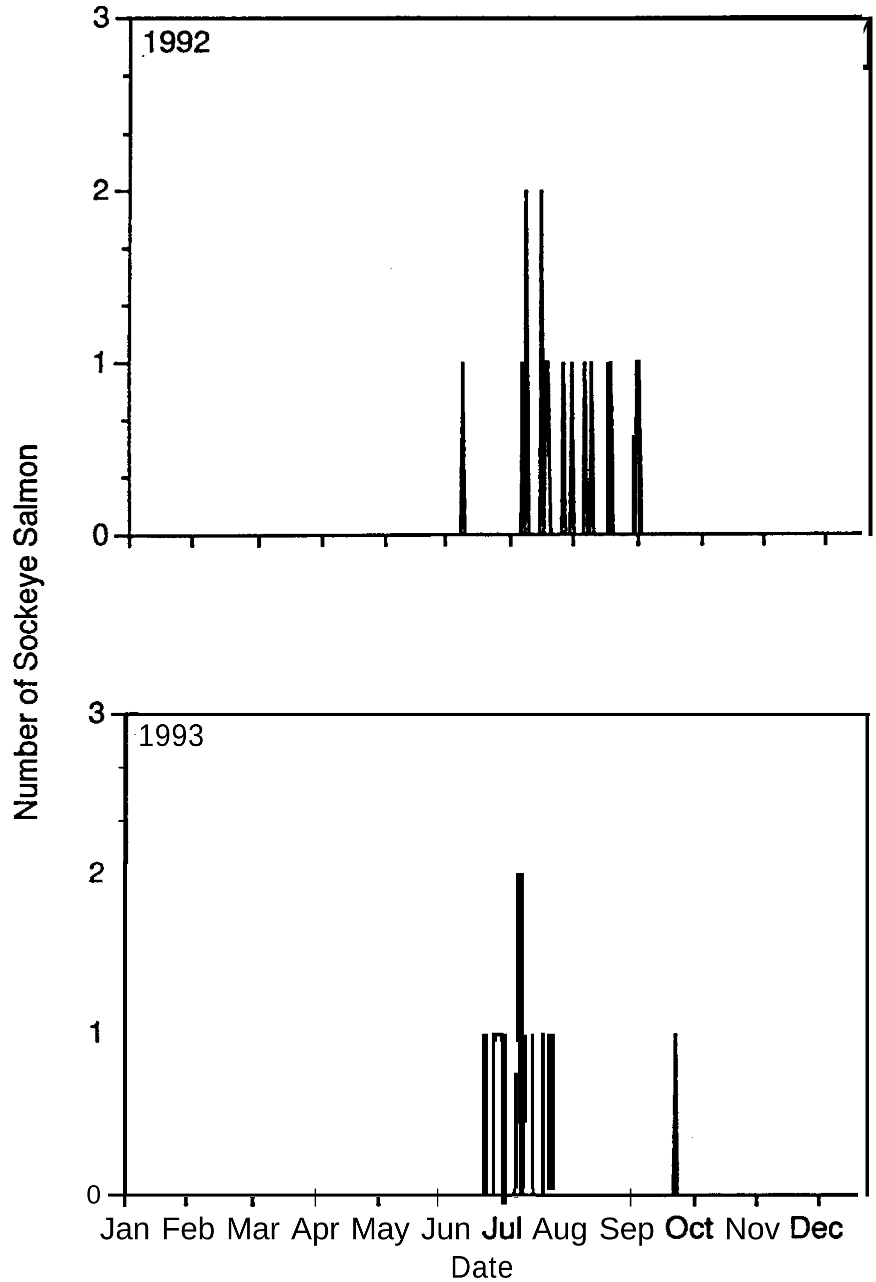


Figure 6. Snake River sockeye salmon fish ladder counts verified using video technology at Lower Granite Dam in 1992 and 1993.

jack chinook salmon were lower in 1993 than 1992. The peak of the 1992 jack chinook migration, representing 12 fish, occurred on 28 May, 1993. The steelhead migration showed a bi-modal distribution. The smaller mode peaked on 3 April 1993 and the larger mode peaked on 7 October 1993 (Figure 5). All sockeye salmon, except two, migrated past the Lower Granite Dam Counting Station during the month of July in 1993 (Figure 6). The exceptions migrated past on 27 June 1993 and 28 September 1993. The highest daily sockeye salmon count was two.

Nighttime Counts

From 1 June through 15 December 1992, a total of 133,300 fish of target species (chinook salmon, steelhead, and sockeye salmon) were counted. Of these 133,300 fish, 8,555 (6.4%) were counted during the nighttime period. The nighttime is that period of time when COE fish counting was not conducted. Video counts of nighttime fish passage were 244 (3.5%), 27 (4.1%), 3 (20.0%), and 8,281 (6.6%), for adult chinook, jack chinook, sockeye, and steelhead; respectively (Figure 7). From 1 March through 15 December 1993, a total of 104,288 fish of target species were counted. Of these 104,288 fish, 8,687 (8.3%) were counted during the nighttime period. Video counts of nighttime fish passage were 1413 (4.6%), 21 (6.2%), 1(9.1%), and 7,252 (1 O.O%), for adult chinook, jack chinook, sockeye, and steelhead; respectively (Figure 7).

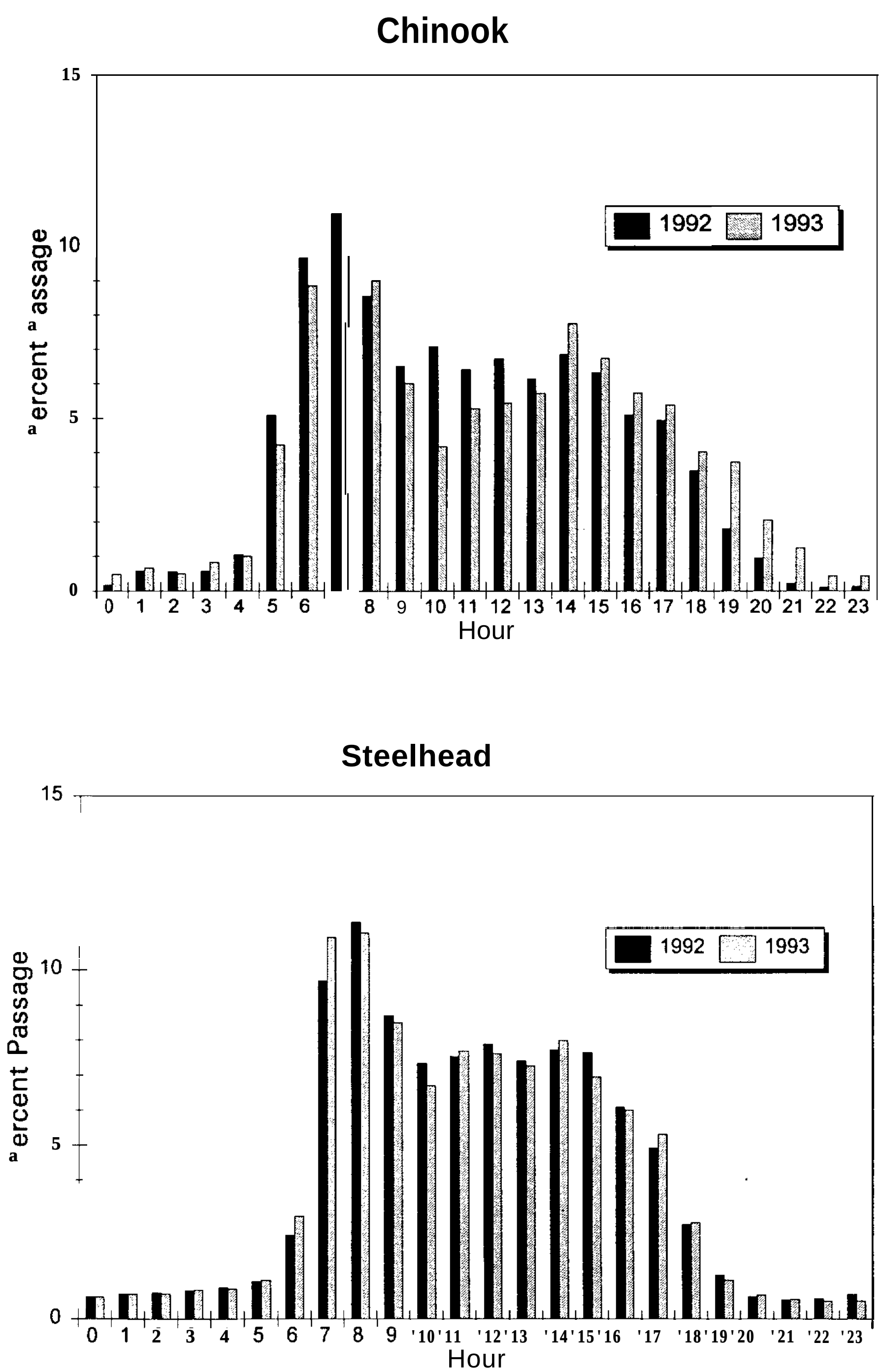


Figure 7. Nighttime passage of steelhead and chinook between 1 June and 15 December 1993. .

Length Estimates

The sockeye salmon length frequency ranged from 356 to 539 mm, and 366 to 578 mm in 1992 and 1993; respectively. The average estimated length of sockeye salmon was 453 mm in 1992, and 505 mm in 1993 (Figure 8).

Fork length estimates of adipose-clipped chinook salmon ranged from 504 mm to 1 ,011 mm and averaged 805 mm, based on 239 observations, made between 28 February 1993 and 18 August 1993. The fork length of chinook salmon with intact adipose fins ranged from 356 mm to 1,067 mm, and averaged 810 mm, based on 958 observations, made between 28 February 1993 and 18 August 1993. Fork length estimates for adipose clipped steelhead ranged from 312 mm to 1 ,019 mm, based on 1,206 observations, between 28 February 1993 and 18 August 1993. The fork length of steelhead with intact adipose fins ranged from 384 mm to 914 mm and averaged 671 mm, based on 333 observations, between 28 February 1993 and 18 August 1993. Table (1) summarizes chinook and steelhead lengths by sample week.

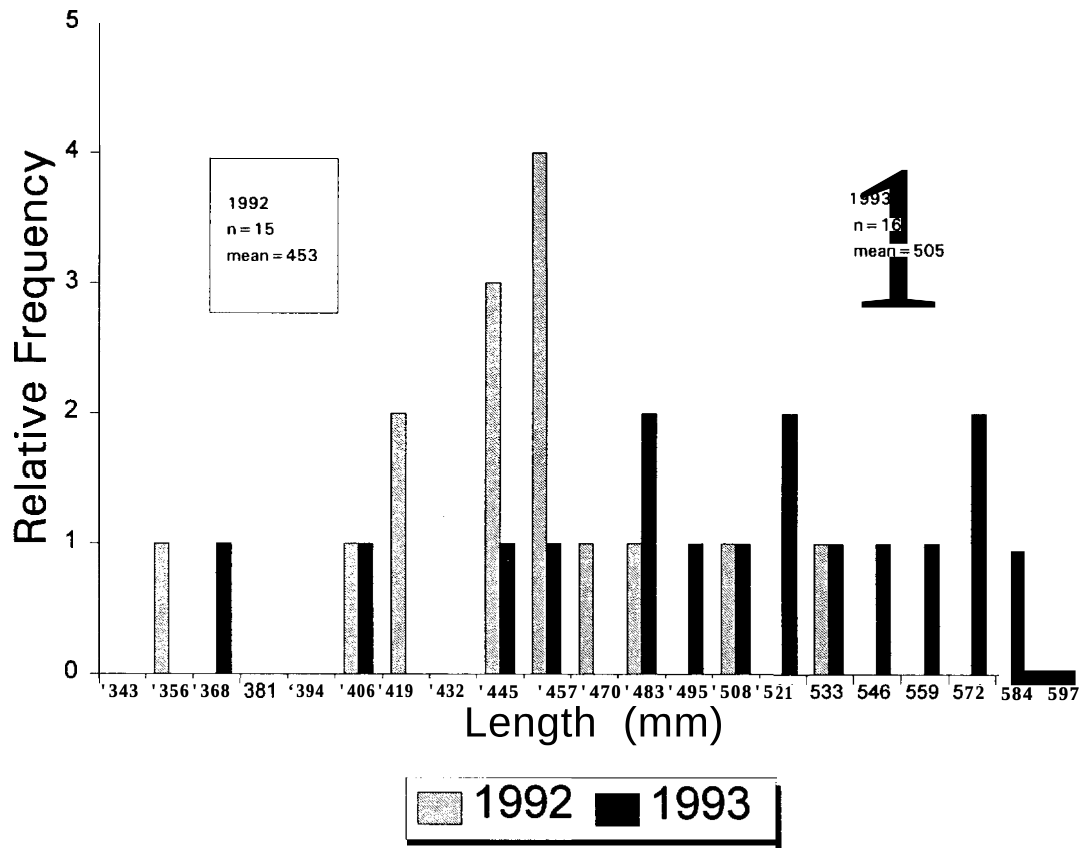


Figure 8. Sockeye salmon length frequency measured from video recorded at Lower Granite Dam in 1992 and 1993.

Table 1. Length estimates for Columbia Basin spring and summer chinook, and steelhead that passed Lower Granite Dam from 28 February 1993 through 18 August 1993.

	Chinook Clipped	Chinook Unclipped	Steelhead Clipped	Steelhead Unclipped
28 February--6 March				
Sample Size			23	3
Minimum (cm)			53.4	53.9
Maximum			101.0	65.6
Mean fork length			68.6	59.8
Standard Deviation			12.3	5.8
7 March--13 March				
Sample Size			70	5
Minimum (cm)			50.9	63.0
Maximum			89.9	89.2
Mean fork length			73.6	75.9
Standard Deviation			10.7	10.4
14 March--20 March				
Sample Size			70	5
Minimum (cm)			44.9	58.9
Maximum			89.6	84.6
Mean fork length			71.4	72.5
Standard Deviation			11.6	10.3
21 March--27March				
Sample Size			63	12
Minimum (cm)			50.4	56.2
Maximum			94.6	90.6
Mean fork length			67.2	67.0
Standard Deviation			11.1	11.8
28 March--3 April				
Sample Size			67	8
Minimum (cm)			48.1	57.2
Maximum			104.0	77.2
Mean fork length			68.6	68.1
Standard Deviation			13.2	6.7
4 April--10 April				
Sample Size			56	19
Minimum (cm)			49.3	57.5
Maximum			91.1	88.6
Mean fork length			70.3	74.1
Standard Deviation			12.4	10.7
11 April--17April				
Sample Size			63	12
Minimum (cm)			48.0	58.7
Maximum			91.4	88.2
Mean fork length			68.3	74.2
Standard Deviation			11.4	9.3

Table 1. Continued

	Chinook Clipped	Chinook Unclipped	Steelhead Clipped	Steelhead Unclipped
18 April--24 April				
Sample Size		9	51	24
Minimum (cm)		41.1	45.4	55.0
Maximum		92.c	83.6	91.4
Mean fork length		70.2	63.2	70.5
Standard Deviation		18.C	9.4	9.4
25 April--1 May				
Sample Size	17	59	52	22
Minimum (cm)	64.8	46.2	46.9	51.5
Maximum	93.8	90.2	84.5	90.0
Mean fork length	74.3	76.E	62.3	70.1
Standard Deviation	7.9	8.E	9.9	10.8
2 **May--8 May**				
Sample Size	13	62	35	40
Minimum (cm)	67.4	63.2	40.6	53.4
Maximum	89.0	98.5	80.2	87.9
Mean fork length	79.8	80.7	57.5	69.1
Standard Deviation	6.9	8.C	8.6	9.9
9 May--15 May				
Sample Size	12	64	38	36
Minimum (cm)	62.8	63.3	48.9	50.3
Maximum	88.4	98.4	73.6	85.9
Mean fork length	77.6	77.9	58.8	65.6
Standard Deviation	7.0	8.5	7.0	10.0
16 May--22 May				
Sample Size	32	4:	25	22
Minimum	61.6	57.5	48.2	52.6
Maximum	96.8	99.4	76.0	79.8
Mean fork length	79.4	79.4	60.1	64.5
Standard Deviation	7.8	8.5	7.2	6.4
23 **May-29 May**				
Sample Size	17	58	11	7
Minimum (cm)	64.8	49.5	47.2	38.3
Maximum	95.5	102.7	74.6	77.6
Mean fork length	77.3	81.5	60.7	64.8
Standard Deviation	a.0	9.2	9.5	14.1
30 May--5 June				
Sample Size	10	65	14	2
Minimum (cm)	69.8	44.9	50.4	54.2
Maximum	96.7	105.1	80.4	59.6
Mean fork length	83.3	83.9	61.8	56.9
Standard Deviation	a.4	11.8	8.8	3.8

Table 1. Continued

	Chinook Clipped	Chinook Unclipped	Steelhead Clipped	Steelhead Unclipped
6 June--12 June				
Sample Size	20	55	11	2
Minimum (cm)	59.6	48.7	52.7	53.3
Maximum	96.0	97.6	72.4	56.0
Mean fork length	80.1	79.3	63.8	54.6
Standard Deviation	9.6	10.5	4.9	1.9
13 June--16 June				
Sample Size	19	56	21	4
Minimum (cm)	64.8	53.8	51.4	62.6
Maximum	96.4	96.5	75.8	69.7
Mean fork length	82.0	82.7	66.5	, 66.9
Standard Deviation	9.0	9.8	5.6	3.1
20 June--26 June				
Sample Size	18	55	34	2
Minimum (cm)	61.9	65.5	44.4	52.7
Maximum	96.4	103.5	100.1	87.5
Mean fork length	82.7	84.7	65.5	70.1
Standard Deviation	8.3	10.0	5.6	24.5
27 June--3 July				
Sample Size	16	56	68	10
Minimum (cm)	71.c	57.1	50.3	60.8
Maximum	96.6	105.3	77.5	87.1
Mean fork length	85.6	81.6	67.1	70.6
Standard Deviation	6.4	9.9	5.4	8.8
4 July--10 July				
Sample Size	17	58	67	a
Minimum (cm)	72.2	63.8	53.4	58.2
Maximum	101.1	101.6	75.9	71.5
Mean fork length	83.9	82.2	66.7	64.9
Standard Deviation	7.9	a.8	4.0	4.8
11 July--17 July				
Sample Size	13	62	74	6
Minimum (cm)	50.4	56.9	31.2	56.7
Maximum	93.0	102.1	77.9	87.1
Mean fork length	80.4	84.3	62.7	64.9
Standard Deviation	13.0	9.9	11.3	11.3
18 July--24 July				
Sample Size	9	66	62	13
Minimum (cm)	64.3	47.3	49.9	61.6
Maximum	99.0	100.4	76.0	73.7
Mean fork length	82.7	81.5	65.8	67.0
Standard Deviation	12.8	10.7	5.1	3 . 9

Table 1. Continued

	Chinook Clipped	Chinook Unclipped	Steelhead Clipped	Steelhead Unclipped
25 **July--31 July**				
Sample Size	13	60	68	9
Minimum (cm)	59.4	54.8	51.7	55.6
Maximum	98.2	101.9	74.3	69.2
Mean fork length	82.E	81.0	64.4	62.2
Standard Deviation	9.2	9.7	5.0	3.7
1 August--7 August				
Sample Size	7	68	60	15
Minimum (cm)	65.1	48.8	52.4	50.7
Maximum	9o.c	106.6	79.8	78.0
Mean fork length	76.E	82.1	64.8	63.1
Standard Deviation	12.1	11.5	6.2	6.8
8 August--14 August				
Sample Size	2	35	53	22
Minimum (cm)	74.2	44.7	50.2	50.8
Maximum	90.9	95.2	75.5	67.6
Mean fork length	82.6	79.7	63.4	60.9
Standard Deviation	11.8	12.2	5.5	4.9
15 August--18 August				
Sample Size	4	27	50	25
Minimum (cm)	72.3	35.6	48.0	52.6
Maximum	91.9	92.2	76.7	76.7
Mean fork length	78.7	71.2	62.5	63.5
Standard Deviation	8.9	14.2	6.6	6.9
7993 Composite				
Sample Size	239	958	1206	333
Minimum (cm)	50.4	35.6	31.2	38.3
Maximum	101.1	106.6	104.0	91.4
Mean fork length	80.5	81.0	65.8	67.1
Standard Deviation	9.0	10.4	9.7	9.5

Task 3. Precision of Video Relative to On-Site Fish Counting

Test I, comparison of on-site and video counts (corresponding time periods)

Using 1992 data, Test 1, revealed that there was a nonsignificant ($p = 0.397$) difference between both methods in the composite count of target species (Table 2). Paired t-tests also resulted in nonsignificant differences between the two methods using steelhead counts ($p = 0.128$). Video counts of chinook salmon were significantly lower than on-site counts for adults and jacks combined ($p = 0.001$), and for separate adult ($p < 0.001$) and jack counts ($p < 0.001$). Pearson and Spearman correlations were all highly significant and ranged from 0.862 to 0.998 for Pearson's r^2 and from 0.897 to 0.997 for Spearman's Rho (Figure 9, Table 3).

Using 1993 data, Test 1, revealed that there was a statistically significant difference ($p = 0.003$) between both methods in the composite count of target species (Table 2). Paired t-tests also resulted in nonsignificant differences between the two methods using chinook adult counts ($p = 0.096$), chinook jack counts (0.158), and total chinook salmon counts ($p = 0.073$). Video counts of steelhead were significantly ($p = 0.013$) less than on-site counts although the mean difference was 2.9 steelhead per day and the annual totals differed by only 1.6% (video total = 95,591 vs. on-site total = 97,137).

Table 2. Comparison (using paired t-tests) between daytime video-based fish counts and on-site counts at Lower Granite Dam in 1992 and 1993 by species. Daytime indicates the time period when both systems operated simultaneously.

Species	Year	n	Mean Diff.	S.D. Diff.	t	DF	P
Chinook Adult	1992	198	-2.727	9.144	-4.197	197	<0.000
Chinook Adult	1993	312	-1.035	10.939	-1.672	311	0.096
Chinook Adult	92&93	510	-1.692	10.303	-3.709	509	< 0.000
Chinook Jx	1992	198	0.646	1.688	5.389	197	<0.000
Chinook Jx	1993	312	-0.093	1.160	-1.416	311	0.158
Chinook Jx	92&93	510	0.194	1.433	3.058	509	0.002
Chinook Ad&Jx	1992	198	-2.081	8.905	-3.288	197	0.001
Chinook Ad&Jx	1993	312	-1.128	11.060	-1.802	311	0.073
Chinook Ad&Jx	92&93	510	-1.498	10.279	-3.291	509	0.001
Steelhead	1992	198	4.869	44.821	1.528	197	0.128
Steelhead	1993	312	-2.926	20.622	-2.506	311	0.013
Steelhead	92&93	510	0.100	32.432	0.070	509	0.945

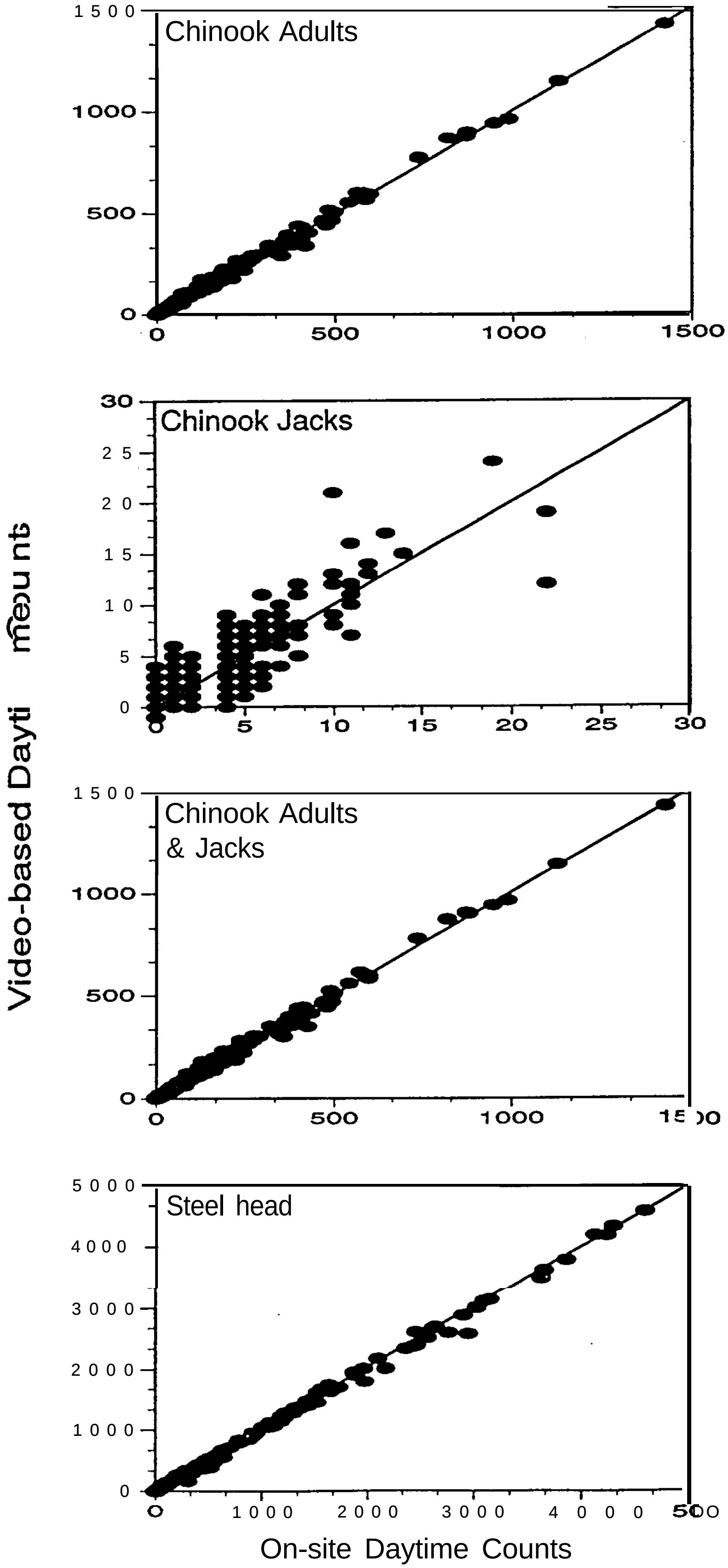


Figure 9. Correlations of video-based fish counts to on-site fish counts made during equivalent time periods (predominantly 16 h-per-day) at Lower Granite Dam in 1992 and 1993. The 24 h-per-day video record was subsampled to represent the same time period on-site counts were made. The diagonal line represents a one-to-one relationship.

Table 3. **Correlation (Pearson's r^2 and Spearman's Rho) between daytime video-based fish counts and on-site counts at Lower Granite Dam in 1992 and 1993 by species.**

Species	Year	n	ratio	S.E.	p	r^2	Rho
Chinook Adult	1992	198	0.933	0.009	<0.000	0.984	0.982
Chinook Adult	1993	312	0.990	0.003	<0.000	0.997	0.989
Chinook Adult	92&93	510	0.987	0.003	<0.000	0.996	0.987
Chinook Jx	1992	198	1.079	0.031	<0.000	0.862	0.897
Chinook Jx	1993	312	0.751	0.023	<0.000	0.781	0.784
Chinook Jx	92&93	510	0.978	0.020	<0.000	0.823	0.845
Steelhead	1992	198	1.003	0.003	<0.000	0.998	0.997
Steelhead	1993	312	0.998	0.003	<0.000	0.996	0.990
Steelhead	928493	510	1.003	0.002	<0.000	0.998	0.993

The practice of expanding 50 min counts to account for break periods results in the elimination of fish counts of 3, 9, 15, and further increments of 6 from COE reported counts. This data phenomenon may have an effect on Test 1 comparisons. Pearson and Spearman correlations were all highly significant and ranged from 0.781 to 0.997 for Pearson's r^2 and from 0.845 to 0.993 for Spearman's Rho (Figure 9, Table 3).

Test 2, comparison of on-site to video counts (24 h video)

Using 1992 data, Test 2, the comparison of daily on-site fish counts to daily video counts (24 h) revealed a significant ($p < 0.001$) difference between the methods using the composite count of target species (Table 4). Steelhead, chinook adult, and chinook jack counts were also significantly different ($p < 0.001$, $p = 0.022$, and $p = 0.001$; respectively). Paired t-tests using combined chinook adult and jack counts revealed nonsignificant differences ($p = 0.269$). Pearson and Spearman correlations were all highly significant and ranged from 0.851 to 0.997 for Pearson's r^2 and from 0.885 to 0.995 for Spearman's Rho (Figure 10, Table 5).

Using 1993 data, Test 2, the comparison of daily on-site fish counts (16 hr, 10 hr, or 8 hr) to daily video counts (24 h) revealed a significant ($p < 0.001$) difference in the composite count of target species (Table 4). Steelhead, chinook adult, and chinook jack counts were also significantly

Table 4. Comparison (using paired t-tests) between 24 h video-based fish counts and on-site counts at Lower Granite Dam in 1992 and 1993 by species.

Species	Year	n	Mean Diff.	S.D. Diff.	t	DF	P
Chinook Adult	1992	198	-1.495	9.090	-2.314	197	0.022
Chinook Adult	1993	312	3.494	15.905	3.880	311	<0.000
Chinook Adult	92&93	510	1.557	13.873	2.534	509	0.012
Chinook Jx	1992	198	0.783	1.788	6.161	197	<0.000
Chinook Jx	1993	312	-0.026	1.153	-0.393	311	0.695
Chinook Jx	92&93	510	0.288	1.485	4.383	509	<0.000
Chinook Ad&Jx	1992	198	-0.712	9.036	-1.109	197	0.269
Chinook Ad&Jx	1993	312	3.468	16.045	3.818	311	<0.000
Chinook Ad&Jx	92&93	510	1.845	13.895	2.999	509	0.003
Steelhead	1992	198	46.692	74.548	8.813	197	< 0.000
Steelhead	1993	312	20.240	44.259	8.078	311	<0.000
Steelhead	92&93	510	30.510	59.281	11.623	509	< 0.000

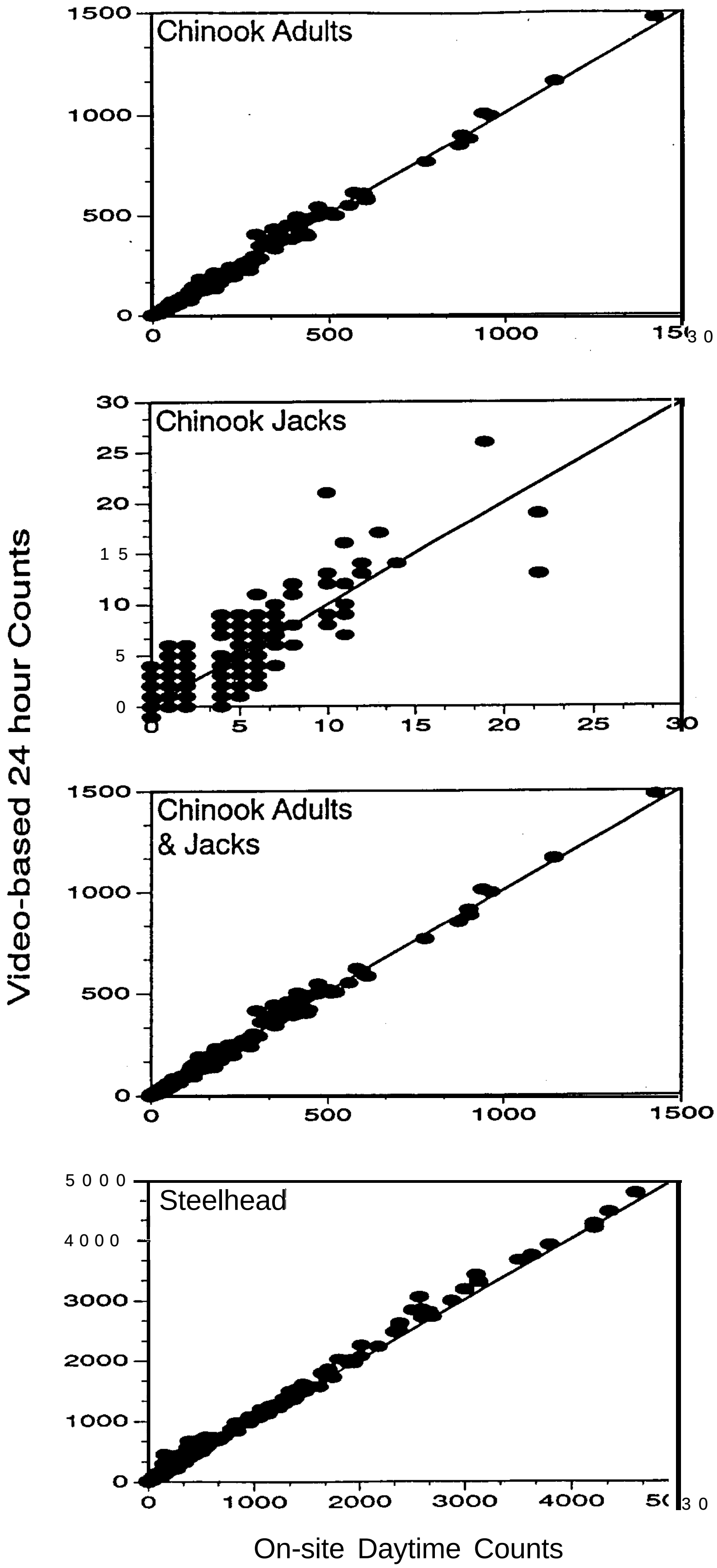


Figure 10. Correlations of 24 h-per-day video-based fish counts to on-site fish counts (predominantly 16 h-per-day) made at Lower Granite Dam in 1992 and 1993. The diagonal line represents a one-to-one relationship.

Table 5. Correlation (Pearson' r^2 and Spearman's Rho) between 24 h video-based fish counts and on-site counts at Lower Granite Dam in 1992 and 1993 by species.

Species	Year	n	ratio	S.E.	p	r^2	Rho
Chinook Adult	1992	198	0.950	0.009	<0.000	0.983	0.974
Chinook Adult	1993	312	1.027	0.004	<0.000	0.995	0.986
Chinook Adult	92&93	510	1.024	0.004	< 0.000	0.994	0.982
Chinook Jx	1992	198	1.092	0.033	<0.000	0.851	0.885
Chinook Jx	1993	312	0.777	0.023	<0.000	0.782	0.774
Chinook Jx	92&93	510	0.998	0.021	<0.000	0.818	0.835
Steelhead	1992	198	1.042	0.004	<0.000	0.997	0.995
Steelhead	1993	312	1.057	0.007	<0.000	0.988	0.984
Steelhead	92&93	510	1.046	0.003	<0.000	0.996	0.991

different ($p < 0.001$, $p = 0.001$, and $p = 0.001$; respectively). Paired t-tests using combined chinook adult and jack counts revealed nonsignificant differences ($p = 0.695$). Pearson and Spearman correlations were all highly significant and ranged from 0.782 to 0.988 for Pearson's r^2 and from 0.774 to 0.986 for Spearman's Rho (Figure 10, Table 5).

Using 1992 and 1993 combined data, Test 2, the comparison of daily on-site fish counts (16 hr, 10 hr, or 8 hr) to daily video counts (24 h) revealed a significant ($p < 0.001$) difference between the methods using the composite count of target species (Table 4). Additionally, individual paired t-tests of steelhead, chinook adult, chinook jack, and chinook adult and jack combined counts were also significantly different ($p < 0.001$, $p = 0.012$, and $p = 0.001$, and $p = 0.003$; respectively). Pearson and Spearman correlations were all highly significant and ranged from 0.818 to 0.996 for Pearson's r^2 and from 0.835 to 0.991 for Spearman's Rho (Figure 10, Table 5).

Test 3, comparison of expanded 50 min. to actual 60 min. video counts

Using 1992 data, Test 3, comparison of expanded 50 min. to actual 60 min. video counts using 1992 data, revealed no significant difference for counts of target species (Table 6). The comparison indicated that there were no significant differences for counts of chinook adults, chinook jacks, combined

Table 6. Comparison (paired t-tests) of 50 minute expanded video-based fish counts with 60 minute video-based counts at Lower Granite Dam in 1992 and 1993 by species. Count expansions were derived by summing daytime 50 minute counts and multiplying by 1.2.

Species	Year	n	Mean Diff.	S.D. Diff.	t	DF	P
Chinook Adult	1992	198	0.101	3.565	0.399	197	0.691
Chinook Adult	1993	328	-0.113	6.488	-0.315	327	0.753
Chinook Adult	92&93	526	-0.032	5.568	-0.133	525	0.894
Chinook Jx	1992	198	-0.106	0.863	-1.729	197	0.085
Chinook Jx	1993	328	0.030	0.487	1.133	327	0.258
Chinook Jx	92&93	526	-0.021	0.657	-0.730	525	0.466
Chinook Ad&Jx	1992	198	0.005	3.667	0.019	197	0.985
Chinook Ad&Jx	1993	328	0.082	6.528	0.228	327	0.819
Chinook Ad&Jx	92&93	526	0.053	5.620	0.217	525	0.828
Steelhead	1992	198	-1.687	28.031	-0.847	197	0.398
Steelhead	1993	328	-0.213	10.496	-0.368	327	0.713
Steelhead	92&93	526	-0.768	19.078	-0.923	525	0.356

chinook adults and jacks, and steelhead (p = 0.691, p = 0.085, p = 0.985, and p = 0.398; respectively). Pearson and Spearman correlations were all highly significant and ranged from 0.971 to 0.999 for Pearson's r^2 and from 0.969 to 0.998 for Spearman's Rho (Figure 11, Table 7).

Using 1993 data, Test 3, revealed no significant difference for counts of target species (Table 6). The comparison indicated that there were no significant differences for counts of chinook adults, chinook jacks, combined chinook adults and jacks, and steelhead (p = 0.753, p = 0.258, p = 0.8 19, and p = 0.713; respectively). Pearson and Spearman correlations were all highly significant and ranged from 0.948 to 0.999 for Pearson's r^2 and from 0.956 to 0.994 for Spearman's Rho (Figure 1 1, Table 7).

Using 1992 and 1993 data, Test 3, the comparison of 60 min. complete count data and 50 min. counts expanded by a factor of 1.2, revealed no significant difference for counts of target species (Table 6). We determined that there were no significant differences for counts of chinook adults, chinook jacks, combined chinook adults and jacks, and steelhead (p = 0.894, p = 0.466, p = 0.828, and p = 0.356; respectively). Pearson and Spearman correlations were all highly significant and ranged from 0.969 to 0.999 for Pearson's r^2 and from 0.963 to 0.996 for Spearman's Rho (Figure 1 1, Table 7).

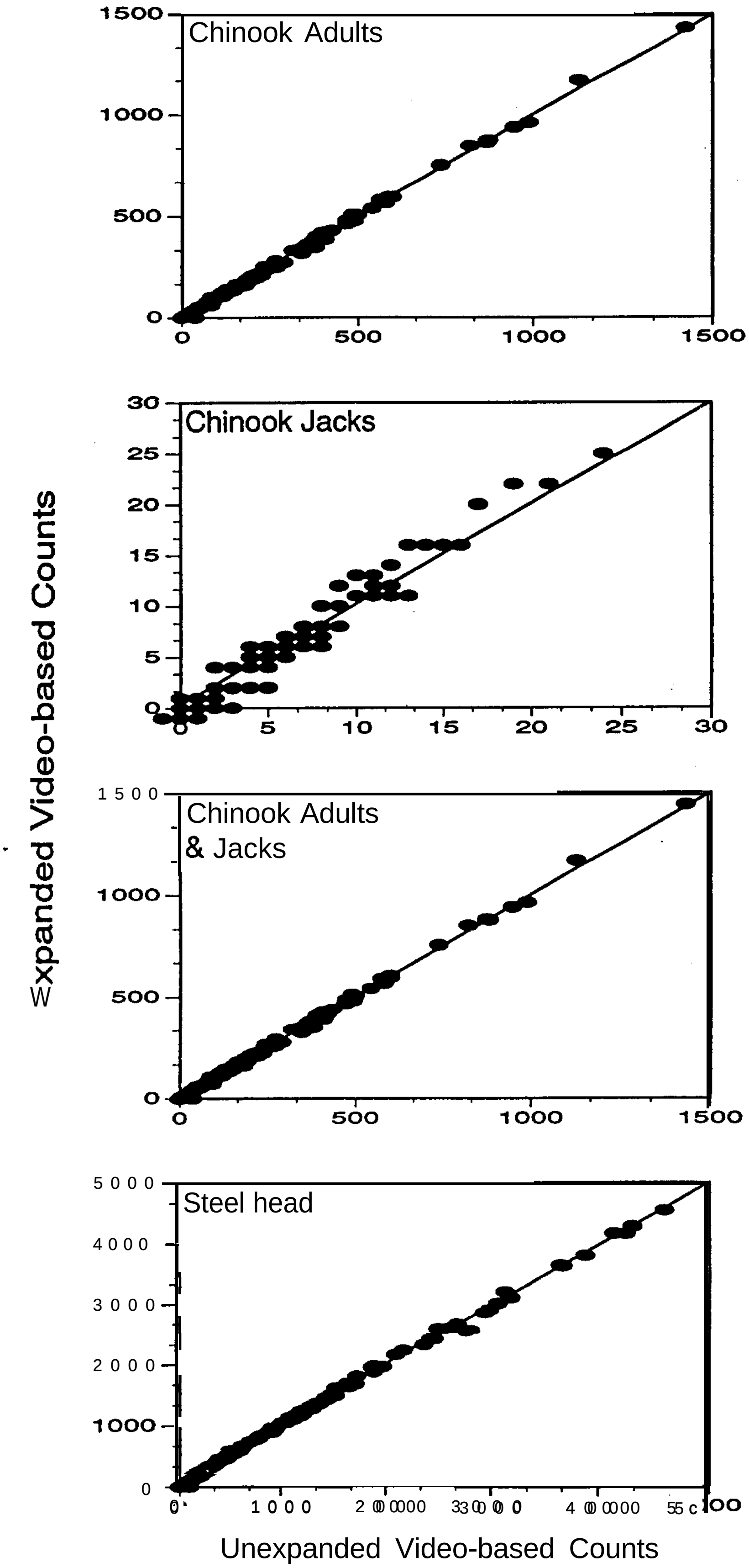


Figure 11. Correlations of daily 50 min.-per-h video counts (expanded x1.2) with actual 60 min.-per-h video counts made at Lower Granite Dam in 1992 and 1993 to test the effect of count expansion used in the on-site method. The diagonal line represents a one-to-one relationship.

Table 7. Correlation (Pearson' r^2 and Spearman's Rho) between daily 50 minute expanded video-based fish counts and daily 60 minute video-based counts at Lower Granite Dam in 1992 and 1993, by species, to test the effect of count expansion used in the on-site method. Count expansions were derived by summing daytime 50 minute counts and multiplying by 1.2.

Species	Year	n	ratio	S.E.	p	r^2	Rho
Chinook Adult	1992	198	0.989	0.004	<0.000	0.987	0.992
Chinook Adult	1993	328	1.006	0.002	<0.000	0.999	0.993
Chinook Adult	92&93	526	1.005	0.001	<0.000	0.999	0.992
Chinook Jx	1992	198	1.062	0.013	<0.000	0.971	0.969
Chinook Jx	1993	328	1.010	0.013	<0.000	0.948	0.956
Chinook Jx	92&93	526	1.050	0.008	<0.000	0.969	0.963
Steelhead	1992	198	0.999	0.002	<0.000	0.999	0.998
Steelhead	1993	328	1.002	0.002	<0.000	0.999	0.994
Steelhead	92&93	526	1.000	0.001	<0.000	0.999	0.996

Fish Swimming Speed

In 1992, the average and minimum amount of time that individual fish spent within the viewing window was 5.48 and 2.77 sec for chinook salmon jacks, 4.49 and 1.70 sec for chinook salmon adults, and 3.20 and 0.93 sec for steelhead. These calculations were based on sample sizes of 22, 90, and 92; for chinook salmon jacks, chinook salmon adults, and steelhead; respectively. Both chinook salmon adults and jacks had a 100% probability of being seen in at least two video frames (Table 8). Steelhead had a 99.5% probability of being seen in at least two video frames (Table 8). In 1993, the average and minimum amount of time that individual fish spent within the viewing window was lower than in 1992 because the viewing area was 26.7 cm narrower. As a result of this narrower viewing area, the weighted mean probability of a fish being seen in at least two frames was 96.6% (Table 8). Chinook had the highest probability of being seen in two or more frames and steelhead had the lower probability. These data are consistent with reported swimming speeds for steelhead, and chinook salmon, both of which exceed the swimming speed of sockeye salmon (Beamish 1978). However, there was still a 100% probability of each target species being recorded in at least one frame based on a sample size of 233 fish.

Table 8. The probability of an individual fish of the target species appearing in X number of video frames in 72 h time-lapse recordings made at Lower Granite Dam in 1992 and 1993.

1992

Species	n	1 frame	2 frames	3 frames	4 frames	5 frames
Chinook	90	1.000	1.000	0.998	0.930	0.857
Chinookjx	22	1.000	1.000	1.000	1.000	0.982
Steelhead	92	1.000	0.995	0.958	0.845	0.690
WT mean	204	1.000	0.998	0.980	0.900	0.795

1993

Species	n	1 frame	2 frames	3 frames	4 frames	5 frames
Chinook	112	1.000	0.990	0.957	0.882	0.746
Chinookjx	17	1.000	1.000	0.869	0.667	0.444
Steelhead	104	1.000	0.933	0.592	0.220	0.057
WT mean	233	1.000	0.966	0.788	0.571	0.416

Task 4. Video and On-Site Counting Cost Comparisons

The estimated two-year cost of an on-site fish counting program at Lower Granite Dam was $95,952. This included 3,874 h in 1992 and 4,122 h in 1993 of fish counter personnel time.

Over the same period, the video-based fish counting program to monitor fish ladder passage of target species for the same 7,996 h would cost an estimated $25,439 (Table 9, Figure 12). This estimate included the entire cost of all equipment used (Table 10).

Task 5. Record, Analyze, and Archive Individual Passage Events

By summing all sockeye salmon passage events reported by on-site and video methods, potentially 18 sockeye salmon passed Lower Granite Dam, in 1992. Only 12 of the 18 (66.7%) potential fish passage events were identified by both counting procedures (Appendix D). Three sockeye salmon counted by on-site counters could not be confirmed by reviewing the videotapes. Three sockeye salmon counted using the video system passed between 2 100 and 0500 hours, when on-site counters were not counting.

By summing all sockeye salmon passage events reported by on-site and video methods, potentially 18 sockeye salmon passed Lower Granite Dam, in 1993. Only 10 of 18 (55.6%) potential fish passage events were identified by

Table 9. **Estimated costs associated with utilizing a video fish counting system to enumerate target species over a two year period at Lower Granite Dam.**

Description	cost	Expanded count program Cost+
Personnel Costs	$15,992	$33,600
Materials and Supplies		
Videotapes	$3,137	$4,250
Mailing Costs	$1,070	$1,450
Equipment maintenance	$500	$500
Total Materials	$4,707	$6,200
Equipment (Table 10)	$4,740	$4,740
Total Cost (2 Years1	**$25.439**	$44.540
Annual Cost	**$12,719**	$22,270

*Expanded program cost would include estimating fish passage for 50 weeks / year.

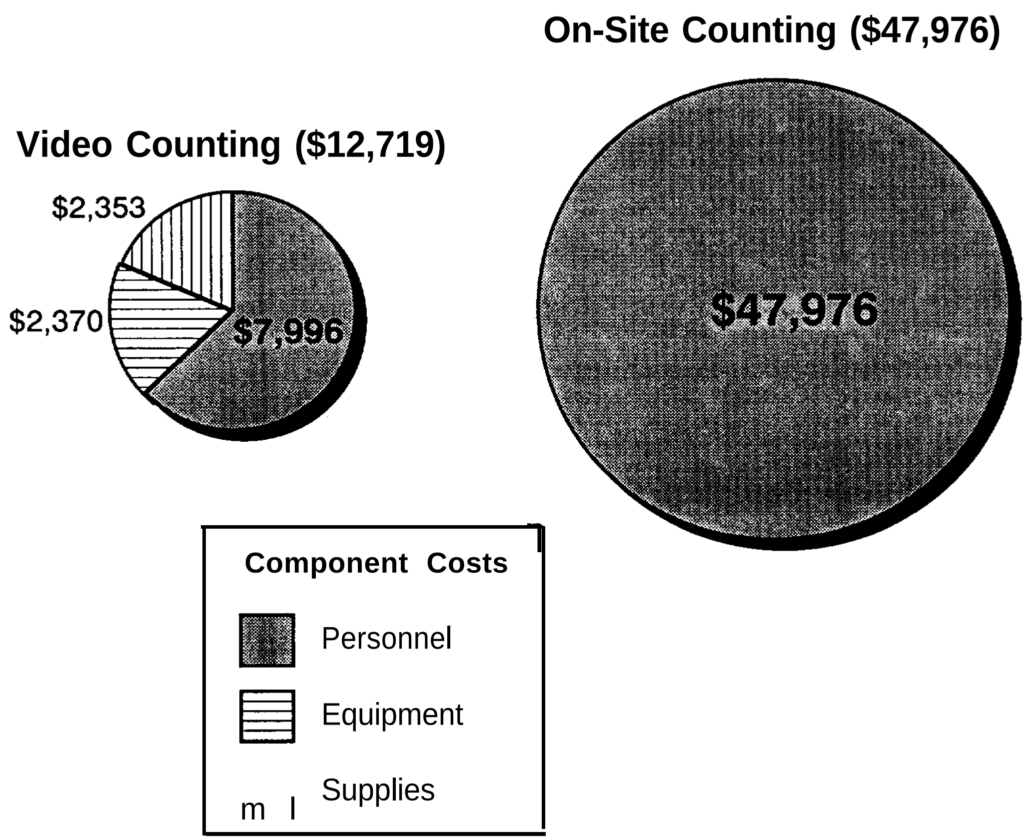


Figure 12. Comparison of estimated annual costs of video and on-site fish counting at Lower Granite Dam.

Table 10. Estimated costs of video fish counting equipment deployed at Lower Granite Dam.

Equipment	**cost**
Panasonic AG-6720 Time Lapse VTR	1,698
Panasonic AG-1960 VTR	967
Panasonic Color WV-D5 100 CCD Camera	1,060
Panasonic WV-LZ14/8AF Zoom Lens	420
Panasonic WV-32038 Power Supply	72
Panasonic WV-CA1 0 Power/Camera Cable	2 5
Panasonic CT-l 382Y Monitor (2 required)	498
Total Cost	**$4,740**
Annual Cost	**$2,370**

both counting methods (Appendix G). Two sockeye salmon that were initially reported by on-site counters could not be confirmed on videotape. One sockeye salmon was counted on video and not observed by on-site counters during the daytime. Five passage events occurred when on-site counters were off duty, four during break times and one after hours during the night. The initial video count identified 11 of the 18 potential passage events. Subsequent review confirmed an additional 5 sockeye salmon passage events that were initially missed.

Task 6. Computerized Counting and Species Identification From Videotape Records

The demonstration counting and speciation program correctly located and identified 67 out of 70 different fish images on eight different video sequences. For a detailed discussion of this task see Appendix (A).

DISCUSSION

Image Quality

The quality of video images is critical to the success of a study such as the one we performed at Lower Granite Dam. Image quality is affected by a variety of factors, most of which are common to any visual-based counting method including the on-site method currently employed at Lower Granite Dam. Image quality throughout this two-year study was adequate (as demonstrated by tests of precision in comparisons with on-site counts [Table 2]), but was not optimal. Two factors which negatively affected image quality were inadequate lighting and viewing-window/count-slot cleanliness. We believe that with minor modifications and standardized conditions and procedures (for both lighting and window/count-slot cleaning), dramatically superior video images would be obtained. In a study at Tumwater Dam on the Wenatchee River, Washington (Hatch and Schwartzberg 1991), such modifications were made in fish passage and observation facilities that are similar to those at Lower Granite Dam. Subsequently, vastly superior image quality was obtained (Hatch et al. 1994).

At Lower Granite Dam, the majority of fish passage occurs through the lower portion of the counting slot, with many fish passing directly along the floor of the viewing chamber. Unfortunately, algae and dirt tend to accumulate

in the lower 7 cm of the chamber making viewing of fish in this area more difficult. A brush is now installed to clean the viewing window glass and backboard but it does not adequately clean the lower area. Video, as well as on-site, image quality would greatly benefit from a brush or cleaning system of different design.

Fish were also not optimally illuminated in the Lower Granite Dam fish viewing chamber. In video installations such as this one, it is important to note that much light is lost between the time it leaves the source and when it reaches the camera, after bouncing off the subject. Approximately 90% of directed light is lost passing through the thick laminated glass of the viewing window and another 60% is likely lost travelling through the first 90 cm of water in the count slot (T. Carlson, Battelle Pacific Northwest Laboratories, personal communication). We added sufficient artificial lighting to improve illumination which proved adequate for specimen identification and counting. However, because conditions, such as the position of the backboard (crowder) and use of a previously installed backlight changed frequently based on individual on-site counter preferences, the uniformity of lighting changed as did subsequent video image quality. We foresee no major difficulties in alleviating these relatively minor problems.

Objective assessments by human observers may not be adequate to best determine the intensity and dispersion of lighting for optimal image quality. We are currently developing a research tool to help in designing lighting systems for different video fish-counting installations (Appendix A). A computer program (IMSCAN) would be used to compare digitized video images pixel-by-pixel to measure differences in image quality too subtle for the human eye to detect. Another potential technical solution to improving video image quality is to incorporate an electronic image-enhancement device that is now commercially available. This instrument produces different image views (one close-up and one full-window view) of the same subject using the video signal from a single camera. Additional magnification of the images (up to 4x) is possible, along with image rotation, panning, and/or tilting. Combining such a system with the time-lapse video recording instruments we used in this study could potentially produce video images at much higher resolution.

Although the amount of additional light we installed produced a total amount of artificial illumination less than that now used in the average mainstem Columbia or Snake River counting station, we believe a general investigation of the effect of lighting on fish passage at each site should be considered. Additional lighting produces extra heat and will potentially increase the temperature of the counting room. We installed exhaust fans and vents to improve conditions for on-site counter’s comfort, but in the future an air

conditioner might provide improved conditions. We also recommend the use of halogen-IR lights which produce more light-per-watt than standard incandescent bulbs.

Video Fish Counting at Mainstem Columbia River Dams - Feasibility and Potential Benefits

Video-based fish counting at mainstem COE count sites offers several potential benefits for managers of Columbia Basin salmon stocks. These include an archived permanent record of fish passage and specimen information, 24 h fish passage monitoring, a method to "passively" estimate lengths and other characteristics of individual specimens, and substantially reduced costs at many locations.

A permanent record of fish passage is created when using videotape recording equipment for fish counting. A record such as this contains valuable information that may be archived for future analyses and used for important management decisions. For example, a potential future study of changes in lengths or morphometrics of a particular stock could draw upon the video record for data that would otherwise be unavailable. Images of certain specimens of particular interest, such as Snake River sockeye salmon recorded at Lower Granite Dam, can be reviewed by several observers to determine a consensus on specimen identification. The video record can be reviewed and

fish counted multiple times. From these multiple readings, or by sampling the video record, a bounded estimate of fish passage can be made.

Video fish counting represents an economical method for counting fish in general, and specifically during periods and at sites where other methods would be relatively expensive, but where data is nevertheless desired. For example, nighttime counts at Columbia and Snake river mainstem dams could be instituted using video systems at relatively little added cost. As well, operating a video system 24 h per day during the sockeye salmon migration would provide for redundant counting systems during 16 h of the day and single system monitoring during the remaining 8 h and during hourly break periods. This added monitoring time is important for evaluating passage of species that are in very low abundance. At Lower Granite Dam, we estimated that combined nighttime passage for chinook salmon, steelhead, and sockeye salmon was 6.4% (8,555 fish) and 8.3% (8,687 fish) in 1992 and 1993. During the early and late' seasonal passage periods, these percentages were substantially higher. Between 1 March and 31 May 1993, nighttime passage of steelhead was 24%, representing 3,839 fish (Figure 13), at Lower Granite Dam. For species in low abundance, the counting of nighttime passage may be even more critical. In 1992, 20% of sockeye salmon we counted using video at Lower Granite Dam passed during the nighttime period, and none during the

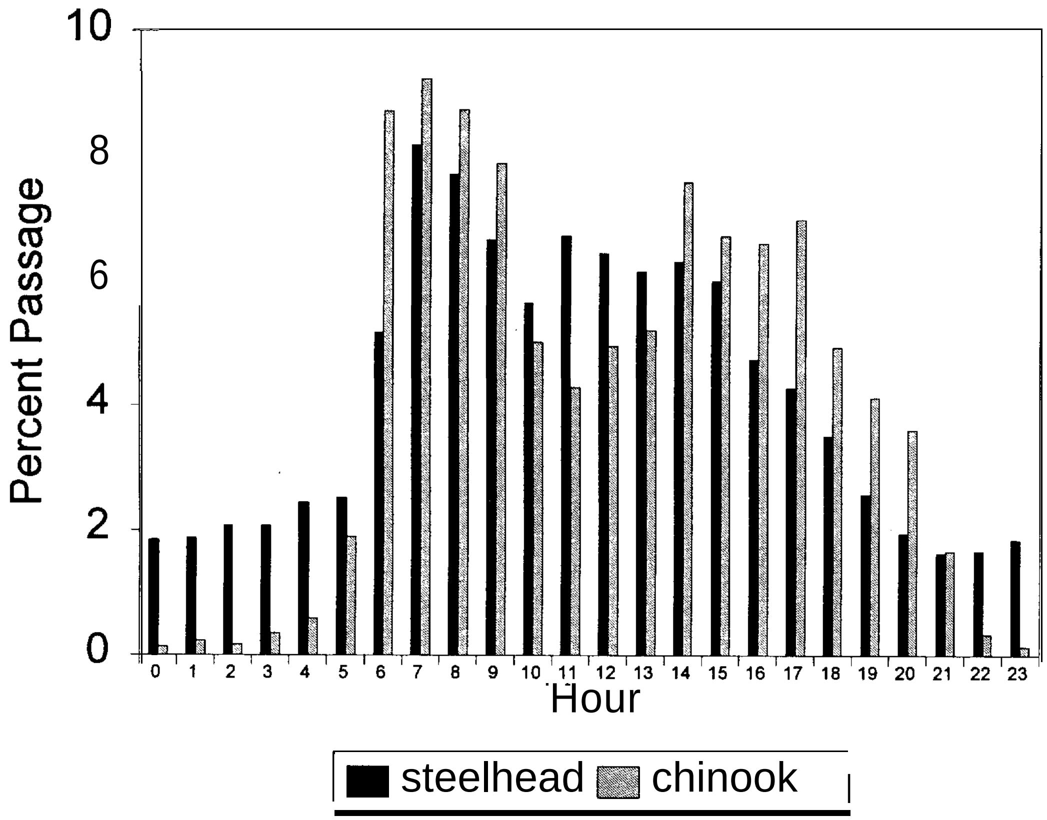


Figure 13. Steelhead and chinook salmon fish ladder passage counts as a function of time of day recorded at Lower Granite Dam between 1 March and 31 May 1993.

break periods. In 1993, 9.1% passed during nighttime and an additional 36.7% during the 1 O-minute-per-hour on-site counters break period.

Fish length estimates can also be made from video records. This estimate can be affected by the way water tends to magnify an image, and length estimates can be affected by the distance of each fish from the viewing glass window and its location in the count slot. Nevertheless, collecting length measurements from video images is a valuable method to “passively” sample populations when trapping and handling of these fish is not suitable. We used this method to estimate lengths of sockeye salmon, steelhead and chinook salmon in our study at Lower Granite Dam. It was a relatively simple procedure to automate the data entry process using a video frame-grabber board installed in a personal computer that is linked to a VCR.

Video fish counting was found to be a relatively inexpensive method of data collection at Lower Granite Dam compared to the on-site method currently employed. We estimated that the cost of video counting was only 26% that of a comparable on-site counting program. This estimate included the entire cost of all video equipment required, as well as personnel costs for both on-site and video (tape reader) counters, but did not include administrative or indirect costs. We believe these financial benefits are compelling, but recognize that the cost of a video-based program is directly proportional to the characteristics of a

particular site. Generally, the lower the relative magnitude of passage at a particular site, the greater the cost efficiencies will be for a video compared to an on-site method.

Technology and Future Potential Applications

Electronic technology is rapidly changing and offers the potential of many new devices, instruments, and techniques that may be applicable to the fish counting issues we have addressed in this study. In fact, developing technologies hold the promise of revolutionizing the way problems such as fish counting and specimen identification are approached. Computer based image-processing systems are likely to someday eliminate the need for human decision making about species identification, movement, condition, length, and the characteristics of a particular specimen. Results of one part of our study suggest that the time when this technology will be available is much closer than most fisheries scientists probably imagine.

The prototype "machine vision" fish counting program developed and described in this report (Appendix A) demonstrates that it may be possible to fully automate video fish counting. The program was able to accurately count and identify fish using existing technology and current image-processing techniques. Based on our study and those of others (McCarthy 1988, Irvine et al. 1991), we believe an operational automated fish counting system could be

developed, installed, and tested at a mainstem COE count site as early as 1995. This system would run in "real time" (30 frames/sec) and counts would be generated almost instantaneously. Length measurements, other morphometric information, and fin clip data could also be collected. In addition, a permanent video record would be produced as an archive and a medium for additional tests and data collection.

Computerized fish counting implemented at a particular site would permit additional automation of fish passage monitoring along with the automation of the data transfer process. For example, hourly counts could be automatically uploaded to an electronic bulletin board, such as CROHMS, to make the information available to managers and the public. Under certain circumstances, the system could also be programmed to upload the entire digital image of a particular fish to the bulletin board. A video image of a sockeye salmon identified and counted at Lower Granite Dam might be the subject for such an operation. Passage at a site could be monitored by a variety of interested parties who would only need a personal computer and modem to access the information. The computerized fish-counting system could also be designed to notify designated authorities if a fish passage problem arose. If the counting slot became clogged with debris, for example, or if water turbidity reached a threshold level, a notification alarm or message could be sent. Finally, the system could be relatively self-monitoring, adjusting to changing conditions.

Video camera focus, lighting modifications (intensity and direction), and viewing-window/backboard cleaning, could be performed by the system automatically.

Our experience in testing video systems for fish counting at Lower Granite Dam suggests that it is a precise, dependable, and economical technique. As detailed above, it offered a number of distinct advantages not possible with other counting methods. We believe the use and application of video counting as the primary fish counting method at other COE mainstem counting sites should be examined. Each site presents unique characteristics that must be taken into account when evaluating the suitability of deploying a video count system. Particular consideration should be given to the relative amount of fish passage (especially shad passage) at the site, water clarity, and the permissible delay between passage time and information distribution to managers and the general public. Employment of our relatively simple recommendations to improve image quality would make application of video count systems even more feasible and useful at a variety of sites.

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Appendix A. **Proof-of-principle report on developing a machine vision fish counting system.**

A MACHINE VISION FISH COUNTING

Final Report

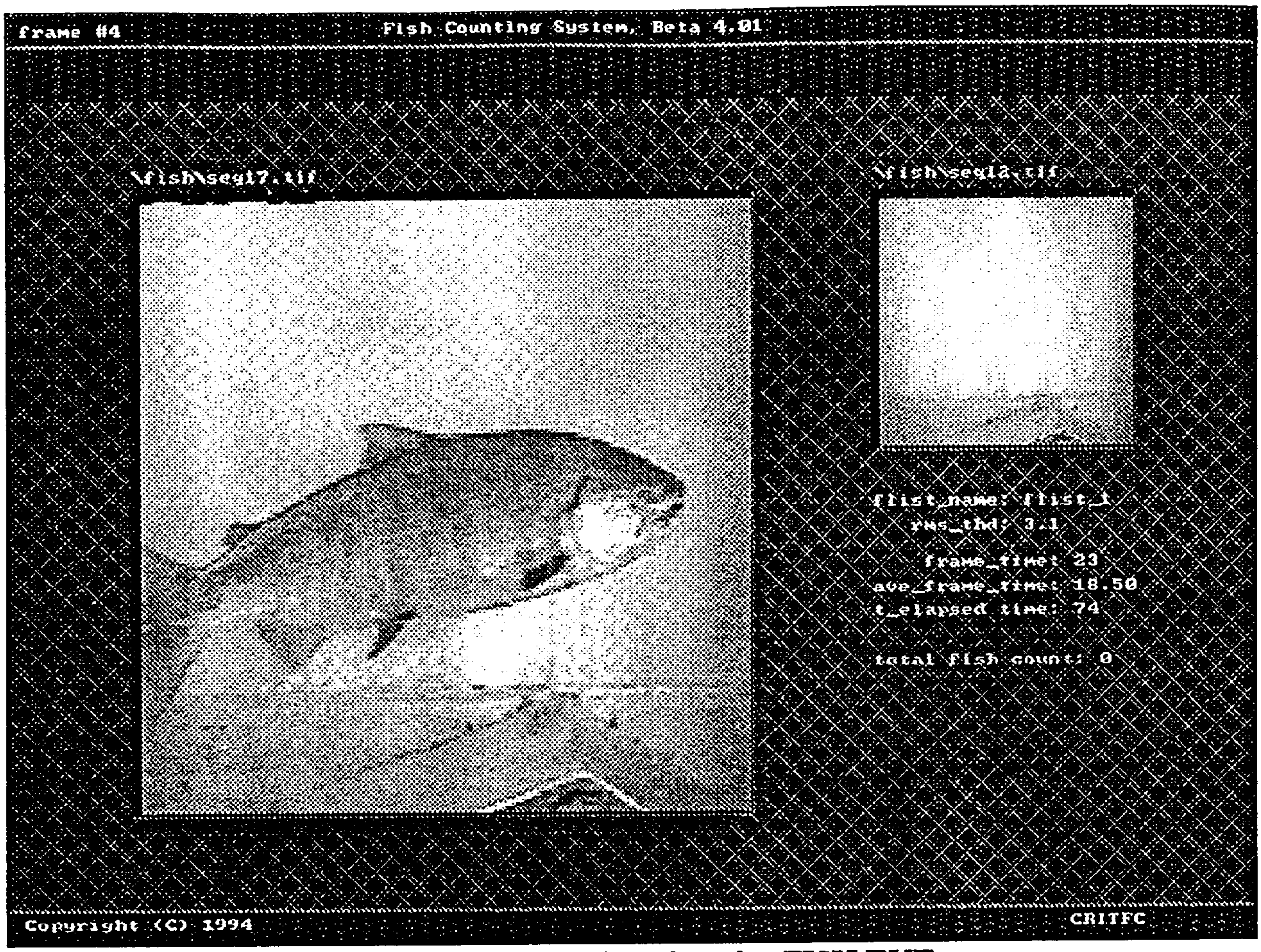
CRITFC Contact: Doug Hatch

Principle Investigators

Dr. Christopher A. Ciarcia
Dr. Thomas W. Tunnel1

23-January-1994

TARDIS Systems
901 18th Street, Suite 301
Los Alamos, New Mexico 87544
(505) 662-9401 Voice
(505) 662-6780 Fax



The new streamlined fish counting system interface for FISH.EXE

SCOPE of WORK

To perform research and development specific to the creation of a software based machine vision fish counting system. This work included:

(1) the optimization of Phase I techniques and software components,

(2) the development of additional codes and procedures to improve accuracy of segmentation and overcoming significant digitization noise,

(3) the development of a fieldable test procedure (IMSCAN) to evaluate the lighting and image noise distributative characteristics,

(3) and, the development of a new interface designed for faster processing and image display.

DELIVERABLES

The final FY93 deliverables consist of 5 components,

(1) a functional machine vision code which processes sequenced digitized video frames in TIF image format,

(2) an “image scanning” utility which can be used interactively to examine lighting and frame noise effects for onsite experimental setup optimization,

(3) examples based on the 5 test cases provided by Doug Hatch,

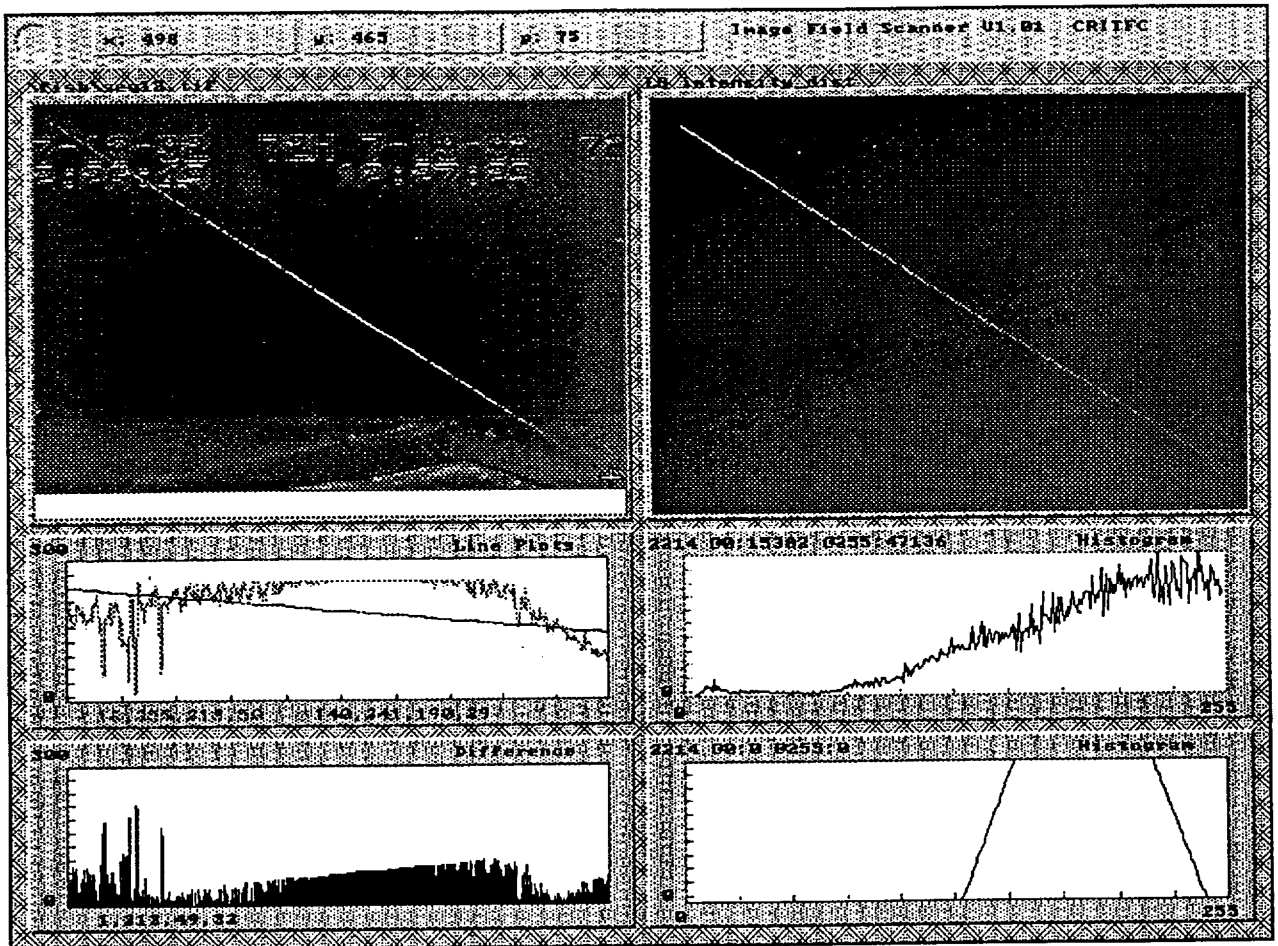
(4) a 90MB bemoulli configured with the entire R&D WATCOM/META development environment including all source code, makefiles and link files,

(5) and, a written final report describing results, noise and lighting characterization studies, and detection, counting & tracking logic.

Phase II Task Accomplishments

Definition of Image Quality

3-D light intensity profiling & noise analysis



IMSCAN intensity distribution. The background intensity profile is fitted with a planar surface in a least-squares fashion to define the best sloped plane. If the intensity is isotropic this plane would be flat.

As is obvious, the ability of the applied AI segmentation, tracking and counting schemes to perform their functions is directly proportional to the “quality” of the images obtained during the data acquisition phase. In general, all of the data to date evidenced the following problems,

* non-uniform intensity distributions,
* phase periodic digital sampling noise,
* raster line “video-sync” phase shift “noise”,

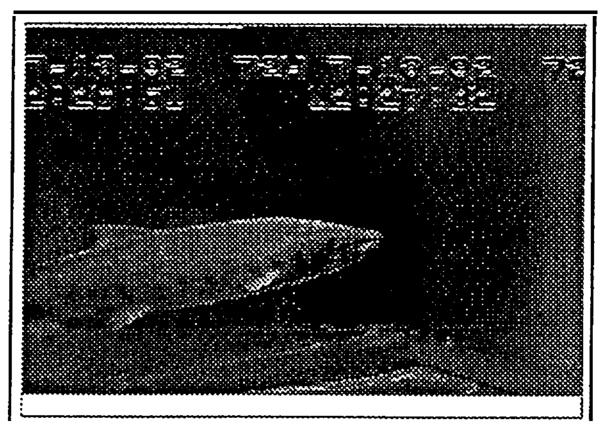
* reflections and points of 'light-source saturation',
* streaking and marks on the glass window 'front-pane',
* and poor contrast evident as low signal-to-noise ratios.

To overcome these 'imaging' difficulties a complicated scheme of noise filtering and region growing segmentation procedures was developed. The results of this work were reported during our last meeting at TARDIS.

Although we achieved 'reasonable' results, the processing time per frame was totally unacceptable. Using a conventional 486/50MHz PC, each frame was taking 2 to 3 minutes to process. We therefore abandoned these procedures, and examined alternative procedures based on learned concepts.

An indepth study into the noise characteristics and lighting distributions was therefore undertaken on the 5 test samples provided by the CRITFC this fall and successfully completed. It was found that streaking, non-uniform lighting, and digital sampling noise contributed heavily to the performance of the implemented area-integrated RMS deviation fish segmentation routine.

Also, comparisons between event and background frames demonstrated "creep" and "noise" effects resulting from the transference of video information using a tape format. We chose to ignore these effects since basic correction using lowpass filters tended to degrade critical fish edge shape areas which already had low signal-to-noise ratios, as well as the undesirable time for implementation.

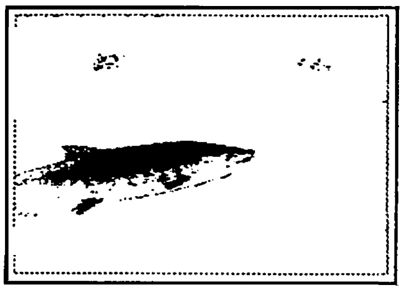


Test image SEQ16.TIF

TARDIS therefore (developed a new set of background/object segmentation procedures; but we also developed a interactive 'image scanning utility', IMSCAN.EXE that we used to optimize these procedures and which should enable CRITFC researchers- to optimize their data acquisition systems. Details on the operation and use of this tool will be discussed in the section on IMSCAN.

New Segmentation Procedures

Phase I implementation demonstrated that segmentation of fish "blobs" could be easily realized by a pixel-to-pixel comparison of the texture and variance of an inclusive set of adjacent pixels in the neighborhood of the primary, between the normalized background and active event frames. With this technique, if significant variance was detected then a fish blob was present and obscuring the background.



Phase I segmentation results on SEQ16.TIF

Segmentation was then performed using a simple rule-based conditional action set triggering a Boolean inclusion or elimination operation between the two data sets.

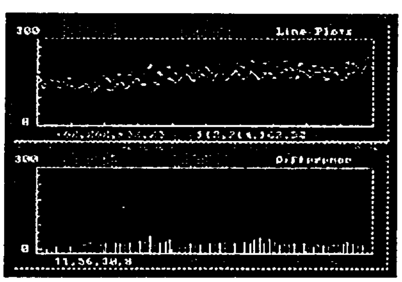
In principle this procedure performed well for high contrast images without the above defined image quality deformations. And this original simple procedure formed the basis for all other processing stages. However, it failed to segment regions of fish imagery which varied less than 1 percent in contrast between fish surface content and background. An example of that failure is shown above. Please note how a good percentage of the fish's belly is lost in the signal to noise ratio.

Instead under Phase II, TARDIS opted to adopt an integral approach. Rather than trying to difference 2 images directly, the new procedures optimize the identification of occupation regions (comprising the fish) and employ coincident component suppression procedures.

The latest procedure is implemented in the following manner:

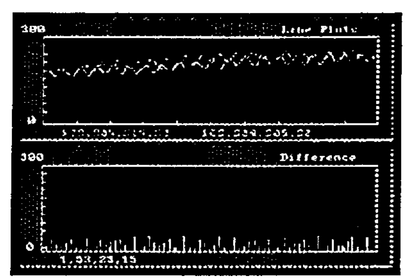
Matching Signals to Optimize Difference Detection

Digitization noise and sync-lock phase errors introduced differences within each frame. Previously we lowpass filtered the image to smooth these differences. Also, the ambient light level from frame to frame often changed as a function of the size and density of fish contained. They tend to occult the light and cast diffuse shadows.



Line plot comparisons of a background and fish frame.

To overcome these effects, we have found it useful to match the fish object image to the background before comparison. This is accomplished by (1) doing a rough differencing between the background and the fish frame to determine areas where parts of the fish definitely reside. (2) At the same time, a SOBEL edge detect is simultaneously passed across both images. Edge points in. coincidence are determined. These points are flagged for elimination from all subsequent analysis procedures. (3) The images are then fitted with a plane in a 3-D least-squares fashion in order to define the trend surfaces through each image field. In the fish image, all definite fish regions determined by the rough differencing procedure, are exclude from the planar fit. This ensures that the fit is truly to the background profile. Then (4), point-by-point, the fish image's trend profile is matched and warped to that of the background. This

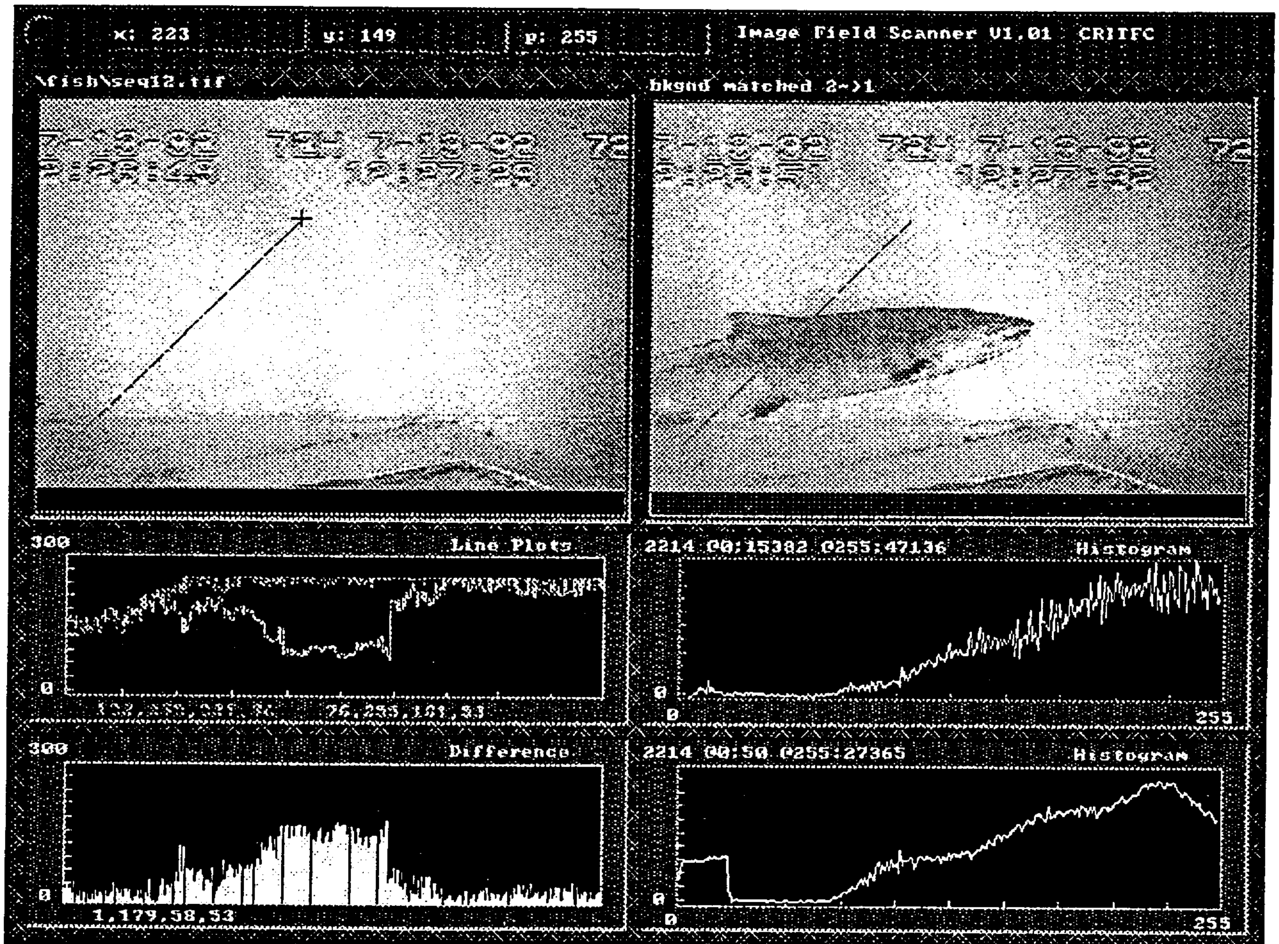


Background match line plot profiles.

forces the absolute magnitude of the differences to be representative of the relative noise variance within common background regions (removing slight shadows etc) and maximizes the variance within the 'still undetected' fish regions.

Examples of the effect of this background trend-surface matching are shown in the 2 sets of line plots above. The curves on the left represent simultaneous plots through the background before matching takes place. The curves on the right were generated after. Note that the difference profiles have changed considerably.

Area-Integrated RMS Deviation

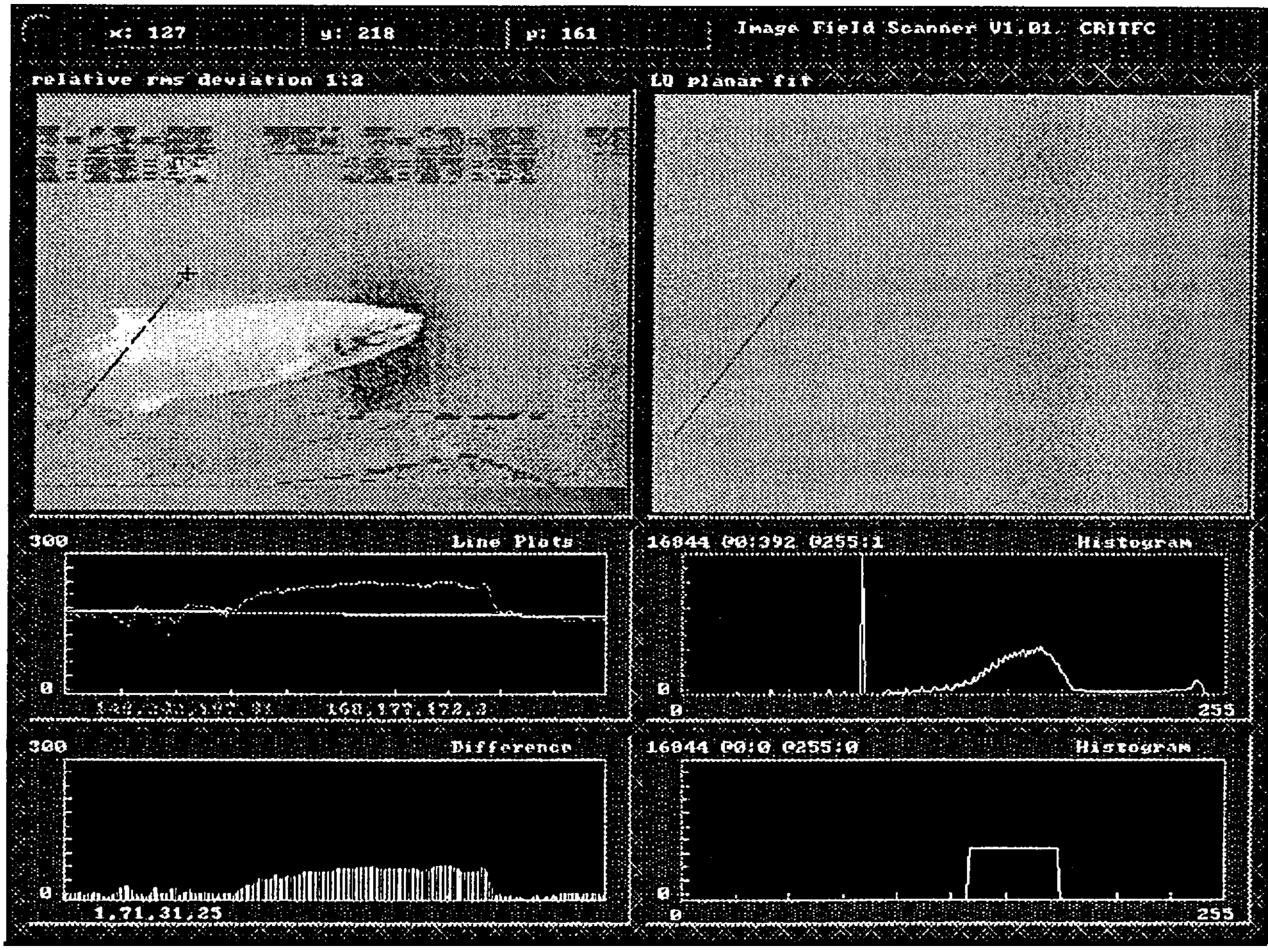


Background trend surface matched images. Note how the profile is coincident within the background but deviates across the fish.

The actual segmentation takes place when the two background trend surface matched images are compared employing an area integrated rms deviation procedure. Here a 3x3 kernel is passed across the surface of the matched images simultaneously. The sum of the

RMS error between the two images is calculated and averaged over the mask. This resulting value is then discriminated against for fish region detection.

The IMSCAN image display above demonstrates the strength of the background matching procedure. Note how the 2 overlaid line plots are matched at each end when they cross the background region; and, the edges of the fish are easily distinguished by the divergence of the two line profiles.



Area Integrated RMS Deviation Mapping between the matched background and fish frames. Note how distinguishable the edge functions are within the line profiles.

However, digitization noise is still evident as oscillations in each of these line traces. As a result it is often difficult to specify a threshold which will account for this variance and for both positive and negative edge function thresholds. However, mapping to the RMS domain stretches the threshold region and enables single valued segmentation clipping. In the 5 test case examples provide by Doug Hatch this past fall, this threshold was set to 3.1 for sequences 1,2,3, and 4. In Sequence 5 it was set to 2.9.

Fish Counting / Tracking

At the beginning of the Phase I procedure, it was assumed by the investigators that accurate fish counting could only be achieved by point-to-point tracking of individually identified species specific fish. However, experience demonstrated that this was not necessarily true nor always possible. Isolation of overlapping fish with significant infornation for type casting was not possible given the nature of the image data. A procedure was therefore developed which scanned and examined each multi-fish blob to determine the number of overlapping fish contained therein, with the species counting broken out as a separate task procedure. This number of fish knowledge was then use to attack the problem as a cell flux-flow condition (It was demonstratably faster and accurate).

In this Phase I procedure, the image field was considered a fish "conserving" flow cell. As long as the number of fish entering, occupying, and exiting the cell where accurately determined from frame to frame, then accurate absolute counting was possible. Coupled to species identification and flow conservation of species type, counting of species was possible. **And the tracking of any one type or group of fish proved to be unnecessary (this allows time-lapsed data processing).** Basic monitoring of in-out transitions from left-to-right along the directional flow of the fish seemed adequate. However, in Phase II we have found that this simplistic approach required the addition of some basic rule-based exceptions.

Counting of Fish within a Blob

Once segmentation was completed employing the area-integrated RMS-deviation procedure, the resulting image was scanned for clustered groups of cells called blobs. These blobs each represented one or more fish isolated from the background.

Blob Segmentation

Implementation of the blob isolation procedure involves a basic region-growing diffusion process. An incremented line seed vector scan of the segmentation is performed horizontally across the field (from top-to-bottom) until the tip of the seed vector impinges on the edge of a new blob. This pixel point is then seeded with a different value from the-results of the segmentation thresholding. Each point in the neighborhood of the seed point is then examined for connectedness. If any pixel is part of the blob within a 3x3 pixel box centered at the seed point (order 1, an order 2 assumes any set pixel within a 5x5 is touching), this value is then changed to the seed value. Then in a iterative manner, each of these new seed points are examined to determine if any connected points are also part of the same object, with-their addresses being stored within an iterative lookup stack as they become associated with the blob. Once all pixels within a local region have been examined, the diffusion operator moves to the next address in the stack, etc etc. When no more pixels are converted to the seed value, the object is then said to be segmented (differentiated) from the rest of the image since its pixel value is different.

As such, each blob consists of a set of contiguous points separate from the contiguous points contained within the other blobs. And, as part of the blob isolation/labeling/identification procedure described above, the number of points within each blob are also indexed and counted. In short, a mapping of the m^{th} point into the n^{th} point of the image is produced, the number of pixels per blob, ranging from i equals zero to pixcnt.

Area Discrimination

After these points have been identified, indexed, and counted the blob is subjected to a size discriminant. In this step, the size of the blob (i.e., the number of pixels within the blob pixcnt) is tested against some threshold (area = 1200). If pixcnt is below this threshold, the data are rejected as being to small. It is either noise, a small part of a fish exiting, or a small part of a fish entering the field of view. If it is **only** a small part of a fish exiting the field of view, the fish has already been tracked in the previous frames so that its exit can be noted and the fish counted. If it is **only** a small part of a fish entering the field of view, it will be tracked and counted before it exits to the right.

Edge Tracing

In preparing the blob for the edge trace, the blob is "trimmed" to eliminate dead-end points along the blob boundary. These dead-end points can cause the edge trace algorithm to fail. Only one iteration is used in the trim process.

After the trimming, the edge of the boundary is traced. This trace not only identifies which points are on the edge, but it also connects them and identifies them in a logical progression. The ability to analyze the edge trace where the points are connected and identified in a logical progression is critical to the edge analysis.

Sometimes the edge trace fails. Two circumstances will cause the edge trace to fail. One will occur when the algorithm can not pass a dead-end point that was not eliminated. At these times, the edge trace will attempt to restart. The restarts will appear as a series of yellow flashes around part of the blob. After a certain number of failed attempts, the edge trace attempt will cease and return a failure flag. The edge trace will also fail if it requires more than 8000 points to define the trace. This failure is also flagged.

Once the blob has been traced (or a failure to trace has been flagged), the number of fish are then determined for the blob. This determination is made by two methods. One method is the edge **analysis** and the other is the shadowgram technique. The shadowgram also evaluates the singularity of the blob fractal dimension. If this singularity is much different from one, then there is more than one fish in the blob.

Fish Detection Employing Edge Feature Analysis

As previously mentioned, the edge analysis depends on the edge trace data. If the edge

trace fails, the number of fish from the edge analysis is defaulted to one.

There 3 steps in the edge analysis. The first step begins with a principle component analysis of the fish. This principle component analysis simply provides a very convenient means of describing the edge. The second step separates the edge profile into segments that bend out from the fish, segments that bend towards the center of the fish, and segments that can not be classified (i.e., very smooth or very rough). The third step analyzes the inward bending segments in greater detail. This analysis determines if these inward bending segments are inflection points due to irregularities in the profile produced by overlapping fish.

These irregularities are called inflection points. Inflection points are discontinuities in the otherwise smooth profile of the fish. These inflection points occur along the top profiles of two or more overlapping fish, near the nose and rear areas of overlapping fish. The inflection points along the top profile of the fish are weak while the others tend to be stronger with the strongest occurring near the nose.

The number of fish are then estimated as (number of inflection points + 3)/2. Thus, a single inflection point will result in the estimation of 2 fish, while 1 fish is predicted when there are no inflection points.

As stated, the edge analysis begins with a principle component analysis of the orientation of the blob. In the principle component analysis, the blob is rotated to fit -the best set of coordinates that best describe the orientation of the blob. In this procedure, a major and minor axis are determined for the blob. These axes intersect at the center of the blob (centroid). The position of the edge trace is then recomputed with respect to this center. To illustrate, let x c and y c be the coordinates of the centroid and let the rotation of the axis described with the parameters vxx, vxy, vyx, and vyy. If the coordinates of a pixel are represented with x and y in the original frame, the coordinates in the rotated frame are

```
x_p = vxx*(x-x_c) + vxy*(y-y_c)
y_p = vyx*(x-x_c) + vyy*(y-y_c)
```

When there is no rotation, vxx = vyy = 1 and vxy = vyx = 0.

Thus, the coordinates of the edge trace can be recomputed in this new coordinate system. The reason for this is the following. The coordinates of the edge trace in this new system are independent of the orientation of the fish. Thus, the y coordinate of top portion of the nose profile file (of a single fish) will always approach the major axis (increase from negative values towards positive values), as long as the fish is facing to the right. The x coordinate should always be positive and increase towards a maximum.

The second step classifies the bend of each edge point. This done in the following manner.

If the edge is reasonably smooth, then it should be possible to specify a point, n, and do the following. It should be possible to locate a point, n-cc, within N edge pixels counterclockwise from n that is also a distance R from n. That is,

$$R^2 = (x\_edge[n] - x\_edge[n\_cc])^2 + (y\_edge[n] - y\_edge[n\_cc])^2$$

In the simple case where the profile is a horizontal line, n-cc = n - R. The same should be possible for a point, n-c, N pixels clockwise from n.

If these conditions prevail (and they will not when the edge profile is very rough), vectors a and b can be constructed. For the purposes of this document, a vector may be though of as defining a direction on a two dimensional plane, such as an image frame. Rather than being simply stated as 90 degrees, 3 o'clock or such, a vector will have components, These components will range between +/- 1 and describe the direction as how much in the horizontal (i component) and how much in the vertical (j component). A value that is negative simply means in the opposite direction. For example li + Oj means directly to the right while -1i + Oj means directly to the left. A value of Oi + 1j means (in image data with 0,0 in the upper left hand corner) directly down.

The vectors from points n, n-cc, and n can be written as

$$a = (x\_edge[n\_cc] - x\_edge[n])i/R + (y\_edge[ncc] - y\_edge[n])j/R$$
$$b = (x\_edge[n\_c] - x\_edge[n])i/R + (y\_edge[nc] - y\_edge[n])j/R$$

There are two vector operations in mathematics that can be performed that will describe how these vectors are orientated towards each other. The first operation is called the dot product. The dot product is evaluated as

$$c \text{ dot } d = c\_i*d\_i + c\_j*d\_j$$

where

$$C = c\_ii + c\_j j$$
$$d = d\_j i + d\_j j$$

The dot product of any two properly normalized vectors will always be between + /- 1. Note that the value of the dot product is commutative. That is, c dot d equals d dot c. The value of + 1 means that the vectors are perfectly aligned while -1 means the vectors point in opposite directions. In the present case, a value of -1 or near -1 means that the profile is very flat. A value near + 1 will mean that there is a sharp discontinuity in the profile. This discontinuity could either be the top of a tail (bend out away from fish), or it could result from overlapping fish (bend inward towards the center of the fish). More information is needed to distinguish.

Part of this additional information is contained in the cross product of the vectors. The cross product is evaluated as

$$c \text{ cross } d = c_i * d_j - c_j * d_i$$

Like the dot product, the cross product will range between +/-1. However, its operation is not commutative. In fact, c cross d = - d cross c. For the purposes of the edge,' a negative cross product (a cross b) means that the edge bends outward while a positive cross product means that the edge bends inward. Thus, inflection points will have positive cross products while protruding features such as the tips of fins, tails, and noses will all have negative cross products.

Using this logic, the second step in the edge analysis classifies each edge pixel as either bending outward (negative cross product) or bending inward (positive cross product). This classification is made only if the dot product is significantly different from -1 (as to focus only on definite arcs or segments).

If it were not possible to find the points n-cc and n-c, the pixel is classified as "rough edge" and is not subjected to further analysis.

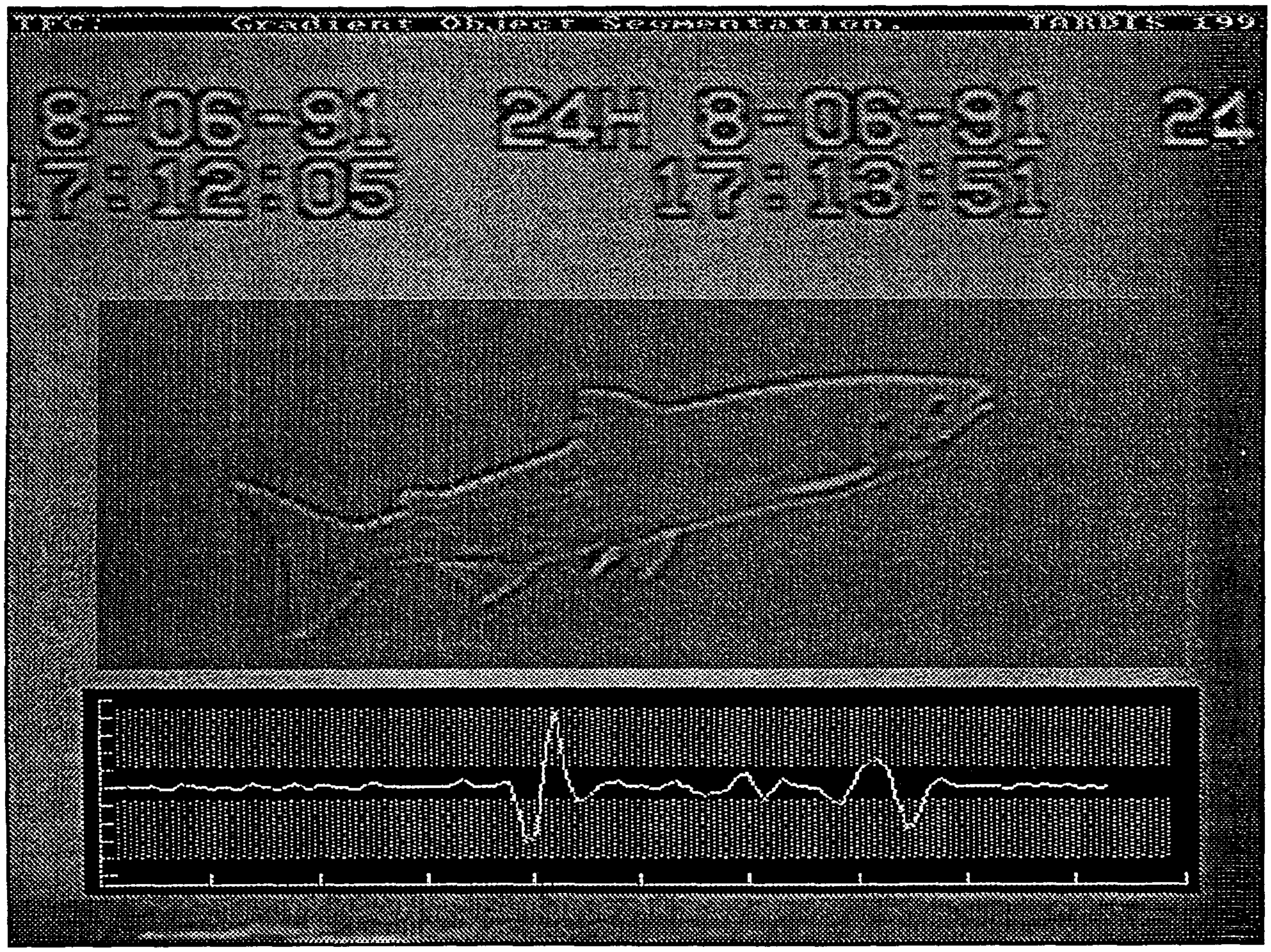
In the third step, the edge points classified as bending inward are submitted for closer examination. In this closer examination, they are identified as weak inflection along the top profile of two overlapping fish, a strong inflection from overlapping fish near the nose, or not an inflection point due to overlapping fish. To make these identifications, set of rules were developed to identify the inflection points.

The rules for a weak inflection point along the top are the following. First, only the front part of the profile is considered, (large, positive x_p along the profile). Second, there must be a continuous drop in the profile (y_p increase from negative values towards positive values). In practice, this means that in a pixel-to-pixel comparison, a large percentage of the time (80 to 95 percent), y c must increase. Third, the profile most be mostly above the major axis. Fourth, there must be a net drop in the profile (net increase in y c). Unfortunately, these same rules also describe the weak inflection point where the front of the dorsal fin joins the fish body. To discriminate against the dorsal fin, the mirror point is found. The mirror point is defined as the first counterclockwise edge point that is equally distant from the major axis as the first point of the segment under test (i.e., has same y-c). The distance between these mirror points is the discriminant. If the distance is less than a certain threshold, the segment is identified as a dorsal fin. Otherwise, the pixel is identified as a weak inflection point from overlapping fish. Finally, this weak inflection point must be contiguous with a certain number of similarly identified weak inflection points. That is, a size criteria is added. There must be at least seven such points. This length criteria is introduced to diminish the effects of segmentation errors.

The rules for a strong inflection point near the nose are the following. First there must be

a strong inflection point (identified later). Second, the profile must be near the front of the fish (nose area). Third, there must be a an initial drop in the profile (increasing y-c). Fourth, there must be an initial decrease in the profile parallel to the major axis.

A strong inflection is defined as one where the dot product is greater than -0.866 and the cross product is positive. This type of inflection does not occur naturally any where along the front part of the fish. If no strong inflection point is found, the segment will not be classified as a strong inflection point.
Similar length criteria are used to discriminate the strong inflection point segments from segmentation errors.



Shadowgram detection of edge deflection points.

Thus, the segments under test must pass either one of these tests to classified as an inflection point. The number, ni, of such segments are counted and the number of fish are then estimated as (ni+ 3)/2.

There are a number of features to address at this point. First, due to the lighting arrangement during data acquisition, many of the fish tails cast shadows as the fish exits the field of view to the right. These shadows can be easily mistaken as additional tails in the edge analysis. This type of problem at this point is unfortunate as, from a tracking perspective, this is where the counting needs to be most accurate. As a consequence, the effort to count the fins, tails, and strong inflection points due to overlapping tails was stopped. It was felt that the shadowgram method would be less subject to misidentification. The shadowgram method is discussed next.

Fish Detection Employing Shadowgram Overlap Boundaries

Implementation of the shadowgram processing procedure is similar to that discussed in the FY92 Phase I final report. However in this implementation we have increased the accuracy by first subjecting each blob to a principle component analysis to determine its central axes. Gradient line scans are then taken parallel to both orthogonal axes at a 1:1 density. They are then thresholded for number density peak detection and the average number of edge boundaries across the blob are determined. In general 1 fish contains 2 edges, 2 overlapping fish have 3 edges, 3 overlapping fish have 4 edges, etc.

Frame to Frame Fish Tracking

The tracking for the low density environment is relatively straightforward. In addition, in the data that were provided, the progression from left to right is steady with no backwards moving fish. For the purposes of tracking this data, the decision was made to develop the tracking for this data, while acknowledging that fish do not always move forward.

For tracking this data, the following assumptions are made. First, fish always move left-to-right. Second, only fish in the right-most blob will move out of the field of view. Thus, if the rightmost blob in frame N+ 1 is behind (to the left of the right most blob in frame N), the right most blob in frame N has moved out of the field of view, and should be counted. Third, if the number of fish exiting (exiting is defined as right most edge of blob is within 25 pixels of the right hand side of the field of view) decreases from one frame to the next (i.e., from to 2 to 1), then one of the exiting fish has left the field of view and should be counted. Fourth, the count of fish within a blob is always accurate. Thus, when an empty frame is encountered, the entire population of fish from the preceding frame have moved out of the field of view and should be counted. If there were no fish in the preceding frame, no error is made. The logical involved is now discussed in more detail.

At the start of the execution the number of fish counted is initialized as 0. While each frame is being process, the portion, extent, and number of fish within each blob are being stored. At the end of each frame, these data are processed to determine how many fish, if any, left the field of view form the last frame. First, if the new frame contains no fish, then all the fish from the preceding frame are assumed to left the field of view and are counted. (This number of fish in the preceding frame is retained on a frame-by-frame basis.) If

there are fish in the current frame, the logic begins to analyze the history of the blobs.

The code first decides if the right-most blob in the preceding frame was exiting. If it were not, then the code determines if the right-most blob in the current frame is to the left of the right most blob in the preceding frame. If it is, the right-most blob from the preceding frame is assumed to have moved out of the field of view and is counted. The number of fish in the previous right-most blob is added to the number of fish to be counted. If the current right-most blob is to the right of the last right-most blob, then the blob is assumed to be approaching the edge and is not yet counted. If its leading edge (right-most extent) is within **25** pixels of the edge, it is determined to be exiting for the purposes of the next frame's analysis.

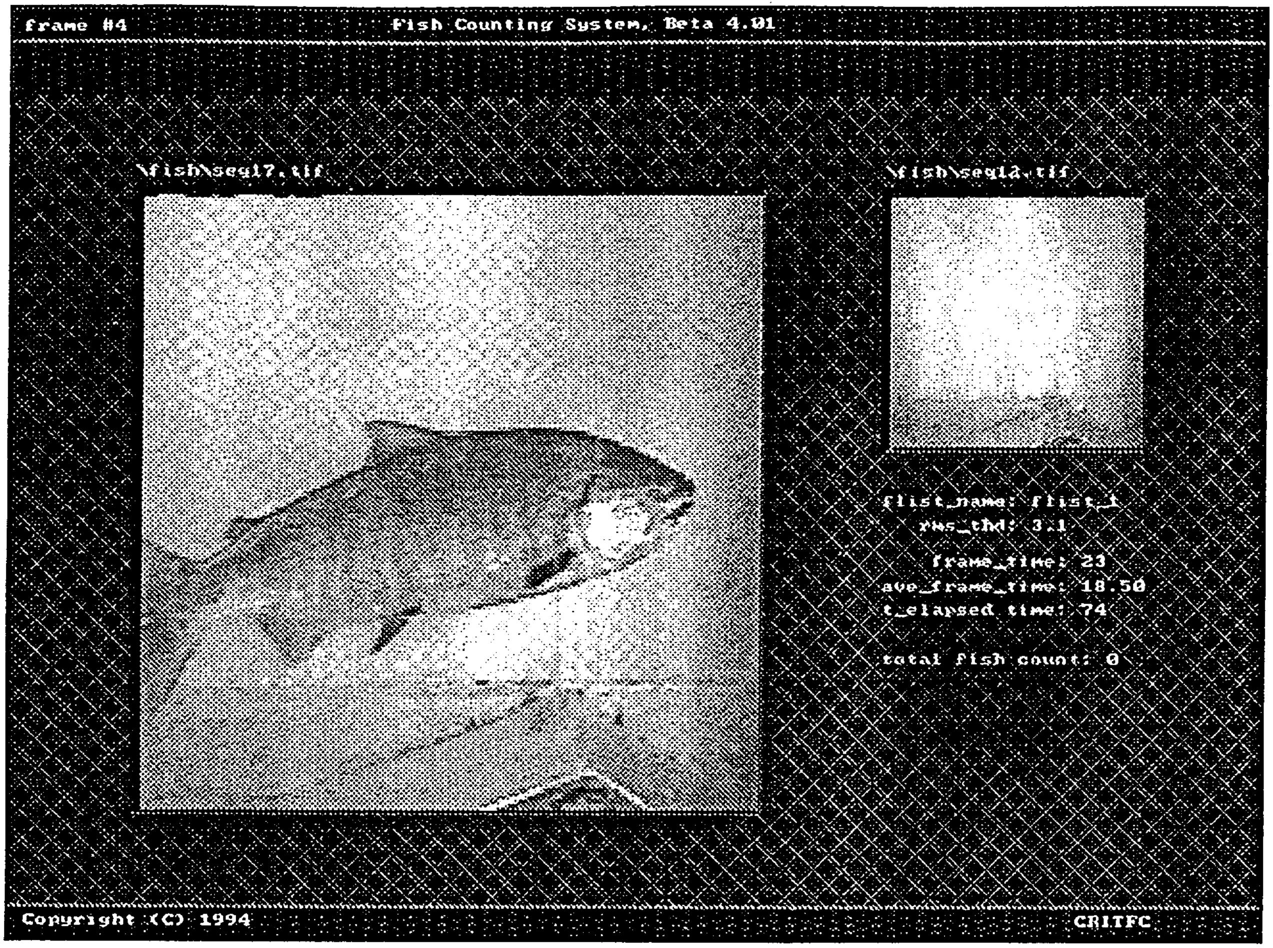
If the right-most blob in the previous frame has been identified as exiting then there are a number of issues to consider. First, if the current right-most blob is exiting and if the number of fish exiting has decreased from last frame, it is assumed that there were more than one fish in the previous right-most blob and that at least one of those fish has exited the field of view and should be counted. Thus, the decrease in the number of fish that are exiting are counted and added to the current total.

If the current right-most blob is not exiting, then it must be determined if the previous right-most blob has left the field of view or is the current right-most blob. The test for this determination is simply is the current right-most blob to the left of the previous? If it is, then the previous right-most blob is counted. If it is not, then no count is made.

In testing this logic, there was one particular failure. This failure occurred in sequence 4. In this sequence, one fish enters the field of view (seq43). In the following frames, another fish enters the field of view just behind the first. The segmentation separates the two fish. In the next frame, the second fish begins to overlap with the first so that the segmentation does not separate the two fish. The result was that the right-most blob shifted back to the left. The tracking logic mistakenly identified this occurrence as a fish exiting the field of view and improperly counted the fish. This problem was fixed by only considering the position of the right-most blob only if it is more than half way across the field of view.

In summary, the tracking logic is sound when the dynamics of the overlapping fish is simple. By simple dynamics, it is meant that fish do not merge or separate near the exit of the field. If this is the case, the tracking can be effectively managed with only a one frame, one blob memory. That is, only one blob per frame is of real interest, except when all blobs exit. The next degree of complication involves one frame, all blob memory. That is, information regarding all the blobs is required for tracking the fish. However, this should not be attempted until better segmentation is accomplished and counting techniques are developed to exploit the segmentation.

CRITFC Fish Counting System. Beta V4.01



running syntax: **FISH** fish-list-filename RMS_deviation-threshold batch-switch

Distribution Disk

The Bernoulli distribution disk provided with this final report contains the full development and testing environment for the FISH.EXE counting system. The code was developed using MetaGraphics 4.3D and WATCOM 9.5d. The disk is laid out in the following format:

```
DIRECTORY             CONTENTS
-----------------------------------------------------------------------D:.
t---FISH              - all SEQ##.TIF files provided by CRITFC for
I   |                   test cases
I   I
|   |
|   └───DOC           - WordPerfect 5.0 documentation + PCX figures
|   |
|   -SRC              - source code and makefiles for FISH.EXE
|     |                 including tiff libraries;.
|     └───LIBTIFF                     MAKEFILE and FISH.LNK
|                       to compile..
|                                     d:\fish\src > WMAKE
|
├───META              - MetaGraphics Version 4.3d libraries
|
|
├───WATCOM            - WATCOM C32/C+ + Version 9.5d
|
|
-TEST                 - test case examples for each of the 5 sequences
                        where,

                        FISH.EXE      counting executable
                        VIDEO.CFG     graphics setup file used by FISH
                                      if need change, run VMODE.EXE
                        RUNB.BAT      batch file for running all seq
                        FLIST_#       fish image list files
                        FISH_#.LOG    logged results of fish counting

                        SMRY.LOG & FISH.LOG runtime logging output
```

Also, the sample **AUTOEXEC.BAT** file provided within the root directory contains all PATH/LIB/INCLUDE and SET specifications for the WATCOM/META environment. For independent compiling the fish counting routine source is contained in **\FISH\SRC** along with the appropriate **makefile** (MAKEFILE) and link file **(FISH.LNK).** Simply invoke **WMAKE** and the resource file **makefile** will be used to create the .EXE.

Running the utility is easy using the following syntax:

FISH fish-list-filename rms_background threshold batch switch

where:

fish_list_filename = a column listing of type TIFF fish images,

* starting with the background frame,

* followed by each fish sequence frame,

* ending with a background frame

NOTE: no blank lines allowed.
For an example see **FLIST_1**

rms_background threshold = the background segmentation threshold

this typically runs between 2.7 and 3.1

test sequences **1,2,3,4** use 3.1
test sequence 5 uses 2.9

batch switch = 0 requires interactive operator for start & end
1 requires no operator interaction

As promised, we have provided for **Restart capability.** This is accomplished using the logging file employed to track detection events. To restart an interrupted sequence:

1. **examine the FISH.LOG** file to determine the last frame processed.

2. create a new **FLIST_#** file with the first entry the original background file name and the next filename **the** NEXT in the sequence

3. restart

Data Logging

The new FISH counting procedure maintains a constant data logic log of all activities for each frame examined within a sequence. This file **is called FISH.LOG.** It **contains the** following types of information:

the name of the background frame

background frame = back

the name of each input fish frame

input frame = \fish\seqllO.tif

the number of points removed from the blob in preparation for the edge trace

eliminated = 12

principle component information

rl = 0.985799 r2 = -0.167929 r3 = 0.167929 r4 = 0.985799
mxx = 9708.050781 mxy = -1530.492310 myy = 984.243408
sxx = 9968.766602 sxy = -0.000176 syy = 723.527710

logic to determine if segment is strong inflection point

test-tarcl 222 376 1894

logic relating to weak inflection points

ttl 11 59 55 61 61 9

counting of the number of contiguous edge inflections

count-infl il = 1 i2 = 1 n = 0

failure flagging of edge trace and how many fish returned with edge + shadow tests

fail data 0 1 1 1 1 0.044272

how many blobs / frame = nobj

fish-flow 00 nobj = 1

number of #fish per blob

fish-flow 000 nfish in blob 0 = 1

and location

fish_flow 000 x = 224 y = 186

tracking info

fish flow 0 0 224 -1 52

and frame timing info

timing 33 20.50 41

Process TIME Benchmark

Timing to determine the average frame processing rate was evaluated on a Gateway 486/50 MHz machine with all TIF files resident on a 17ms Bernoulli removable 90MB disk drive. All 5 control test sequences were processed and the average time per frame was determined. This proved to be 23.28 seconds per frame.

Basic TEST Results

The 5 test sequences provided by Doug Hatch during the late fall of 1993 where run through the procedure. The first four of these sequences where from the Wenatchee River and the fifth was from the Snake River. Although, species types were provided,-we were unable to implement type classification due to the poor quality of the digital imagery.·As mandated by Doug Hatch of the CRITFC, we therefore concentrated on counting statistics.

Sequence	Chinook	Sockeye	Sucker	TOTAL,	detected
1	2	4	0	6	7
2	1	9	0	10	10
3	0	3	0	3	3
4	0	2	0	2	2
5	1	0	1	2	2
				---	---
				23	24

Please Note
FISH.EXE is a graphics based utility designed for a SVGA card supporting 640x480, 800x600, or 1024x768 by 256 color video modes. The current distribution is set up for the ATI Wonder/Ultra modes. If the video mode fails on your system, run the support utility VMODE.EXE and set the appropriate mode. This will create a VIDEO.CFG file which is accessed each time FISH or IMSCAN are used. Also a copy of HSI's image conversion/display utility is provided for off line examination of TIF imagery. To learn how to run ALCHEMY,

```
d:\fish\src > alchemy -h                        for help
d:\fish\src> alchemy \fish\seq###.tif -V        to display an image
```

the name of the background frame

background frame = back

the name of each input fish frame

input frame = \fish\seq1 10.tif

the number of points removed from the blob in preparation for the edge trace

eliminated = 12

principle component information

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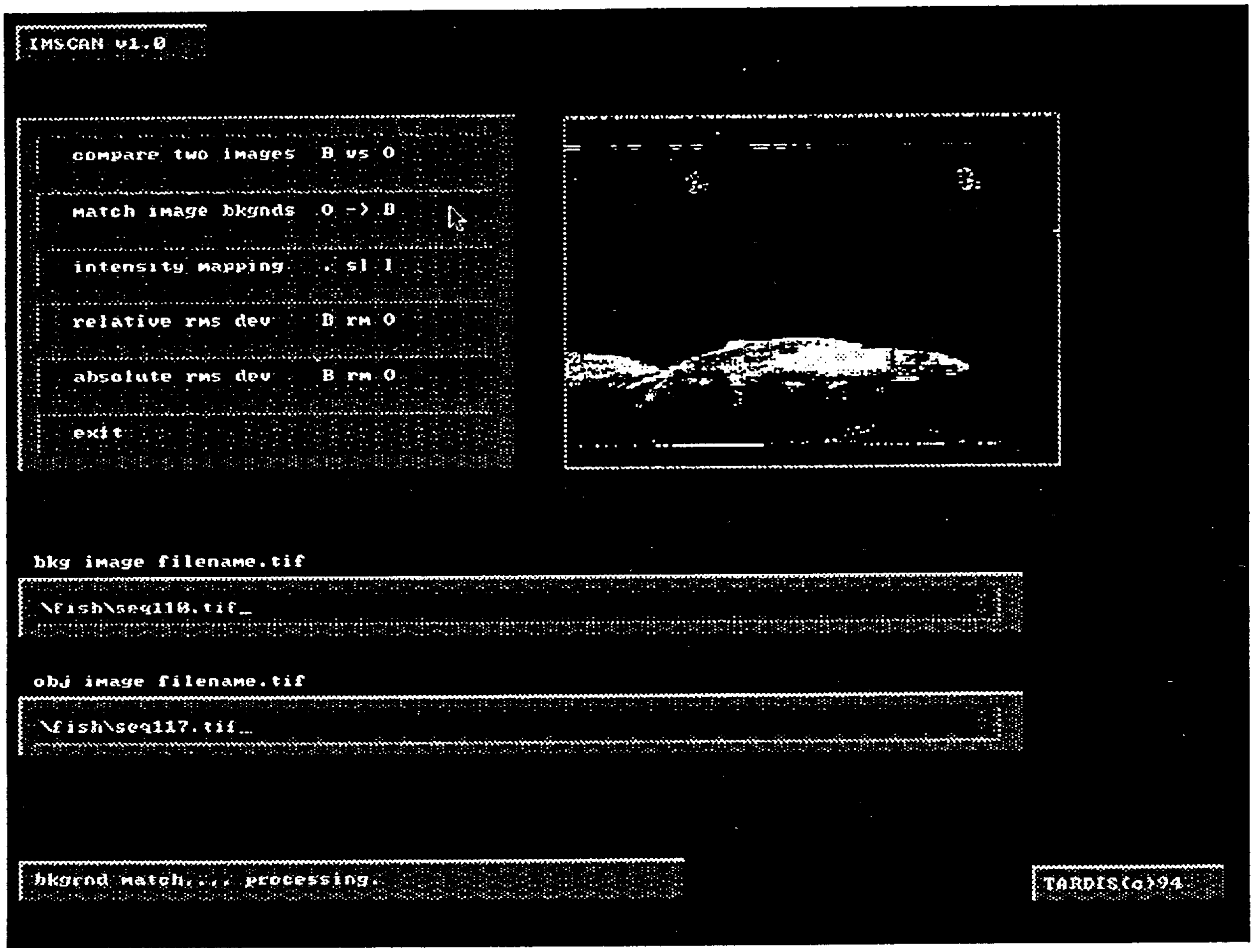
d:\fish\src > alchemy -h	for help
d:\fish\src > alchemy \fish\seq###.tif -V	to display an image

Running IMSCAN

IMSCAN is a basic image intensity profiler and image comparison or matching utility. It is specifically designed to enable interactive 'live' optimization of the video data acquisition environment by the CRITFC folks.

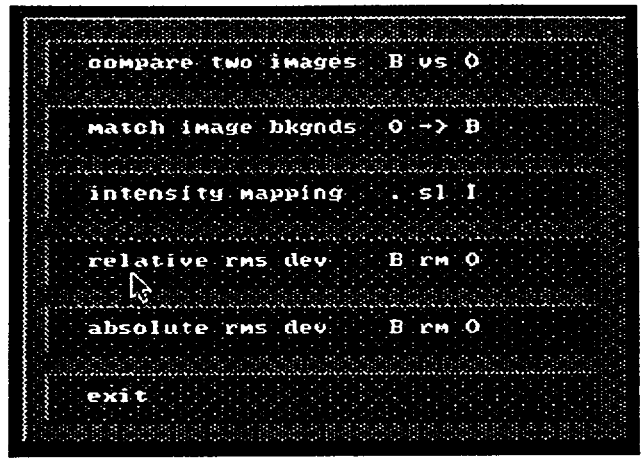


The IMSCAN option window.

As in the FISH execution, the IMSCAN utility employs the DOS4GW extender and MetaGraphics video modes specified within the VIDEO.CFG setup file. Creating or changing the graphics setup file can be accomplished by running VMODE.EXE

To start the image scanning utility run IMSCAN.

IMSCAN is mouse interactive, so once you have activated its main interface, the following option window will appear:



IMSCAN option list.

Compare 2 Images

This option allows the input of 2 TIF formatted files for side-by-side display with simultaneous line plotting and differencing available.

(optimal for comparing differences in fish frame backgrounds taken at different time intervals or different digitizers)

Match Backgrounds

This procedure matches the background pixels of the object to the background image by trend profiling (planar least-squares fitting to background points with discrimination against coincident edge points and distinctive object originated differences) and then warp mapping the 2 trend surfaces together.

Intensity Mapping

This procedure fits a planar surface to a single image's intensity profile. It enables comparison overlaid line plotting between the best-fit trend surface and the original data.

(optimal for determining light intensity distributions across the image field. The directional slope in either the trend or data profile defines the range, magnitude and direction of the light intensity distributions. The image histograms define the range and extent of that distribution. If the field is isotropic, then the histogram should be single valued and the plot lines horizontally flat for lines taken in all directions.)

Relative RMS Mapping

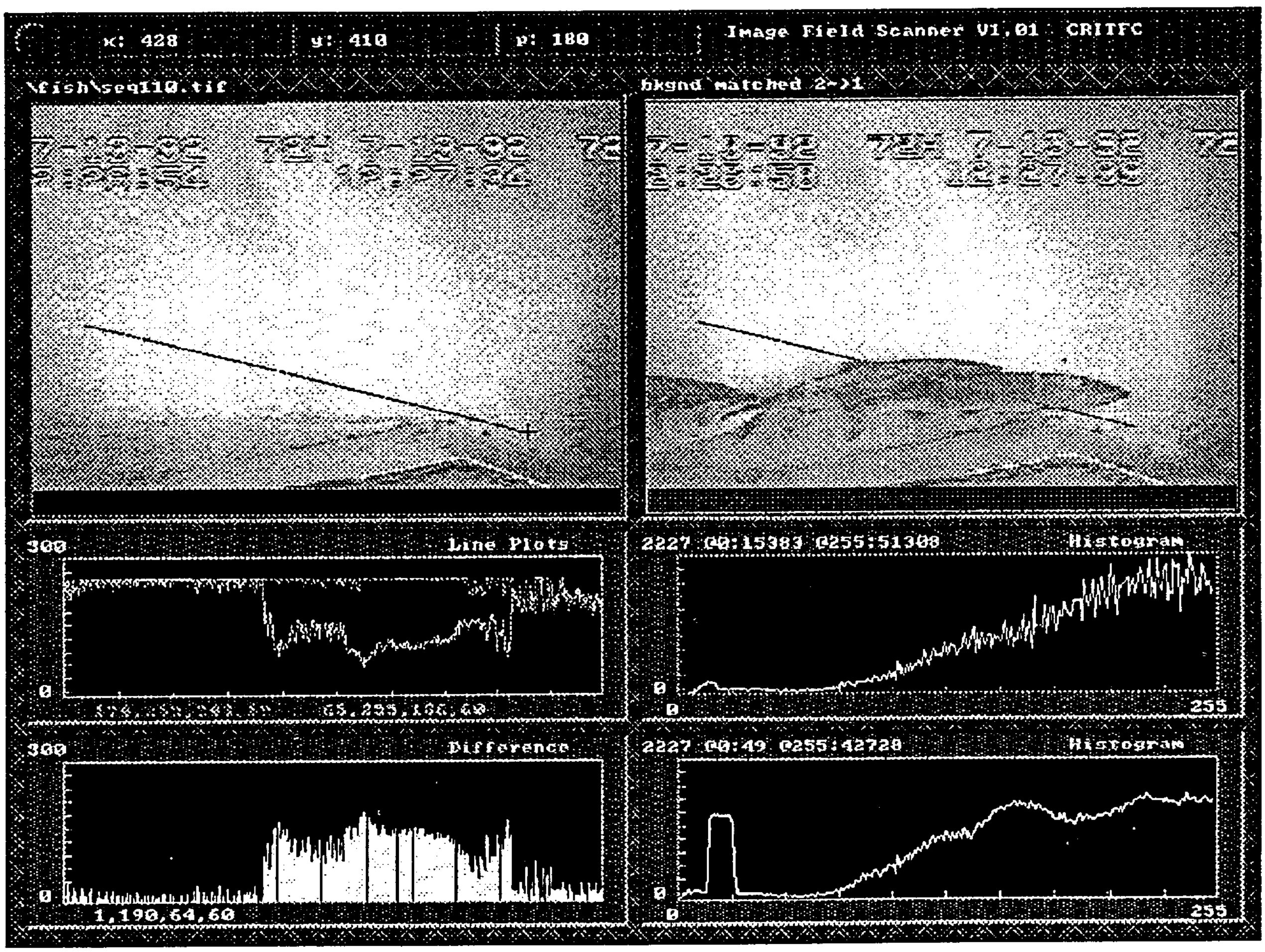
This procedure maps a background image and an object image into RMS deviation space. Both images are background trend-surface matched before applying the area-integrated RMS operator.

Absolute RMS Mapping

This procedure maps a background image and an object image into RMS deviation space. The images are not trend mapped before applying the area-integrated RMS operator.

(this procedure is ideal for comparison of background to fish frames to determine the range and extent of the digital noise and absolute deviation from frame to frame. It provides all necessary statistics for sequential frame noise characterization.)

To activate a selection, move the mouse to an option field bar and press the left-mouse button. Input fields for defining source files will be displayed. Click your mouse within an input field and type in the TIF filename. Then press ‘enter’. Once filename selection is complete, click on the ‘depressed’ option bar again and the file read/processing will begin.



IMSCAN data display field.

Once within the data display field you can do the following Functions:

1. pressing the left-mouse key within either image window returns the mouse pixel coordinates and intensity value (x,y,p) at the top of the data display field window

2. pressing the left-mouse key within the left image window anchors your rubber-banded plot line. Each time you press this button the line will be re-anchored to the current mouse position

3. Once anchored, moving the mouse will stretch simultaneous lines in both image windows. If you move outside the image field, the lines will disappear.

4. Pressing the right-mouse button activates the line plot sample mode. The line intensity profiles for each image field will be overlaid in the first plot directly below the left image. The red line corresponds to the left line profile and the green to the right profile.

   At the bottom of this plot are 2 sequences of numbers in red and green. The color defines the association. These numbers represent the min,max,ave and std deviation for the color coded plot line.

   A second plot will also be generated directly below the overlay. This plot represents the difference between the 2 plot lines. The difference min,max,ave,std is also displayed.

5. If you move the mouse into either of the plots and press the left-mouse button, the plot information for that point on the curve will be displayed at the top of the plot field. Information includes the number of points, the point number on the line, and the line values at that point.

6. If you press the left-mouse button within the histogram plots below the right image, the pixel value and it occurrence (p,n) within the associated image will be displayed at the top of the data display field.

7. To exit, click the mouse on the small button in the upper lefthand comer or press the ESC key. If you chose the button exit, an input window requesting- the input of a plot line data filename will appear.

   Clicking on the input-field left button will exit without creating a file.

   Entering a name and clicking on the right-button will store all the information on the data display window into an ascii file. The mouse then returns to the data display window so you can output another profile without exiting.

Appendix B. **Daily and annual total chinook salmon passage estimates at Lower Granite Dam in 1992.**

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Niaht
06/01	198	189	186	3	6	8	8	0
06/02	185	210	203	7	11	10	10	0
06/03	178	218	211	7	8	11	11	0
06/04	229	229	221	8	4	8	7	1
06/05	275	252	250	2	10	21	21	0
06/06	163	179	173	6	8	8	8	0
06/07	188	189	188	1	10	12	12	0
06/08	131	148	147	1	6	8	7	1
06/09	190	165	157	8	8	8	8	0
06/10	215	190	189	1	4	5	5	0
06/11	229	193	189	4	2	1	1	0
06/12	272	227	226	1	8	11	11	0
06/13	178	132	126	6	1	4	4	0
06/14	190	159	157	2	7	10	·10	.0
06/15	212	194	184	10	7	7	7	0
06/16	248	235	236	-1	10	9	9	0
06/17	156	129	130	-1	2	2	2	0
06/18	148	150	139	11	11	16	16	0
06/19	146	1'35	130	5	5	8	8	0
06/20	127	140	134	6	1	4	3	1
06/21	151	147	148	-1	12	14	14	0
06/22	49	47	44	3	4	3	2	1
06/23	41	29	30	-1	6	4	4	0
06/24	83	83	83	0	8	12	1 2	0
06/25	62	50	49	1	2	5	5	0
06/26	22	11	13	-2	1	1	1	0
06/27	43	46	45	1	7	7	7	0
06/28	74	56	56	0	7	6	6	0
06/29	107	76	73	3	14	14	15	-1
06/30	90	89	88	1	13	17	17	0
07/01	163	182	161	21	19	26	24	2
07/02	404	405	399	6	22	19	19	0
07/03	115	102	100	2	6	11	9	2
07/04	77	80	77	3	8	8	7	1
07/05	157	152	152	0	4	9	9	0
07/06	114	116	116	0	11	12	12	0
07/07	85	73	72	1	5	7	7	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	.WDW	Video Total	Video Day	Video Niahf
07/08	118	107	105	2	8	11	11	0
07/09	61	54	54	0	6	9	9	0
07/10	60	66	64	2	10	13	13	0
07/11	52	48	49	-1	12	13	13	0
07/12	41	37	37	0	8	8	7	1
07/13	55	71	68	3	8	8	7	1
07/14	54	70	69	1	11	12	11	1
07/15	44	48	49	-1	6	4	4	0
07/16	40	33	30	3	0	3	3	0
07/17	34	30	30	0	7	6	6	0
07/18	18	18	18	0	5	3	3	0
07/19	6	8	8	0	2	5	5	0
07/20	2	4	4	0	2	1	1	0
07/21	1	1	1	0	2	4	4	0
07/22	5	4	4	0	1	2	. 2	0
07/23	13	11	11	0	11	10	10	0
07/24	14	15	15	0	4	3	3	0
07/25	20	24	24	0	0	0	0	0
07/26	6	6	6	0	6	6	6	0
07/27	10	10	9	1	4	4	3	1
07/28	12	11	9	2	7	6	6	0
07/29	11	12	12	0	2	3	3	0
07/30	7	7	7	0	2	3	3	0
07/31	0	1	1	0	0	1	1	0
08/01	2	4	4	0	1	3	3	0
08/02	1	3	3	0	4	4	4	0
08/03	5	5	5	0	2	2	2	0
08/04	7	6	5	1	0	0	0	0
08/05	8	5	4	1	0	0	0	0
08/06	11	7	6	1	0	3	2	1
08/07	7	5	5	0	1	4	4	0
08/08	18	12	12	0	0	0	0	0
08/09	6	5	4	1	0	0	0	0
08/10	4	4	3	1	0	0	0	0
08/11	0	-1	-1	0	0	0	0	0
08/12	0	1	1	0	0	1	1	0
08/13	1	1	1	0	0	0	0	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
08/14	0	0	0	0	0	0	0	0
08/15	0	0	0	0	0	0	0	0
08/16	2	2	2	0	0	1	1	0
08/17	0	0	0	0	0	0	0	0
08/18	4	1	1	0	0	2	2	0
08/19	1	1	1	0	0	0	0	0
08/20	0	1	1	0	0	1	1	0
08/21	0	0	0	0	0	0	0	0
08/22	1	1	1	0	0	2	2	0
08/23	1	1	1	0	0	1	1	0
08/24	0	0	0	0	0	0	0	0
08/25	6	2	2	0	1	0	0	0
08/26	0	3	3	0	0	1	1	0
08/27	5	4	4	0	0	0	0	0
08/28	4	2	2	0	0	0	0	0
08/29	4	2	2	0	0	0	0	0
08/30	1	3	3	0	0	0	0	0
08/31	2	3	3	0	0	0	0	0
09/01	0	0	0	0	0	0	0	0
09/02	7	8	7	1	1	1	1	0
09/03	8	8	7	1	0	0	0	0
09/04	11	9	9	0	0	1	1	0
09/05	10	11	10	1	1	1	1	0
09/06	29	23	23	0	1	4	4	0
09/07	16	14	14	0	1	1	1	0
09/08	13	13	9	4	0	0	0	0
09/09	18	16	16	0	0	0	0	0
09/10	24	27	24	3	0	0	0	0
09/11	12	14	12	2	0	1	1	0
09/12	17	23	23	0	0	0	0	0
09/13	16	20	18	2	1	2	2	0
09/14	23	17	16	1	0	3	2	1
09/15	17	13	13	0	2	2	2	0
09/16	19	18	15	3	0	3	3	0
09/17	41	38	37	1	2	6	5	1
09/18	43	42	41	1	4	9	8	1
09/19	28	25	23	2	4	9	8	1

Pate	Chinook Adult WDW	Chinook Adult Video Total	Chinook Adult Video Day	Chinook Adult Video Night	Chinook Jack WDW	Chinook Jack Video Total	Chinook Jack Video Day	Chinook Jack Video Night
09/20	34	32	28	4	7	8	8	0
09/21	7	8	7	1	4	4	4	0
09/22	8	11	9	2	1	6	6	0
09/23	8	9	8	1	1	3	2	1
09/24	19	20	20	0	1	4	4	0
09/25	12	11	11	0	1	2	2	0
09/26	18	13	13	0	4	4	4	0
09/27	34	25	25	0	6	11	11	0
09/28	22	17	14	3	1	5	5	0
09/29	11	12	11	1	0	2	1	1
09/30	7	8	6	2	1	2	2	0
10/01	18	16	16	0	4	3	3	0
10/02	12	10	10	0	6	8	8	0
10/03	10	12	12	0	4	2	2	0
10/04	12	11	11	0	1	3	2	1
10/05	5	6	5	1	2	2	2	0
10/06	5	6	6	0	5	4	4	0
10/07	12	7	7	0	5	4	4	0
10/08	8	9	9	0	1	2	2	0
10/09	13	14	10	4	6	2	2	0
10/10	4	4	4	0	0	1	1	0
10/11	4	4	3	1	0	3	2	1
10/12	8	10	9	1	1	2	2	0
10/13	16	10	10	0	4	7	6	1
10/14	6	5	5	0	2	1	1	0
10/15	2	4	3	1	0	0	0	0
10/16	10	12	10	2	0	0	0	0
10/17	5	6	4	2	1	1	1	0
10/18	4	6	5	1	0	0	0	0
10/19	10	10	9	1	1	1	1	0
10/20	6	6	5	1	1	1	1	0
10/21	5	5	5	0	0	0	0	0
10/22	5	7	5	2	0	0	0	0
10/23	6	6	4	2	0	0	0	0
10/24	8	7	7	0	2	2	2	0
10/25	20	8	8	0	2	2	1	1
10/26	4	4	4	0	1	0	0	0

Appendii B. continued. v

	Chinook Adult				Chinook Jack			
Pate	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
10/27	4	2	2	0	0	0	0	0
10/28	10	10	8	2	0	0	0	0
10/29	4	7	3	4	0	0	0	0
10/30	7	9	8	1	1	0	0	0
10/31	6	9	8	1	1	2	2	0
11/01	6	7	5	2	0	2	1	1
11/02	4	4	2	2	0	1	0	1
11/03	1	7	1	6	0	1	1	0
11/04	7	7	6	1	1	1	1	0
11/05	4	2	2	0	0	0	0	0
11/06	10	12	9	3	0	0	0	0
11/07	6	8	4	4	0	0	0	0
11/08	2	4	3	1	0	1	0	1
11/09	0	4	1	3	1	0	0	0
11/10	0	3	0	3	0	-1	-1	0
11/11	2	2	2	0	2	1	1	0
11/12	2	4	2	2	0	0	0	0
11/13	1	3	1	2	0	1	1	0
11/14	1	1	1	0	0	1	1	0
11/15	0	1	0	1	0	0	0	0
11/16	0	1	0	1	0	1	0	1
11/17	6	2	2	0	0	0	0	0
11/18	0	1	1	0	1	0	0	0
11/19	0	0	0	0	0	0	0	0
11/20	0	2	0	2	0	0	0	0
11/21	1	0	0	0	0	0	0	0
11/22	1	2	0	2	0	0	0	0
11/23	0	1	0	1	0	0	0	0
11/24	0	1	0	1	0	0	0	0
11/25	1	2	2	0	0	0	0	0
11126	0	5	4	1	0	0	0	0
11/27	0	0	0	0	0	0	0	0
11/28	0	0	0	0	0	0	0	0
11/29	0	0	0	0	0	0	0	0
11/30	0	0	0	0	0	0	0	0
12/01	0	0	0	0	0	0	0	0
12/02	0	0	.0	0	0	0	0	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
12/03	0	0	0	0	0	0	0	0
12/04	0	0	0	0	0	0	0	0
12/05	0	0	0	0	0	0	0	0
12/06	0	0	0	1	0	0	0	0
12/07	0	0	0	0	0	0	0	0
12/08	0	0	0	0	0	0	0	0
12/09	0	0	0	0	0	0	0	0
12/10	0	0	0	0	0	0	0	0
12/11	0	0	0	0	0	0	0	0
12/12	0	0	0	0	0	0	0	0
12/13	0	0	0	0	0	0	0	0
12/14	0	0	0	0	0	0	0	0
12/15	0	0	0	0	0	0	0	0
Total	7316	7020	6776	244	511	666	639	27

Appendix C. Daily and annual total steelhead passage estimates at Lower Granite Dam in 1992.

Pate	WDW	video total	video day	video night
06/01	1	0	0	0
06/02	0	1	0	1
06/03	1	1	1	0
06/04	0	1	1	0
06/05	0	0	0	0
06/06	2	5	5	0
06/07	2	3	3	0
06/08	0	0	0	0
06/09	0	0	0	1
06/10	1	2	2	0
06/11	0	0	0	0
06/12	4	4	4	0
06/13	1	5	5	0
06/14	1	1	1	0
06/15	1	0	0	0
06/16	7	6	6	0
06/17	2	5	5	0
06/18	1	1	1	0
06/19	5	5	5	0
06/20	4	6	5	1
06/21	6	5	5	0
06/22	6	10	9	1
06/23	2	3	3	0
06124	2	3	3	0
06/25	2	0	2	-2
06/26	1	1	1	0
06/27	5	3	3	0
06/28	4	2	2	0
06/29	10	10	9	1
06/30	5	5	3	2
07/01	16	12	12	0
07/02	5	3	4	-1
07/03	18	12	12	0
07/04	14	13	13	0
07/05	34	33	32	1
07/06	42	30	30	0
07/07	30	28	26	2
07/08	43	30	30	0
07/09	37	31	32	-1

Date	WDW	video total	video day	video night
07/10	31	38	36	2
07/11	25	33	32	1
07/12	31	37	37	0
07/13	35	31	30	1
07/14	30	31	30	1
07/15	23	28	26	2
07/16	22	23	21	2
07/17	14	18	17	1
07/18	16	17	16	1
07/19	17	15	15	0
07/20	5	5	3	2
07/21	7	4	4	0
07/22	16	16	16	0
07/23	23	28	25	3
07/24	34	30	28	2
07/25	23	23	23	0
07/26	16	17	17	0
07/27	19	19	16	3
07/28	32	35	33	2
07/29	32	32	32	0
07/30	23	18	17	1
07/31	12	8	9	-1
08/01	11	8	8	0
08/02	11	15	12	3
08/03	53	56	46	10
08/04	48	49	47	2
08/05	64	68	52	16
08/06	127	134	118	16
08/07	144	144	128	16
08/08	145	166	149	17
08/09	145	156	151	5
08/10	101	112	105	7
08/11	48	58	53	5
08/12	37	29	29	0
08/13	22	21	21	0
08/14	18	19	19	0
08/15	22	21	20	1
08/16	40	43	42	1
08/17	23	19	19	0

Date	WDW	video total	video day	video night
08/18	1 1	11	10	1
08/19	20	23	22	1
08/20	14	23	19	4
08/21	40	51	47	4
08/22	48	66	56	10
08/23	59	83	75	8
08/24	42	59	42	17
08/25	98	104	92	12
08/26	109	120	107	13
08/27	113	129	122	7
08/28	169	172	163	9
08/29	132	135	132	3
08/30	59	56	55	1
08/31	36	43	43	0
09/01	41	49	43	6
09/02	72	73	62	11
09/03	73	83	73	10
09/04	148	158	150	8
09/05	132	120	109	11
09/06	188	207	178	29
09/07	211	224	193	31
09/08	266	323	268	55
09/09	342	401	357	44
09/10	358	393	340	53
09/11	342	431	374	57
09/12	553	686	641	45
09/13	524	667	552	115
09/14	605	724	632	92
09/15	607	673	589	84
09/16	581	695	619	76
09/17	1901	2015	1888	127
09/18	2692	2727	2644	83
09/19	2384	2618	2465	153
09/20	4594	4763	4577	186
09/21	1950	1954	1869	85
09/22	2370	2508	2430	78
09/23	2012	2072	1963	109
09/24	3508	3666	3620	46
09/25	4206	4257	4224	33

Pate	WDW	video total	video day	video night
09/26	3629	3740	3644	96
09/27	4208	4182	4117	65
09/28	3000	3180	3028	152
09/29	3127	3297	3145	152
09/30	2341	2476	2367	109
10/01	2879	2993	2904	89
10/02	2572	3053	2949	104
10/03	3797	3911	3849	62
10/04	2590	2855	2767	88
10/05	1279	1371	1293	78
10/06	2603	2716	2460	256
10/07	3104	3416	3093	323
10/08	2510	2837	2568	269
10/09	4346	4452	4283	169
10/10	1678	1733	1561	172
10/11	1703	1858	1723	135
10/12	1339	1493	1324	169
10/13	2664	2810	2623	187
10/14	2179	2234	2099	135
10/15	1459	1605	1515	90
10/16	1639	1788	1650	138
10/17	796	874	775	99
10/18	1747	1715	1634	81
10/19	962	1077	951	126
10/20	1897	1952	1884	68
10/21	1375	1468	1370	98
10/22	1146	1247	1179	68
10/23	2017	2254	2171	83
10/24	1613	1566	1522	44
10/25	1286	1336	1285	51
10/26	1048	1113	1069	44
10/27	849	931	884	47
10/28	1115	1134	1081	53
10/29	670	682	630	52
10/30	794	849	793	56
10/31	618	658	598	60
11/01	388	668	519	149
11/02	575	723	621	102
11/03	539	654	520	134

Pate	WDW	video total	video day	video night
11/04	622	730	616	114
11/05	286	417	293	124
11/06	574	635	557	78
11/07	494	642	550	92
11/08	440	506	467	39
11/09	289	385	317	68
11/10	312	359	316	43
11/11	470	535	494	41
11/12	245	295	235	60
11/13	372	416	373	43
11/14	264	286	253	33
11/15	166	188	163	25
11/16	52	86	56	30
11/17	169	220	173	47
11/18	283	390	299	91
11/19	289	445	340	105
11/20	557	692	558	134
11/21	370	469	375	94
11/22	427	528	439	89
11/23	192	271	233	38
11/24	187	269	200	69
11/25	226	333	276	57
11/26	154	455	308	147
11/27	286	315	263	52
11/28	136	156	136	20
11/29	154	179	157	22
11/30	97	115	86	29
12/01	88	125	93	32
12/02	55	82	49	33
12/03	30	48	36	12
12/04	142	185	137	48
12/05	60	83	73	10
12/06	29	43	32	11
12/07	47	50	47	3
12/08	23	34	27	7
12/09	38	41	37	4
12/10	8	21	16	5
12/11	59	72	57	15
12/12	46	54	47	7

Pate	WDW	video total	video day	video night
12/13	28	30	24	6
12/14	13	19	16	3
12/15	24	27	24	3
Total	116354	125599	117318	8281

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Appendix D. **Dates and times of recorded sockeye salmon passage at Lower Granite Dam in 1992 (A (+) indicates a sockeye confirmation, A (-) indicates an unconfirmed sockeye passage).**

Potential Sockeye Salmon Passage Events	COE		Video Detection[1] Initial Review		Confirmation
06/08	+	(15:00-15:50)	+	(16:07:25)	+
07/04	+	(18:00-18:50)	+	(19:34:19)	+
07/06	+	(06:00-06:50)	+	(07:36:00)	+
07/06	+	(08:00-08:50)	+	(09:24: 10)	+
07/13	+	(06:42)	+	(07:41:50)	+
07/13	+	(13:42)	+	(14:31:25)	+
07/15	+	(14:45)	+	(15:33:49)	+
07/15	+	(15:25)	-		
07/16			+	(00:01:00)	+
07/23	+	(11:10)	+	(12:09:14)	+
07/27	-		+	(01:20:24)	+
08/02			+	(04:16:11)	+
08/05	+	(15:24)	+	(16:24:00)	+
08/14	+	(06:26)	+	(7:25:22)	+
08/16	+	(19:00-19:50)	-		
08/26	+	(12:40)	+	(13:37:17)	+
08/27	+	(12:05)	+	(13:05:16)	+
08/30	+	(10:32)	-		

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[1]Passage is recorded in Daylight Savings Time, which is one hour ahead of Pacific Standard Time, used by WDW and the COE.

Appendix E. Daily and annual total chinook salmon passage estimates at Lower Granite Dam in 1993.

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
03/01	0	0	0	0	0	0	0	0
03/02	0	0	0	0	0	0	0	0
03/03	0	0	0	0	0	0	0	0
03/04	0	0	0	0	0	0	0	0
03/05	0	0	0	0	0	0	0	0
03/06	0	0	0	0	0	0	0	0
03/07	0	0	0	0	0	0	0	0
03/08	0	0	0	0	0	0	0	0
03/09	0	0	0	0	0	0	0	0
03/10	0	0	0	0	0	0	0	0
03/11	0	0	0	0	0	0	0	0
03/12	0	0	0	0	0	0	0	0
03/13	0	0	0	0	0	0	0	0
03/14	0	0	0	0	0	0	0	0
03/15	0	0	0	0	0	0	0	0
03/16	0	0	0	0	0	0	0	0
03/17	0	0	0	0	0	0	0	0
03/18	0	0	0	0	0	0	0	0
03/19	0	0	0	0	0	0	0	0
03/20	0	0	0	0	0	0	0	0
03/21	0	0	0	0	0	0	0	0
03/22	0	0	0	0	0	0	0	0
03/23	0	0	0	0	0	0	0	0
03/24	0	0	0	0	0	0	0	0
03/25	0	0	0	0	0	0	0	0
03/26	0	0	0	0	0	0	0	0
03/27	0	0	0	0	0	0	0	0
03/28	0	0	0	0	0	0	0	0
03/29	0	0	0	0	0	0	0	0
03/30	0	0	0	0	0	0	0	0
03/31	0	0	0	0	0	0	0	0
04/01	0	0	0	0	0	0	0	0
04/02	0	0	0	0	0	0	0	0
04/03	0	0	0	0	0	0	0	0
04/04	0	0	0	0	0	0	0	0
04/05	0	0	0	0	0	0	0	0
04/06	0	0	0	0	0	0	0	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
04/07	0	0	0	0	0	0	0	0
04/08	0	0	0	0	0	0	0	0
04/09	0	0	0	0	0	0	0	0
04/10	0	0	0	0	0	0	0	0
04/11	0	0	0	0	0	0	0	0
04/12	0	0	0	0	0	0	0	0
04/13	0	0	0	0	0	0	0	0
04/14	0	0	0	0	0	0	0	0
04/15	0	0	0	0	0	0	0	0
04/16	0	0	0	0	0	0	0	0
04/17	1	0	0	0	0	0	0	0
04/18	0	0	0	0	0	0	0	0
04/19	0	0	0	0	0	0	0	0
04/20	1	1	1	0	0	0	0	0
04/21	1	1	1	0	0	0	0	0
04/22	2	2	2	0	0	0	0	0
04/23	2	4	4	0	0	0	0	0
04/24	0	0	0	0	0	0	0	0
04/25	8	9	8	1	0	0	0	0
04/26	6	6	5	1	0	0	0	0
04/27	17	24	21	3	0	0	0	0
04/28	67	68	61	7	0	0	0	0
04/29	232	234	223	11	0	0	0	0
04/30	301	290	290	0	0	0	0	0
05/01	511	500	498	2	0	0	0	0
05/02	505	513	494	19	0	2	2	0
05/03	599	607	598	9	0	0	0	0
05/04	462	493	467	26	0	2	2	0
05/05	378	392	378	14	4	0	0	0
05/06	559	547	541	6	2	2	2	0
05/07	779	768	738	30	0	0	0	0
05/08	872	849	822	27	2	1	1	0
05/09	899	882	873	9	5	2	2	0
05/10	264	269	251	18	0	1	1	0
05/11	520	499	484	15	4	5	5	0
05/12'	941	1009	948	61	0	2	0	2
05/13	1421	1475	1424	51	6	6	6	0
05/14	1141	1165	1128	37	1	1	1	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
05/15	960	997	988	9	5	1	1	0
05/16	467	494	490	4	2	2	2	0
05/17	222	247	244	3	0	0	0	0
05/18	245	245	239	6	2	3	3	0
05/19	359	373	372	1	1	0	0	0
05/20	144	149	144	5	0	2	2	0
05/21	176	193	192	1	1	0	0	0
05/22	128	146	142	4	2	0	0	0
05/23	86	93	90	3	4	2	2	0
05/24	127	126	124	2	4	3	3	0
05/25	136	186	158	28	2	4	4	0
05/26	316	361	340	21	7	7	7	0
05/27	247	252	240	12	7	4	4	0
05/28	394	399	382	17	6	9	8	1
05/29	880	900	869	31	22	13	12	1
05/30	382	454	405	49	5	4	2	2
05/31	408	492	425	67	5	8	8	0
06/01	371	432	372	60	8	6	5	1
06/02	412	445	399	46	10	8	8	0
06/03	469	540	468	72	2	4	4	0
06/04	574	610	588	22	11	10	10	0
06/05	293	408	350	58	6	7	7	0
06/06	343	433	416	17	5	9	8	1
06/07	119	147	134	13	5	4	4	0
06/08	190	196	191	5	10	9	9	0
06/09	64	64	59	5	4	3	3	0
06/10	128	128	115	13	2	1	1	0
06/11	366	410	359	51	5	6	5	1
06/12	289	300	271	29	2	2	2	0
06/13	228	231	212	19	5	3	3	0
06/14	138	150	133	17	0	0	0	0
06/15	280	278	270	8	1	2	2	0
06/16	259	266	255	11	4	4	4	0
06/17	346	394	377	17	4	2	1	1
06/18	437	399	397	2	2	3	2	1
06/19	286	276	271	5	2	2	2	0
06/20	276	270	264	6	4	1	1	0
06/21	116	140	123	17	0	0	0	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
06/22	606	584	580	4	3 2	2	2	0
06/23	228	204	201	3	2	2	2	0
06/24	432	410	406	4	11	7	7	0
06/25	607	574	565	9	7	9	9	0
06/26	401	390	387	3	10	8	8	0
06/27	444	485	475	10	2	5	4	1
06/28	344	335	317	18	5	5	5	0
06/29	305	352	340	12	7	7	6	1
06/30	235	247	222	25	4	3	3	0
07/01	394	383	368	15	5	7	7	0
07/02	276	281	268	13	6	5	4	1
07/03	252	248	236	12	11	9	10	-1
07/04	94	89	85	4	2	1	0	1
07/05	296	282	268	14	6	7	7	0
07/06	170	162	160	2	4	4	4	0
07/07	166	191	180	11	4	5	5	0
07/08	106	119	116	3	5	4	4.	0
07/09	110	118	110	8	1	3	3	0
07/10	146	123	117	6	2	4	3	1
07/11	74	82	72	10	5	3	3	0
07/12	96	90	79	11	0	0	0	0
07/13	67	61	63	-2	0	1	1	0
07/14	113	98	85	13	0	4	4	0
07/15	56	42	43	-1	4	1	1	0
07/16	103	104	101	3	0	1	1	0
07/17	29	31	30	1	2	3	3	0
07/18	56	..	..	..	1	..	..	..
07/19	46	..	..	..	1	..	..	..
07/20	54	3		3	2	0	..	0
07/21	43	38	38	0	0	0	0	0
07/22	55	59	57	2	2	3	3	0
07/23	48	43	44	-1	0	2	1	1
07/24	18	18	18	0	2	2	2	0
07/25	28	22	21	1	0	1	1	0
07/26	20	17	17	0	1	0	0	0
07/27	22	30	28	2	1	0	0	0
07/28	20	27	25	2	0	0	0	0
07/29	12	11	11	0	0	1	1	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
07/30	38	43	43	0	0	3	3	0
07/31	19	25	24	1	1	0	0	0
08/01	23	28	28	0	1	1	1	0
08/02	8	5	5	0	0	0	0	0
08/03	12	7	7	0	0	0	0	0
08/04	6	4	4	0	0	0	0	0
08/05	11	7	7	0	0	0	0	0
08/06	7	7	6	1	0	0	0	0
08/07	13	13	12	1	0	0	0	0
08/08	7	5	5	0	0	0	0	0
08/09	12	8	8	0	1	1	1	0
08/10	6	7	7	0	0	1	1	0
08/11	5	2	4	-2	0	0	0	0
08/12	1	0	3	-3	1	0	0	0
08/13	5	6	6	0	0	0	0	0
08/14	22	21	21	0	0	1	1	0
08/15	0	0	0	0	0	0	0	0
08/16	1	0	0	0	0	0	0	0
08/17	6	6	6	0	1	1	1	0
08/18	11	12	11	1	0	0	0	0
08/19	34	37	35	2	0	0	0	0
08/20	13	11	10	1	0	0	0	0
08/21	14	15	14	1	0	0	0	0
08/22	8	9	9	0	0	0	0	0
08/23	4	5	5	0	0	0	0	0
08/24	5	5	5	0	0	1	1	0
08/25	7	7	7	0	0	0	0	0
08/26	0	6	4	2	0	0	0	0
08/27	10	9	8	1	0	0	0	0
08/28	2	3	3	0	0	0	0	0
08/29	7	11	11	0	0	0	0	0
08/30	6	5	5	0	0	0	0	0
08/31	5	8	8	0	0	1	1	0
09/01	10	7	6	1	0	1	1	0
09/02	10	10	9	1	0	0	0	0
09/03	7	8	8	0	0	0	0	0
09/04	12	11	11	0	0	0	0	0
09/05	10	7	7	0	1	1	1	0

	Chinook Adult				Chinook Jack			
Date	W D W	Video Total	Video Day	Video Night	W D W	Video Total	Video Day	Video Night
09/06	23	23	23	0	0	0	0	0
09/07	10	14	14	0	0	0	0	0
09/08	13	12	12	0	0	0	0	0
09/09	14	16	15	1	0	0	0	0
09/10	13	15	13	2	1	1	1	0
09/11	10	9	9	0	0	0	0	0
09/12	25	27	24	3	1	2	2	0
09/13	23	23	20	3	0	0	0	0
09/14	31	41	38	3	0	1	0	1
09/15	14	17	16	1	0	2	1	1
09/16	55	54	53	1	0	0	0	0
09/17	47	59	54	5	0	0	0	0
09/18	53	53	50	3	1	0	0	0
09/19	50	55	54	1	2	1	1	0
09/20	47	47	47	0	6	3	3	0
09/21	35	33	32	1	0	1	1	0
09/22	24	22	20	2	5	6	6	0
09/23	24	19	18	1	0	2	2	0
09/24	34	34	32	2	1	0	0	0
09/25	24	23	23	0	1	1	1	0
09/26	22	26	26	0	1	1	1	0
09/27	14	17	17	0	0	0	0	0
09/28	20	22	22	0	0	1	1	0
09/29	12	12	12	0	0	2	2	0
09/30	28	28	26	2	1	0	0	0
10/01	38	36	34	2	1	1	1	0
10/02	31	32	29	3	0	0	0	0
10/03	17	19	19	0	2	1	1	0
10/04	34	32	31	1	4	0	0	0
10/05	10	13	11	2	1	0	0	0
10/06	20	18	17	1	2	1	1	0
10/07	18	15	14	1	4	4	3	1
10/08	10	12	12	0	0	0	0	0
10/09	13	14	13	1	0	0	0	0
IO/IO	8	9	9	0	0	0	0	0
1 O/l 1	12	11	11	0	1	0	0	0
10/12	11	14	14	0	0	1	0	1
10/13	0	2	2	0	0	3	3	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
10/14	5	6	5	1	0	0	0	0
10/15	6	6	5	1	0	0	0	0
10/16	4	3	3	0	1	0	0	0
10/17	2	2	2	0	0	0	0	0
10/18	4	3	3	0	0	0	0	0
10/19	2	2	2	0	0	0	0	0
10/20	2	2	2	0	0	1	0	1
10/21	7	6	5	1	0	0	0	0
10/22	2	5	4	1	0	0	0	0
10/23	4	4	4	0	0	0	0	0
10/24	1	0	0	0	1	0	0	0
10/25	4	3	3	0	0	0	0	0
10/26	7	5	5	0	0	0	0	0
10/27	4	3	3	0	0	0	0	0
10/28	0	2	0	2	0	0	0	0
10/29	2	3	3	0	0	0	0	0
10/30	4	3	3	0	0	0	0	0
10/31	1	2	0	2	0	0	0	0
11/01	6	2	1	1	0	0	0	0
11/02	2	4	1	3	0	0	0	0
11/03	2	6	4	2	0	0	0	0
11/04	4	5	2	3	0	0	0	0
11/05	4	4	2	2	0	0	0	0
11/06	1	4	2	2	0	0	0	0
11/07	2	3	2	1	0	0	0	0
11/08	1	3	1	2	0	0	0	0
11/09	2	10	4	6	0	0	0	0
11/10	2	7	2	5	0	0	0	0
11/11	4	5	4	1	0	0	0	0
11/12	2	5	3	2	0	0	0	0
11/13	0	3	2	1	0	0	0	0
11/14	1	1	0	1	0	0	0	0
11/15	2	2	2	0	0	0	0	0
11/16	2	0	0	0	0	0	0	0
11/17	2	4	2	2	0	0	0	0
11/18	1	2	2	0	0	0	0	0
11/19	0	0	1	-1	0	0	0	0
11/20	0	0	0	0	0	0	0	0

	Chinook Adult				Chinook Jack			
Date	WDW	Video Total	Video Day	Video Night	WDW	Video Total	Video Day	Video Night
11/21	0	2	0	2	0	0	0	0
11/22	1	2	1	1	0	0	0	0
11/23	-1	-2	-1	-1	0	0	0	0
11/24	0	0	0	0	0	0	0	0
11/25	1	1	1	0	0	0	0	0
11/26	0	1	0	1	0	0	0	0
11/27	0	-1	0	-1	0	0	0	0
11/28	0	0	0	0	0	0	0	0
11/29	0	0	0	0	0	0	0	0
11/30	0	0	0	0	0	0	0	0
12/01	0	0	0	0	0	0	0	0
12/02	0	0	0	0	0	0	0	0
12/03	0	0	0	0	0	0	0	0
12/04	0	0	0	0	0	0	0	0
12/05	0	0	0	0	0	0	0	0
12/06	0	0	0	0	0	0	0	0
12/07	0	0	0	0	0	0	0	0
12/08	0	0	0	0	0	0	0	0
12/09	0			0	0	0	0	0
12/10	0	0	0	0	0	0	0	0
12/11	0	0	0	0	0	0	0	0
12/12	0	0	0	0	0	0	0	0
12/13	0	0	0	0	0	0	0	0
12/14	0	0	0	0	0	0	0	0
12/15	0	0	0	0	0	0	0	0
	30088	31022	29609	1416	351	339	318	21

Appendix F. Daily and annual total steelhead passage estimates at Lower Granite Dam in 1993.:

Date	WDW	Video Total	Video Day	Video Night
03/01	1	2	1	1
03/02	0	2	0	2
03/03	1	2	1	1
03/04	2	2	2	0
03/05	2	5	1	4
03/06	10	12	8	4
03/07	11	14	9	5
03/08	1	4	1	3
03/09	10	12	10	2
03/10	16	20	12	8
03/11	14	27	15	12
03/12	53	100	51	49
03/13	102	173	104	69
03/14	74	139	72	67
03/15	112	159	98	61
03/16	72	112	63	49
03/17	85	100	68	32
03/18	41	80	36	44
03/19	166	198	148	50
03/20	197	301	190	111
03/21	240	425	275	150
03/22	175	285	162	123
03/23	188	252	172	80
03/24	156	207	126	81
03/25	198	329	194	135
03/26	246	335	227	108
03/27	234	359	201	158
03/28	266	402	236	166
03/29	206	360	205	155
03/30	210	400	197	203
03/31	143	297	125	172
04/01	418	464	415	49
04/02	402	552	444	108
04/03	401	581	462	119
04/04	546	740	631	109
04/05	475	680	550	130
04/06	498	622	511	111
04/07	438	575	482	93
04/08	370	555	465	90

Date	WDW	Video Total	Video Day	Video Night
04/09	536	648	546	102
04/10	511	552	483	69
04/11	488	601	500	101
04/12	389	461	386	75
04/13	247	331	245	86
04/14	264	361	278	83
04/15	290	342	294	48
04/16	264	329	272	57
04/17	194	250	202	48
04/18	258	278	233	45
04/19	198	255	214	41
04/20	157	188	155	33
04/21	158	153	140	13
04/22	107	115	94	21
04/23	115	141	130	11
04/24	71	77	66	11
04/25	74	96	82	14
04/26	34	55	46	9
04/27	90	89	79	10
04/28	61	55	49	6
04/29	35	44	38	6
04/30	29	27	26	1
05/01	36	44	41	3
05/02	30	34	30	4
05/03	32	21	20	1
05/04	26	34	30	4
05/05	25	26	25	1
05/06	13	19	18	1
05/07	23	27	24	3
05/08	10	18	16	2
05/09	20	23	21	2
05/10	14	16	16	0
05/11	20	15	13	2
05/12	18	18	16	2
05/13	8	13	9	4
05/14	16	13	12	1
05/15	2	10	9	1
05/16	11	13	13	0
05/17	2	6	4	2

Date	WDW	Video Total	Video Day	Video Night
05/18	6	7	5	2
05/19	7	8	8	0
05/20	6	7	7	0
05/21	2	3	3	0
05/22	4	5	5	0
05/23	5	7	7	0
05/24		1	1	0
05/25	4	3	3	0
05/26	5	4	4	0
05/27	2	3	3	0
05/28	5	5	5	0
05/29	2	0	0	0
05/30	11	4	4	0
05/31	1	1	1	0
06/01		1	0	1
06/02	11	5	5	0
06/03	1	5	4	1
06/04	2	1	1	0
06/05		0	0	0
06/06		1	1	0
06/07	1	4	4	0
06/08	2	3	3	0
06/09	0	0	0	0
06/10	2	0	0	0
06/11	5	4	4	0
06/12	1	4	4	0
06/13	2	2	2	0
06/14		0	0	0
06/15	4	5	5	0
06/16	1	-1	-1	0
06/17	4	3	3	0
06/18	7	8	6	2
06/19	6	6	6	0
06/20	4	4	3	1
06/21	4	3	2	1
06/22	18	13	12	1
06/23	11	19	17	2
06/24	6	9	9	0
06/25	8	9	9	0

Date	WDW	Video Total	Video Day	Video Night
06/26	11	11	10	1
06/27	17	14	15	-1
06/28	22	21	18	3
06/29	18	26	23	3
06/30	23	24	23	1
07/01	22	30	31	-1
07/02	30	29	28	1
07/03	31	34	32	2
07/04	30	30	28	2
07/05	49	44	44	0
07/06	56	47	46	1
07/07	47	51	49	2
07/08	48	44	41	3
07/09	65	54	53	1
07/10	49	54	54	0
07/11	66	73	64	9
07/12	120	116	114	2
07/13	67	79	75	4
07/14	88	92	86	6
07/15	59	56	53	3
07/16	94	111	105	6
07/17	77	79	75	4
07/18	60	14	14	0
07/19	74	0	0	0
07/20	86	53	49	4
07/21	98	101	97	4
07/22	131	127	123	4
07/23	96	101	98	3
07/24	124	120	117	3
07/25	100	107	106	1
07/26	144	104	103	1
07/27	145	122	117	5
07/28	143	141	139	2
07/29	106	120	116	4
07/30	203	203	198	5
07/31	113	127	120	7
08/01	167	142	139	3
08/02	127	115	113	2
08/03	167	168	164	4

Date	WDW	Video Total	Video Day	Video Night
08/04	143	139	136	3
08/05	132	146	138	8
08/06	174	164	160	4
08/07	188	167	169	-2
08/08	200	175	172	3
08/09	158	156	152	4
08/10	120	131	126	5
08/11	125	104	104	0
08/12	206	205	201	4
08/13	295	284	278	6
08/14	258	210	207	3
08/15	100	92	89	3
08/16	60	58	57	1
08/17	145	122	120	2
08/18	175	173	163	10
08/19	347	318	317	1
08/20	217	202	197	5
08/21	265	261	245	16
08/22	240	227	224	3
08/23	198	191	188	3
08/24	175	180	169	11
08/25	264	260	257	3
08/26	131	128	123	5
08/27	119	106	104	2
08/28	115	121	117	4
08/29	120	125	124	1
08/30	64	68	64	4
08/31	103	106	103	3
09/01	85	76	71	5
09/02	133	127	125	2
09/03	108	89	84	5
09/04	154	119	117	2
09/05	112	103	93	10
09/06	191	165	163	2
09/07	122	117	113	4
09/08	157	148	144	4
09/09	88	105	97	8
09/10	168	151	147	4
09/11	108	116	92	24

Date	WDW	Video Total	Video Day	Video Night
09/12	391	395	387	8
09/13	180	179	165	14
09/14	242	250	234	16
09/15	163	186	162	24
09/16	402	418	386	32
09/17	390	430	413	17
09/18	511	497	478	19
09/19	540	554	507	47
09/20	644	667	635	32
09/21	443	446	421	25
09/22	432	445	407	38
09/23	367	398	374	24
09/24	569	596	563	33
09/25	462	496	476	20
09/26	504	554	541	13
09/27	467	485	455	30
09/28	683	695	656	39
09/29	510	541	490	51
09/30	1048	1066	1012	54
10/01	1103	1130	1076	54
10/02	1127	1121	1089	32
10/03	954	976	922	54
10/04	1384	1388	1343	45
10/05	888	974	909	65
10/06	1930	2017	1889	128
10/07	1694	1822	1707	115
10/08	1798	2023	1972	51
10/09	1230	1222	1187	35
IO/IO	1402	1532	1434	98
10/11	1092	1187	1106	81
10/12	1139	1183	1141	42
10/13	578	660	596	64
10/14	913	995	925	70
10/15	1364	1345	1311	34
10/16	1207	1275	1212	'63
10/17	1068	1127	1050	77
10/18	1478	1486	1423	63
10/19	1282	1284	1223	61
10/20	1356	1458	1354	104

Date	WDW	Video Total	Video Day	Video Night
10/21	836	978	819	159
10/22	1520	1566	1484	82
10/23	838	836	792	44
10/24	1072	1196	1117	79
10/25	473	545	477	68
10/26	718	746	708	38
10/27	475	517	475	42
10/28	382	439	390	49
10/29	478	535	509	26
10/30	558	588	570	18
10/31	282	335	294	41
11/01	323	383	322	61
11/02	145	182	139	43
11/03	2 2 7	269	208	61
11/04	338	329	290	39
11/05	294	308	277	31
11/06	214	228	202	26
11/07	338	344	333	11
11/08	166	151	134	17
11/09	107	121	96	25
11/10	132	145	120	25
11/11	271	216	217	-1
11/12	101	107	104	3
11/13	208	216	202	14
11/14	66	60	50	10
11/15	136	156	139	17
11/16	104	111	93	18
11/17	104	71	61	10
11/18	31	50	32	18
11/19	84	113	97	16
11/20	44	75	61	14
11/21	108	131	118	13
11/22	28	28	21	7
11/23		18	18	0
11/24	30	34	27	7
11/25	61	69	63	6
11/26	17	26	21	5
11/27	11	17	13	4
11/28	1	18	16	2

Date	WDW	Video Total	Video Day	Video Night
11/29	5	6	5	1
11/30	4	6	2	4
12/01	18	22	18	4
12/02	13	21	15	6
12/03	5	10	4	6
12/04	12	30	23	7
12/05	11	17	14	3
12/06	4	9	8	1
12/07	2	4	2	2
12/08	6	7	6	1
12/09	1	4	1	3
12/10	24	20	18	2
12/11	23	23	19	4
12/12	16	27	22	5
12/13	19	30	23	7
12/14	16	23	18	5
12/15	11	10	10	0
	66698	72733	65515	7218

Appendix G. Dates and times of recorded sockeye salmon passage at Lower Granite Dam in 1993 (A (+) indicates a sockeye confirmation, A (-) indicates an unconfirmed sockeye passage).

Potential Sockeye Salmon Passage Events	COE		Video Detection[2]		
			itial Review		Confirmation
06/27	+	(18:35)	+	(17:37:03)	+
07/02	-		+	(07:51:32)[3]	+
07/03	-		+	(08:35:42)	+
07/04	-		+	(05:50:53)	+
07/05	+	(08:09)		(09:09:18)	+
07/07	+	(05:40)	-		
07/07	+	(13:50)	-	(14:48:27)	+
07/13	+	(12:47)	-	(13:45:38)	+
07/13	+	(13:23)	+	(14:21:32)	+
07/14	-		+	(17:49:38)	+
07/16	+	(06:37)			
07/17			+	(22:32:07)	+
07/20	+	(10:49)	+	(11:49:37)	+
07/26	+	(07:11)	+	(08:11:49)	+
07/27			+	(07:53:59)	+
07/28	+	(14:09)	+	(15:08:48)	+
07/30	+	(14:30)	-	(15:30:19)	+
09/28	+	(10:04)	-	(11:04:12)	+

[2]Passage is recorded in Daylight Savings Time, which is one hour ahead of Pacific Standard Time, used by WDW and the COE.

[3]The on-site counter saw this sockeye during their normal break persiod, and therefore this sighting was not reported to CROHMS.