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J. R. Irvine , B. R. Ward , P. A. Teti & N. B. F. Cousens

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J. R. Irvine

Department of Fisheries and Oceans, Biological Sciences Branch
Pacific Biological Station, Nanaimo, British Columbia V9R 5K6, Canada

B. R. Ward

Ministry of Environment, Fisheries Branch, Research and Development Section
2204 Main Mall, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada

P. A. Teti

Pisces Computing Ltd., 3025 Penticton Street
Vancouver, British Columbia V5M 3C5, Canada

N. B. F. Cousens

J. C. Lee and Associates Ltd., 4B-2520 Bowen Road
Nanaimo, British Columbia V9T 3L3, Canada

Abstract.—A prototype of a computerized video-camera system successfully counted and measured juvenile salmon in the field. Known numbers of smolts of coho salmon *Oncorhynchus kisutch* swimming through transparent acrylic tunnels were videotaped, and the videotapes were subsequently interpreted with a microcomputer. Unaided, the computer underestimated the number of fish because fish sometimes overlapped while swimming through the tunnels and were thus recorded as a single fish. However, revised estimates were accurate when portions of the tapes were viewed by an operator and expansion factors for computer-generated counts determined. When a mouse pointing device was used to obtain measurements from videotapes of individual fish swimming through the tunnels, these measurements were accurate. The software did not reliably produce accurate fish-length measurements when unassisted, again because of fish crowding and overlap in the tunnels. When a computer operator viewed the tapes and rejected those fish measurements that were obviously in error, there were no differences among computer-generated length-frequency distributions and those obtained by direct measurements of the same fish in the field. The technology exists to use computerized video-camera systems to accurately count and measure live fish when the size range of fish being sampled is small. Potential benefits to the user of this developing technology include time savings, reduction of stress to the fish, the possibility of more accurate and consistent results, and the assurance of permanent records in the form of videotapes and computer files.

Often there is the need to accurately enumerate and measure large numbers of fish in a short period of time. This is true in natural systems, and increasingly, at aquaculture facilities. Although fish can be counted and measured manually, recent technological advances have permitted the development of automated techniques that have the potential for saving labor, increased accuracy and precision, and reduced stress to fish. For instance, video cameras have been used in conjunction with microcomputers to study zooplankton (Ramcharan and Sprules 1989) and insects (Febvay et al. 1986; Shinn and Long 1986).

Automated techniques that have been used successfully to count or measure fish, or both, include the use of measuring boards or electronic calipers connected to a computer (McAllister and Planck 1981; Bayley and Illyes 1988), resistivity fish counters (Dunkley and Shearer 1982), sonar counters (Raemhild et al. 1985), and systems relying on machine vision in which a computer is used to interpret visual data obtained with a video camera (McCarthy 1988). In the last example, fish in a commercial processing plant were photographed with a video camera, identified to species by their contour outline, assigned to a length–weight category, and subsequently routed on to a filleting line. Our paper describes and gives results from a test of a prototype of a computerized video-camera system that was built to enumerate and measure live juvenile salmonids in the field. We know of no other publications describing the use of such a system to count and measure live fish.

Methods

Fish inventory system and field tests performed.—The fish inventory system was tested at the site of a fish-enumeration fence on the Keogh River on northern Vancouver Island, British Columbia (Irvine and Ward 1989). Smolts of coho salmon *Oncorhynchus kisutch* migrating down the river during 25–27 May 1988 were captured at the fence and held in large holding boxes before being used in field trials.

We used a black-and-white video camera (Pulnix TM-440S) and videocassette recorder to record fish swimming through the imaging section of a plywood box (86 cm long × 53 cm wide × 33 cm deep), which was suspended almost fully immersed in a large (about 1 m^3) plastic tub (Figure 1). The hopper and imaging sections of the plywood box were separated by a vertical partition. The imaging section contained a central removable bank of transparent acrylic tunnels with rectangular entrance and exit openings (each tunnel opening was about 3.5 cm wide × 5 cm high). This tunnel size was selected to minimize fish overlap in the tunnels so that, usually, individual fish would be photographed at a constant distance from the camera. There were two mirrors placed at a 45° angle to the vertical on either side of the tunnels. These mirrors presented side views of fish passing through the tunnels. A reflective divider separating columns of tunnels provided a high-contrast background. A 12-V illumination source was mounted directly overhead on an attached frame. The imaging area and camera were covered with a black plastic shroud to eliminate stray light and reflections.

River water was pumped into the loading hopper. The water flowed by gravity through the imaging tunnels into the surrounding plastic tub, from which it overflowed to waste. Fish were added manually by dip net to the hopper and were directed to the tunnel entrance openings in the partition by guide screens of formed, perforated polyvinyl chloride sheet, which acted as a funnel. A drop gate regulated the passage of fish into and out of the tunnel bank. Preliminary tests indicated that most fish entered and passed through the imaging tunnels more readily when moving with rather than against the direction of water movement, and in all tests reported here, the fish passed downstream through the tunnels and out into the surrounding plastic tub (Figure 1).

To test the ability of the system to count known numbers of fish, four groups of coho salmon smolts were videotaped while the fish were swimming through the tunnels (Table 1). The fish in each group were anesthetized, counted, and, except for group 4, measured, before being videotaped. Group 4 consisted of an entire day's catch (697 fish) of coho salmon smolts at the fish counting fence, and encompassed a much wider range of sizes of fish than the other groups. For replication purposes, the fish in each group swam through the tunnels twice, with the exception of the first group, which swam through four times. For this first group, water velocity through the tunnels was greater during the second pair of video trials (3 and 4) than for other trials. After fish had recovered from the anesthetic, they were introduced to the hopper in groups of five or six. It took about 5 min for 200 fish to swim through the apparatus.

To assess the ability of the system to measure fish, after the above tests were completed, 65 additional coho salmon smolts were anesthetized and measured manually. When these fish had recovered from the anesthetic, they were put into the hopper individually and then videotaped as they swam one at a time through the tunnels.

Analysis of tapes.—Videotapes were subsequently analyzed with a JVC videotape player, an IBM-AT-compatible microcomputer running under MS-DOS, a Targa 8 frame grabber (computer expansion card) from TrueVision, Inc., software written by and available from one of us (P.A.T.) for the project, and a Zenith composite video monitor. The high-frequency analog video signal delivered a full frame of information every $\frac{1}{60}$ s. The frame grabber digitized the analog video signal into computer-readable form in real time, creating a two-dimensional array of numbers representing scene brightness at discrete pixel locations. Individual pixel values were read by the software at memory locations that corresponded to locations in the camera's field of view. The frame grabber updated pixel values every $\frac{1}{60}$ s, allowing real-time analyses.

The software, written in Turbo Pascal, contained algorithms that interpreted two-dimensional groups of pixels received from the frame grabber in terms of fish size and shape. The source code comprised about 3,000 lines, and the executable program was 43,000 bytes in size, requiring 256 kilobytes of system random-access memory. To estimate fish numbers, the software defined two

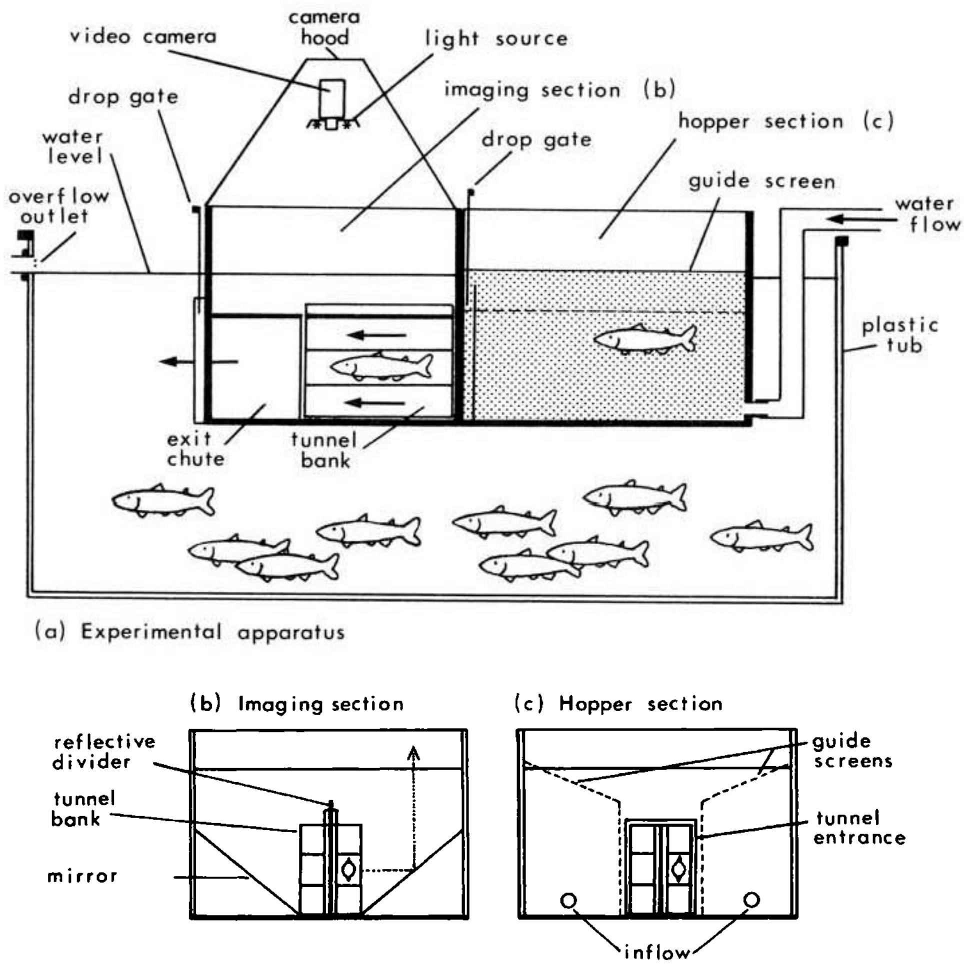

FIGURE 1.—Diagrams of the fish inventory system used to videotape coho salmon smolts at the Keogh River. (a) A cut-away side view of the entire experimental apparatus. (b) A cross section of the imaging section. (c) A cross section of the hopper section.

imaginary optical "trip wires," spaced about one-fifth of a fish length apart. The software was configured to only count fish swimming in a downstream direction and subtracted any fish swimming in the opposite direction.

We realized that computer-generated estimates of fish numbers would be low because fish sometimes overlapped while swimming through the tunnels, and the software did not separate these individuals. To improve the accuracy of the computer estimates, expansion factors were determined. To do this, the videotapes were stratified into non-overlapping sections (*N* in Table 1) containing about 20 fish, and these sections were viewed directly by an operator with the video monitor. The ratio between the actual number of fish and the computer-generated estimate was determined for each tape section, and the mean of these estimates was the expansion value used for that video trial.

For the 65 coho salmon smolts measured manually in the field and videotaped one at a time, fork lengths were subsequently measured from the videotapes with a mouse pointing device by freezing video frames of individual fish images. Raw dimensions in the form of pixels were converted to millimeters with a 100-mm scale bar in the field of view at the same distance from the camera as the fish.

A semiautomated software procedure for extracting fork-length measurements from video images sampled from the tapes was also tested for groups 1–3. The software measured fork length (and body depth) and displayed each result, and

TABLE 1.—Number of coho salmon smolts from the Keogh River used in video trials, number estimated by the computer unaided, number of portions of each video tape viewed directly (*N*), mean expansion factor obtained for each trial, and the revised computer estimate based on this expansion factor.

Group	Video trial	Number of fish	Computer estimate	*N*	Expansion factor[a]	Revised estimate
1	1	200	164	4	1.30	213
	2	198[b]	160	5	1.18	189
	3	200	166	5	1.14	199
	4	200	188	4	1.04	196
2	1	200	159	5	1.15	183
	2	200	172	5	1.08	186
3[c]	1	100	84			
	2	100	87			
4	1	697	437	19	1.87	817
	2	697	488	15	1.50	732

[a] Expansion factors were obtained by directly viewing portions of tape and determining the ratio of actual counts to counts generated by computer for those same tape segments.
[b] Two fish in this trial did not go through the tunnels.
[c] Because sample size was small, expansion factors were not determined.

the computer operator would decide whether or not to accept each measurement. Based on this procedure for groups 1–3 (Table 1), a separate length-frequency distribution was computed for each video trial. Goodness-of-fit *G*-values (Sokal and Rohlf 1969) were calculated to determine whether the length-frequency distributions for each trial of a group were different from each other or from the length-frequency distribution obtained by manually measuring all of the fish in the field.

Results

Ability of the System to Count Known Numbers of Fish

As expected, the computer, unaided, consistently underestimated the number of fish (Table 1). The average computer-generated estimate was 25% less than the true number. Computer estimates for the number of fish in group 4, the group with the widest size range of fish, were the least accurate.

When the expansion factors obtained by an operator directly viewing portions of the tapes were used to obtain revised computer estimates, these revised estimates were much more accurate than the unaided computer estimates (Table 1). The revised estimates varied by an average of 6.4% from the true number.

Ability of the System to Measure Fish

For the 65 fish measured and videotaped individually, fish lengths obtained by using the mouse pointing device to define fork lengths from the videotapes were accurate (Figure 2). There was a high correlation ($r^2 = 0.93$) between the fork lengths measured from fish in the field and those measurements made from the videotape.

The semiautomated length-measurement process is illustrated by photographs of computer-measured coho salmon smolts taken on seven randomly selected occasions (Figure 3). In the first (top photograph), sixth, and seventh instances, the semiautomatic measurements provided by the software were accepted by the computer operator.

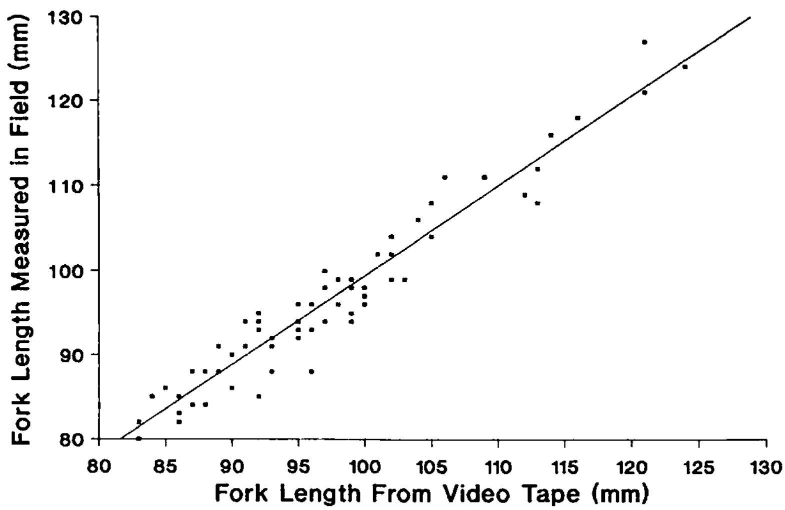

FIGURE 2.—Relationship between fork-length measurements obtained from video tapes (*X*-axis) and fork-length measurements for the same 65 coho salmon smolts recorded in the field (*Y*-axis) ($Y = 1.05X - 6.018$; $r^2 = 0.93$).

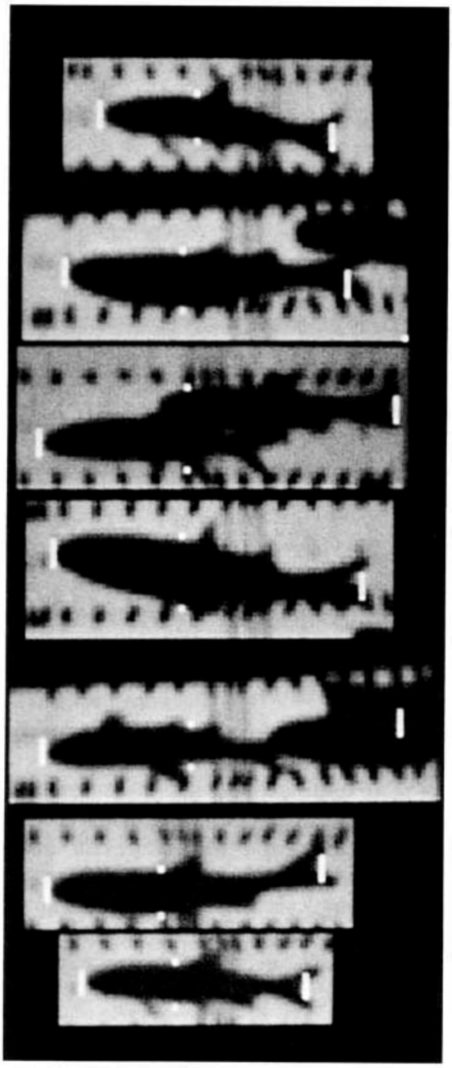

FIGURE 3.—Photographs of seven random recordings of coho salmon smolts during their passage through a tunnel system monitored by video camera at the Keogh River, May 1988. The vertical white bars illustrate fork length, and the white dots indicate body depth measurements, as measured by the software.

In the other instances, because fish swimming through the tunnels overlapped, their measurements were in error, and therefore the measurements were rejected by the operator.

Of 1,398 fish that were videotaped (each trial of groups 1–3, Table 1), 384 measurements (27.5% of the fish) were accepted by the operator as valid. In some instances, fish that were videotaped were not included in the measurement sample because the computer could only measure one fish at a time, and fish sometimes went through separate tunnels simultaneously. Other fish passed through the tunnels in groups, and their measurements were rejected as inaccurate (Figure 3).

Frequency distributions of length measurements accepted by the operator for the different video trails were similar in all cases to the actual length-frequency distributions obtained in the field (Figure 4). For each group for which the semiautomated length measurement process was tested (i.e., groups 1–3), the calculated G-value was less than the critical chi-square value ($P = 0.05$), indicating that there were no significant differences among the frequency distributions obtained by viewing the videotapes and those obtained by obtaining measurements in the field.

Discussion

Potential benefits of using a computerized video-camera system to count and measure fish are (1) increased accuracy of measurements; (2) savings in time and, consequently, money; (3) reduced stress to the fish because handling and obstruction of passage are eliminated; and (4) permanent records (videotapes and computer files) of the fish are obtained. Although the experiments reported in this paper were primarily designed to evaluate the accuracy of an early prototype (first advantage listed above) and identify potential for further developments, some comments on the other potential benefits can be made.

Using a computerized video system to enumerate and measure fish should take less time than manual processing. The more fish in a sample, the greater is the potential time to be saved. It took an average of 5 min to process 200 fish in the field tests reported here. In a hatchery, we have counted up to 30,000 fish/h. In other tests, we have counted up to 6,000 fish/h and extracted accurate height and length data from more than 10% of the fish counted (P. A. Teti, unpublished data).

The total time to obtain data from the videotapes is a combination of the times required to set up the necessary equipment, view and interpret the videotapes, and analyze the data. For repetitive analyses, the time for set-up and data analysis is generally less than 1 h total. Efficiency is maximized when multiple video segments of long duration are subjected to similar analyses.

Because fish are not normally handled or anesthetized when a computerized video-camera system is used, the amount of stress to them is less than when the fish are manually processed. It is also possible to obtain a much larger measurement

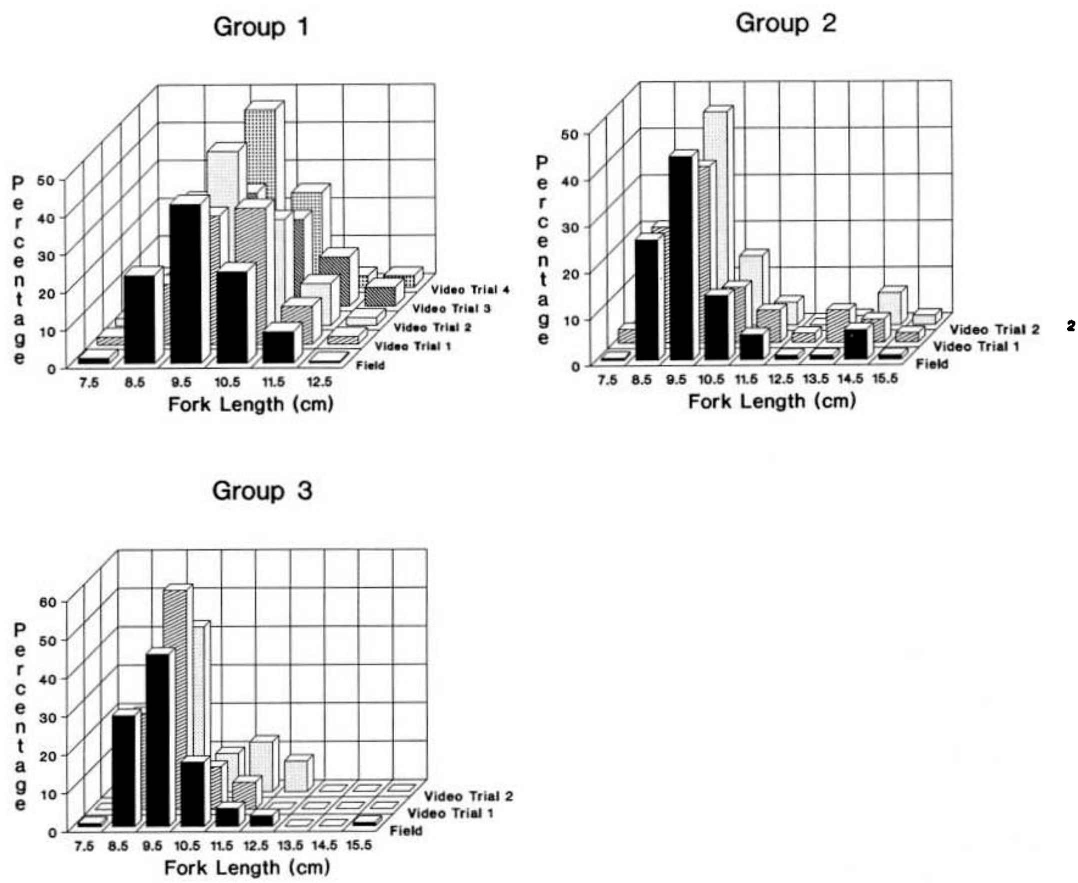

FIGURE 4.—Length-frequency distributions of three groups of coho salmon smolts as measured in the field during May 1988, and length-frequency distributions for the same groups of fish generated by the video–computer system. Group 4 fish were not measured.

sample from the tape than may be practical manually. The results generated by a computer are objective. Fatigue and lack of alertness are not normally a problem. Having videotapes of the fish is particularly useful when time or other constraints do not permit immediate analysis.

Our system was moderately successful at enumerating known numbers of fish. When the tapes were viewed, calibration counts were performed and expansion factors were determined; then estimates were much more accurate. Initial computer estimates were low because of fish overlapping while they swam through the tunnels; groups of fish were consequently recorded by the computer as one fish.

The number of fish used in the experiments reported here was lower, and the proportion of the total number used to obtain calibration counts was much higher, than in our normal use of the system. A similar computerized video-camera system was used to enumerate juvenile coho salmon at the Nanaimo River Hatchery on Vancouver Island in April 1988. A computer-generated estimate of 6,470 fish was adjusted to an estimate (±95% confidence interval) of 6,696 ± 67 fish with an expansion factor determined by stratifying the tape. The calibration count consisted of 12 stratified samples totaling 1,183 fish, compared to a computer count of 1,143 fish. The computerized video-camera system was more accurate at the hatchery than at the Keogh River because the fish at the hatchery were of relatively uniform size, and it was possible to construct tunnels so that only rarely did more than one fish pass through a tunnel at a time.

In the tests reported here, the software was unable to produce accurate fish-length measurements unaided, again because of fish crowding in the tunnels. However, when a computer operator viewed the tapes and rejected those measurements that were obviously in error, there were no differences among computer-generated length-frequency distributions and those distributions obtained in the field. When a mouse pointing device was used to define fork lengths of fish, measurements were also accurate. Again, experience with more uniformly sized fish at a hatchery demonstrated that the computer could measure fish reliably without our viewing the tapes for manual correction, although operator control of the measurement sample is still recommended when high accuracy and precision are desired.

One of us (P.A.T.) is currently improving the software and hardware, and we hope to field-test an improved prototype that will separate different sizes of juvenile salmonids before they reach the imaging area. If this is successful, we will have overcome the main problems encountered with the tests reported in this paper.

Computerized video-camera systems offer promise when large numbers of fish have to be processed, whether these fish are to be processed in the field, at a hatchery, or at an aquaculture facility. At the latter two, because fish are almost always of a single species and generally of a uniform size distribution, obtaining accurate counts and sizes for the fish is relatively easy. In natural systems, the challenge is greater, but the potential rewards are large. Not only should one be able to count and measure fish, but it may become possible to separate species, and perhaps eventually stocks (Winans 1984; Taylor and McPhail 1985), based on their morphometric characteristics.

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