Study to Determine the Biological Feasibility of a New Fish Tagging System

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A STUDY TO DETERMINE THE BIOLOGICAL FEASIBILITY OF A NEW FISH TAGGING SYSTEM

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EXECUTIVE SUMMARY

A multiyear cooperative project to evaluate the technical and biological feasibility of adapting a new identification system to salmonids was established between the Bonneville Power Administration and the National Marine Fisheries Service (NMFS) in 1983. The system is based upon a miniaturized passive-integrated-transponder (PIT) tag. This report discusses the work completed in 1989 and is divided into four sections: laboratory studies, field studies, systems development, and information transfer.

Evaluations of both tags and marks should include their biological effects on organisms. Knowledge of how tags affect survival, growth, and maturation is required to extrapolate information derived from tagged fish to the population they index. The sockeye salmon (<u>Oncorhynchus nerka</u>) and chinook salmon (0. <u>tshawytscha</u>) studies described in this report and previous studies (Prentice et al. 1984, 1985, 1986, 1987, 1990a,c) were intended to determine how PIT tags and PIT tagging affected salmonid growth, survival, and maturation schedules, and to estimate tag-retention and operational life. The experimental designs successfully yielded tag-retention and operational information. However, we now realize these studies suffered from a common design weakness (lack of independence among the variables), which prevented the studies from distinguishing container and treatment effects. The design used was necessary from the practical standpoint of space limitation and from the technical standpoint because we lacked the knowledge regarding tag-retention and operational information. Therefore, conclusions drawn about the biological effects should be viewed with caution.

A laboratory study to determine the effects of PIT tags on subyearling sockeye salmon as well as to determine long-term tag operation characteristics has been conducted with the Canada Department of Fisheries and Oceans since 1987. Two sizes of parr and smolts were initially tagged. In 1988, the histological examination of PIT-tagged fish serially sacrificed over 45 days showed no adverse host response to the tagging operation or tag. Six to 8 months after tagging, survival and growth were comparable in tagged and untagged controls. Survival at 12-14 months posttagging was never below 95% in any test group. Tag failure ranged from 0 to 5% and tag loss was 1% when the test groups were combined at 125-182 days posttagging. Tag failure and loss were followed through 1989. Few (0-1.4%) tags were lost in immature fish; however, 21% or four fully mature females rejected or lost their tags while no mature males had lost tags by November, or 907 days posttagging.

A laboratory study with juvenile chinook salmon to determine tag operational life and biological effects on the host was started in 1988. Survival rates, mean fork lengths, and tag performance data (where appropriate) were obtained for each of the five treatments: PIT-tagged treatment, sham-PIT-tagged treatment (tagging needle only), coded-wire (CW)-tagged treatment, sham-CW-tagged treatment, and control treatment (no tag or tagging needle). The relative orders of the groups for mean fork lengths and survival rates seemed to vary with

each sampling period. One trend, however, was for the PIT-tagged fish to be smaller than the control fish. Survival in fresh water varied from 97 to 100% among treatments. In seawater, survival was poor in all groups. When the fish were last examined in October 1989, sham-CW-tagged (48.3%) and PIT-tagged (44.8%) fish had the highest survival rates, and the CW-tagged (35.5%) and sham-PIT-tagged (37.7%) groups had the lowest survival rates. The control fish showed an intermediate survival rate, 43.0%. PIT-tag retention was 99.7% and tag malfunction was only 1.2% over the 19-month study.

A field study to evaluate the effects of different passageway parameters on the volitional movements of chinook salmon smolts was conducted in 1989. Shapes (tubular and open-surfaced channel), light properties (hue and light intensity), and a PIT-tag monitoring system's electromagnetic field were evaluated.

Fish significantly preferred to pass through a channel rather than a tube passageway. The light properties of the passageways affected fish passage: more fish passed through white tubes than through transparent tubes, and light intensity appeared to be more important than material hue. No significant difference was seen in fish passage between the on and off modes of the monitoring system, suggesting that juvenile chinook salmon volitional passage was not affected by the PIT-tag detector's 400-kHz electromagnetic field.

A field study to compare juvenile coho salmon (0. <u>kisutch</u>) tagged with coded-wire (CW) tags, PIT tags, or both tag types began in January 1989 at the Washington State Department of Fisheries Skagit River Hatchery. These fish were released into the wild from the hatchery in

June 1989. Tag presence was confirmed prior to release on subsamples and was estimated to be above 99% for all test groups. Returning fish were and will be interrogated for tag presence starting in 1989.

All PIT-tag monitoring systems at Lower Granite, Little Goose, and McNary Dams operated reliably during the 1989 field season. The major problems encountered with the systems were human-induced rather than electronic.

Juvenile and adult PIT-tag monitoring systems at Lower Granite Dam and juvenile monitors at Little Goose and McNary Dams were evaluated for tag-reading efficiency in 1989. The release of a known number of tagged fish directly above the monitor system (first direct method), the use of reference tags (second direct method), and an indirect statistical method were used to determine tag-reading efficiencies and system operational status.

The release of PIT-tagged fish directly above the PIT-tag monitoring systems showed that tag-reading efficiency was higher than the 95% criterion established by NMFS in all but one case. The lower efficiency (92.0%) was obtained at Lower Granite Dam for juvenile chinook salmon. It was determined that a gate in the fish and debris separator had been ajar during the test, allowing fish to escape detection by the monitoring system. Further testing, after the gate problem was corrected, showed a 99.1% efficiency in detecting tagged juvenile steelhead (0. mvkiss).

In past studies, tag-reading speed was a main limiting factor affecting PIT-tag monitor tag-reading efficiency at hatcheries and fish pumps. The monitor system's controller computer firmware, which processes the PIT-tag code, was modified to reduce code-processing time. Tests conducted after this modification showed that a hatchery raceway, containing about 2,500 PIT-tagged fish within a population of 40,000 fish, could be evacuated in 23 minutes using a fish pump. Tag-reading efficiency under such conditions was over 95%. It was concluded from this and related studies that fish could be successfully monitored as they were crowded or pumped from hatchery facilities. It was also recommended that, where possible, dual-coil PIT-tag monitors be placed in tandem to provide increased tag-reading efficiency as well as a backup in case of system failure.

In spring 1989, a prototype system to separate PIT-tagged from untagged fish was installed near the two exit ports of the fish and debris separator at Lower Granite Dam. Each PIT-tag separator consisted of a PIT-tag monitoring system and a slide gate mounted in the bottom of the fish and debris separator exit flume. Mechanical and biological tests were conducted to determine system reliability and effectiveness at separating PIT-tagged from non-PIT-tagged fish. The test results suggested that several modifications to the system were required before it would operate as planned.

A PIT-tag interrogation system is being planned for Little Goose Dam's new juvenile salmon collection and sampling facility. The new interrogation system will be operational in 1990. A system similar to that installed at Lower Granite Dam to separate PIT-tagged from non-PIT-tagged fish is also being planned for the facility for the early 1990s.

A prototype PIT-tag monitoring system having extended tag-reading range is under development, with studies to determine its tag-reading ability, power requirements, and electromagnetic shielding requirements. Results are not available from these tests' at this time.

A PIT-tag information system (PTAGIS) was developed for the Columbia River Basin. All PIT-tag data obtained within the basin was directed to a prototype centralized database that was developed and managed by the Pacific States Marine Fisheries Commission. The information system processed, stored, and made available PIT-tagging recovery information to all parties.

Future work related to PIT-tag systems development is described and discussed.

INTRODUCTION

In 1983, the National Marine Fisheries Service (NMFS) began a multiyear cooperative research program with the Bonneville Power Administration (BPA) to evaluate a new miniature identification system that could be used with salmonids. The system is referred to as a passive-integrated-transponder (PIT) tagging and monitoring system. The program focused on determining the effects of the PIT tag upon both juvenile and adult salmonids and the development of tagging and monitoring systems. Results of the program have been described in annual summaries and journals cited in this report.

This report reviews the laboratory and field studies conducted in 1989 and is divided into four sections: laboratory studies, field studies, systems development, and information transfer.

LABORATORY STUDIES

Experimental Design Caveat

Evaluations of both tags and marks should include their biological effects on organisms. Knowledge of how tags affect survival, growth, and maturation is required to extrapolate information derived from tagged fish to the population they index. The sockeye salmon (Oncorhynchus nerka) and chinook salmon (O. tshawytscha), studies described in this report and previous laboratory studies (Prentice et al. 1984, 1985, 1986, 1987, 1990a,c) were intended to determine how PIT tags and PIT tagging affected salmonid growth, survival, and maturation schedules, and to estimate tag-retention and operational life. The experimental designs successfully yielded tag-retention and operational information. However, we now realize these studies suffered from a common design weakness, which prevented the studies from distinguishing container and treatment effects. The design used was necessary from the practical standpoint of space limitation and from the technical standpoint because we lacked the knowledge regarding tag-retention and operational information.

In these PIT-tag studies, each treatment group was reared in a separate container with only one container per treatment. This violated the assumption of independence (Martin and Bateson 1986) by confounding container variables (density, flows, location, feeding, etc.) with treatment variables (tag effects). Thus, it is impossible to know if PIT-tagged fish are smaller than sham PIT-tagged fish because of the presence of the tag or because their rearing container, for example, received less food or had reduced water flow. Whenever individual treatments are maintained in separate containers without replication, as occurred in these PIT-tag studies, the biological effects of growth, survival, and maturation as related to tagging should be considered suspect.

The problem can be reduced with replication, in which each treatment is reared in several containers (tanks, net-pens) or eliminated by rearing all treatments in the same container. The latter approach is preferred, as it spreads container effects equally across all treatments. The replicated approach averages container effects, but does not eliminate interaction effects related to treatment-induced differential growth or survival. With our current knowledge of tag-retention rates and operational life, the one-container approach is now feasible. In our more recent studies (coho salmon, O. kisutch, longevity, overwinter survival, predation), we have eliminated this design problem by placing all treatments in the same container and using either double tags or our knowledge of tag loss to determine an individual's treatment group. We strongly urge that our earlier work with captive chinook and sockeye salmon populations be replicated with a new experimental design to determine how PIT tags affect the growth, maturation, and survival of salmonids.

The Effects of PIT Tags on Cultured Sockeye Salmon

Introduction

Studies have been conducted with yearling and subyearling chinook salmon, coho salmon, and steelhead (0. mykiss) to determine the effects of PIT tagging and PIT-tag presence (Prentice et al. 1984, 1985, 1986, 1987, 1990a,c). In these studies, the differences in observed growth due to the presence of PIT tags were relatively small. The natural history of lacustrine sockeye salmon contrasts sharply with the above stream-based salmonids. Furthermore, biologists contend this species is more sensitive to handling. Therefore, this study was originally conducted to determine the effects of the PIT tag on the growth and survival of this species and to provide baseline information on tag loss and failure over several years.

Methods and Materials

The study was conducted at the Canada Department of Fisheries and Oceans (CDFO) hatchery in Rosewald, British Columbia. Two populations of 1986-broodyear sockeye salmon were ponded on 3 February 1987 and maintained in circular tanks with flowing fresh water. These fish were cultured using standard techniques. The exception was that growth of fish in one tank was accelerated by maintaining the photoperiod at 9.5 hours of light/day from ponding to 7 April 1987. These accelerated fish smolted as subyearlings while their nonaccelerated counterparts smolted the following year.

In May 1987, an untagged control group, a sacrificial PIT-tag group, and a nonsacrificial PIT-tag group of about 200 fish each were randomly selected and removed from the nonaccelerated population. Collectively, these three treatments were designated as small parr. All small parr were anesthetized in MS 222, measured to the nearest 1 mm on a digitizer pad, and weighed to the nearest 0.1 g on an electronic balance. PIT tags were inserted into the body cavity of the sacrificial and nonsacrificial small-parr groups with the hand-held injector technique described in Prentice et al. (1990c).

In July, three additional test groups of approximately 200 fish each were established from the same population and were collectively referred to as large parr. As above, one group remained untagged and two groups were PIT tagged, this time using the automatic injector described in Prentice et al. (1990c).

Based on their behavior, coloration, and morphology, the fish in the accelerated group were classified as smolts in July 1987, at which time they were randomly divided into three groups of 200 fish each, using the same categories as above. These three groups are collectively referred to as smolts.

On days 0, 5, 10, 15, 20, and 45 posttagging, 20 fish from each sacrificial group were randomly selected and sacrificed. Each fish was visually examined by CDFO personnel for the condition of tagging wound, tag location, and tissue response. An additional 10 fish from this group were preserved for histological examination on each sacrificial sampling date.

Approximately every 2 months for the first year of the study, the control and nonsacrificial fish were examined. At each examination the fish were anesthetized in MS 222, measured with a digitizer board, and at least 50 fish/group were weighed. In addition, PIT-tagged fish were interrogated for tag presence. Interrogated fish that failed to respond with a code were sacrificed, and tag presence or absence was determined.

The main study on the effects of PIT tags on the growth and survival of sockeye salmon was completed in January 1988. Treatment fish of all sizes from all three categories were then combined in a single tank. Combinations of pectoral and adipose fin clips were used in an attempt to distinguish each group. More PIT-tagged fish from the original fish population were also added to this tank; however, these fish were only used to yield tag retention and failure information. All fish were interrogated for PIT-tag presence in September 1988, August 1989, and November 1989. These fish are being maintained to observe long-term, PIT-tag retention and failure.

Independent t-tests were used to compare fork lengths for the groups at the time they were tagged. Statistical significance was set at $P < 0.05$.

Results and Discussion

When the small-parr groups were established, the recorded mean length of PIT-tagged fish was significantly (P = 0.000) greater than their controls (Table 1). We believe this is an artifact produced by a technician not properly calibrating the digitizer equipment for the PIT-tag group. The means for fork lengths of the PIT-tagged large parr and smolts did not significantly (P = 0.625, P = 0.075) differ from their controls when they were tagged.

It was necessary to grow all groups in individual tanks and, therefore, it is possible that later differences in size of PIT-tagged and control fish were due to container-related effects such as water flow or feeding regime. Consequently, all we will say is that growth was similar for all three sizes of PIT-tagged and control fish (Table 2).

Six to 8 months after tagging, survival in the PIT-tagged groups was comparable to their controls (Table 3). In fact, survival was high for all groups, never falling below 95%.

Tag loss and failure during the primary study ranged from 0 to 5% (Table 4). These levels of tag loss are comparable to or less than those reported for coded-wire tags (Blankenship 1981, Elrod and Schneider 1986, Fletcher et al. 1987) and some external tags (Franzin and McFarlane 1987, Dunning et al. 1987).

All tag loss occurred in the small-parr group with 1% of these fish losing their tags. Another 1% of this group's tags failed. The most tag failures occurred in the smolt group (5%) over 182 days.

Table l.- Mean fork length (mm) of sockeye salmon in each group when tagged. The small parr were tagged in May 1987, the large parr in July 1987, and the accelerated smolts in July 1987. Probability values are based on independent t-tests comparing the fork lengths of control and PIT-tagged fish.

	Small parr		Large parr		Smolts	
Statistic	Control	PIT-tag"	Control	PIT-tag	Control	PIT-tag
Fish (N)	200	200	199	200	200	199
Mean length	63.9	68.3	82.3	81.9	96.3	97.1
SD	4.8	4.1	6.8	7.0	4.0	4.5
t value	t = -9.878		t = 0.489		t = -1.788	
Probability	P = 0.000		P = 0.625		P = 0.075	

[a] The values for this data set are based on records in an original file which may be inaccurate due to a technician failing to calibrate digitizer.

Table 2.-- Mean fork length (mm) of sockeye salmon in each group at end of primary study in January 1988.

	Small parr		Larse parr		Smolts	
Statistics	Control	PIT-tag	Control	PIT-tag	Control	PIT-tag
Fish (N)	202"	195	197	189[b]	194	188[b]
Mean length	135.1	137.5	133.9	133.9	142.7	146.3
SD	9.6	10.7	10.1	10.4	9.3	9.4

[a] The value presented does not account for missing data entries.

[b] Data not taken on all fish.

Table 3.-- Number and percentage of surviving sockeye salmon at the end of primary study in January 1988.

	Small parr		Large parr		Smolts	
Statistic	Control	PIT-tag	Control	PIT-tag	Control	PIT-tag
Live (N)	202"	195"	197	190	194	193
Dead (N)	1	1	2	10	6	6
Survival (%)	99.5	99.5	99.0	95.0	97.0	97.0

[a] The value presented does not account for missing data entries.

Table 4.-- Number and percentage of PIT tags rejected and failing in each of the three groups of PIT-tagged sockeye salmon by the end of the primary study in January 1988.

Statistic	Small parr	Large parr	Smolts
Elapsed days	229	181	182
Number fish tagged	200	200	199
Number (%) rejected	2 (1)	0 (0)	0 (0)
Number (%) failing	2 (1)	0 (0)	10 (5)

After the three study groups of PIT-tagged fish were combined with other PIT-tagged sockeye salmon from the same population, overall tag loss and failure remained low in immature fish (Table 5); 99.8% of the immature fish had retained their tags 405 to 462 days after tagging (September 1988). The one maturing male retained his tag. Tag failure in these fish was 0.2%. When the remaining fish were interrogated 754 to 811 days after tagging, only eight (1.4%) immature fish had lost their tags. Another 0.2% of these immature fish had failing tags. In November 1989, when immature fish were examined 850 to 907 days after tagging, 100% of the tags were functional. All the mature males (Table 6) had retained operational PIT tags. However, four (21%) of the mature females had lost their PIT tags. Maturing females absorb body fat and other tissue which may allow PIT tags to drift freely among the eggs and ovarian fluid. If these tags come to rest near the ovipositor, they may be rejected as irritants or extruded with the eggs. This type of tag loss is probably limited to salmonids, as they are the only teleosts lacking an oviduct. Salmonid eggs rupture into the coelomic cavity and exit through a pore adjacent to the urinary and anal openings. This type of tag loss was not observed by Harvey and Campbell (1989) in maturing female largemouth bass (_Micropterus salmoides_), which have a distinct oviduct.

Subsamples of serially sacrificed fish were examined to document the rate of wound healing, tag location within the body cavity, and histological tissue reaction to the tag. Wound healing was complete in all groups by day 47 (Table 7). The tagging wounds of the small parr healed at a slightly greater rate than those of the large parr and

Table 5.--Number and percentage of functional, rejected, and failing PIT tags in the immature fish of all groups of PIT-tagged sockeye salmon at three sampling periods.

Statistic	September 1988	August 1989	November 1989
Days after tagging	405-462	754-811	850-907
Number (%) functional	939 (99.8)	563 (98.4)	189 (100)
Number (%) rejected	0 (0.0)	8 (1.4)	0 (0.0)
Number (%) Failing	2 (0.2)	1 (0.2)	0 (0.0)

Table 6.-- Number and percentage of functional, rejected, and failing PIT tags in the mature sockeye salmon examined in November 1989, 850 to 907 days after tagging.

Statistic	Male	Female
Number (%) functional:	35 (100)	15 (79)
Number (%) rejected:	0 (0)	4 (21)
Number (%) failing:	0 (0)	0 (0)

Table 7.-- Description of wound condition over time for the three groups of tagged juvenile sockeye salmon.

	Percent of fish within a wound classification code[a]					
	Small parr		Large parr		Smolts	
Days post-tagging	Wound type	Percent[b]	Wound type	Percent[b]	Wound type	Percent[b]
0	A	100	A	100	A	100
5	B	100	A	60	A	65
			B	40	B	35
10	B	100	A	60	A	40
			B	40	B	60
15	B	75	B	100	B	100
	C	25				
20	B	100	B	55	B	75
			C	45	C	25
45	C	100	C	100	C	100

[a] Wound codes

A = An open wound.

B = A wound closed by a thin membrane and healing--at times a slight red or pinkish coloration is noticeable in the wound area.

C = A wound completely healed that may or may not be noticeable due to a scar. There is no red or pink coloration in the wound area.

[b] Twenty fish were examined per group on each sampling day.

smolts. All tagging wounds were closed in the small group by day 5 while complete wound closure was not seen in the other sizes until day 15. Growth rate and status of smoltification may account for this difference in healing rate.

Tag location within the body cavity of the small parr was fairly consistent for all observation periods (Table 8). This suggested that the tag did not migrate from the implant area and that the tag implant procedure was fairly consistent for these fish.

Unlike fish in the small-parr group, fish in the large-parr and smolt groups did not show consistent tag location after day 10 (Table 8). This observation suggested tag migration within the body cavity, or that initial tag placement was not consistent. The latter explanation is more likely, as these were the first two groups of fish tagged with the newly developed automatic tag injector.

After the main study was completed and the tag groups were combined, excess fish were sacrificed annually to keep tank densities at reasonable levels. A small number (3.2%) of PIT tags were found in the swim bladders of these fish. It is unknown whether the tags had been injected or migrated into the thin-walled swim bladders. In either case this may be a mechanism of tag loss, with tags being evacuated through the pneumatic duct into the digestive tract.

Serially sacrificed fish were examined by an independent pathologist to determine histological tissue reaction to the tagging operation and to the tag. The pathologist's report indicated that all damage to tissue was induced by the hypodermic needle and not by the tag itself (Appendix A). The epidermis completely covered the wound by

Table 8.-- Description of tag location over time for the three groups of tagged juvenile sockeye salmon.

	Percent of fish within a tag location classification code[a]					
	Small parr		Large parr		Smolts	
Days post-tagging	Tag Location	Percent[b]	Tag Location	Percent[b]	Tag Location	Percent[b]
0	E	25	E	75	E	90
	F	75			F	10
5	E	50	E	45	E	40
	F	50	F	55	F	60
10	E	60	E	15	E	5
	F	40	F	65	F	65
			G	15	G	30
			H	5		
15	E	55	E	55	E	65
	F	45	F	40	F	35
			G	5		
20	E	55	E	15	E	5
	F	45	F	15	F	75
			G	20	G	20
45	E	75			E	90
	F	25	F	100		
					G	10

[a] Tag location codes

E = Tag found between the pyloric caeca and mid-gut

F = Tag near abdominal musculature and often embedded in the posterior area of pyloric caeca near the spleen or in the adipose tissue at the posterior area of the pyloric caeca.

G = Tag found in an area other than those noted--generally between the mid-gut and air bladder or between the liver and pyloric caeca.

H = No tag present.

[b] Twenty fish were examined per group on each sampling day.

day 5 and the dermis was completely restored by day 47. Regeneration and healing of skeletal muscle was also nearly complete by day 47. The pathologist observed no convincing evidence that the presence of the PIT tag caused adverse effects on organs other than those that were physically damaged by the hypodermic needle.

The results of the histological analysis indicating no adverse tissue reaction (Appendix A) contrasted with studies on paraffin encapsulated radio tags (Marty and Summerfelt 1986, Lucas 1989) and anchor tags (Vogelbein and Overstreet 1987) in which tissue responses were noted. The lack of tissue response to the PIT tag is a product of its glass encapsulation. Unfortunately, as the tags seldom become embedded in tissue, they may become more prone to loss when females are fully mature, as observed in November 1989.

The Effects of PIT Tags on Cultured Chinook Salmon

Introduction

An evaluation of tags and marks should determine both their biological effects on organisms and their life expectancy. Knowledge of how tags affect survival, growth, and maturation is required to extrapolate information derived from tagged fish to the population they index. Similarly, knowledge of tag life expectancy is necessary to compensate for tag loss in population studies. This work examined the operational life expectancy of implanted PIT tags in cultured chinook salmon. In addition, it covered the general effects of PIT tags on several biological variables with the knowledge that the experimental design limited the ability to draw conclusions.

In a previous study, Prentice et al. (1987) observed that 100% of the PIT tags implanted into cultured chinook salmon remained operational up to 400 days after tagging. They found that the survival of PIT-tagged fish and untagged controls were comparable. However, the mean fork length of the tagged fish was shorter (2.9%) than the control mean at 400 days after tagging. The experimental design reported here expanded upon the earlier work by adding a binary coded-wire-tag treatment to compare the biological effects of the PIT tag to an established counterpart. In addition, sham-tag treatments were included to determine the independent effects of tagging and tag presence. Fish were also tagged at two different ages to examine the relationship between tagging and parr development.

Methods and Materials

On 10 March 1988, the five groups for the younger treatment series (YTS) were established from a stock population of 1987-brood, ocean-type chinook salmon maintained at the NMFS Freshwater Culture Facility in Seabeck, Washington. Each group initially consisted of 300 parr. The fish in all five groups were anesthetized with MS 222, measured to the nearest mm (fork length) with a digitizer system, weighed to the nearest 0.1 g, and then released into culture tanks. The control-group parr received no tag-related handling. Following the procedure described in Prentice et al. (1990c), a PIT tag was inserted with a hand tagger into the coelomic cavity of each fish in the PIT-tagged treatment just prior to length measurement. The fish in the sham-PIT-tagged treatment were similarly pierced with a 12-gauge PIT-tagging needle; however, no tag was inserted into their body cavity. As described in Jefferts et al. (1963), binary coded-wire tags were inserted into fish in the CW-tag treatment just prior to length measurement. The sham-CW-tagged fish were treated identically, except that no tag was inserted.

Five groups for the older treatment series (OTS) were created by repeating the above procedures with fish removed from the main stock population on 28 March 1988.

Treatment groups were maintained in separate 1.2-m circular tanks until mid-May 1988, when all groups were transported to the NMFS Manchester Field Station. The fish were reweighed, remeasured, vaccinated against Vibrio sp., and (where appropriate) interrogated for tag presence. Due to improper vaccination of the untagged controls, the YTS treatments had to be eliminated from all growth and survival aspects of the study after seawater transfer, but continued to be monitored for tag loss. All fish were gradually acclimated to seawater over a S-day period and then released into marine net-pens. Each treatment was held in a separate seawater net-pen and maintained with standard cage-culture techniques for the remainder of the study. No weights were taken after this time as the available electronic scales failed to integrate on the floating net-pen structure.

The fish were remeasured periodically, reinterrogated for tag presence, and assessed for stage of maturity in autumn 1988 and 1989. When the fish were sampled, the groups were transferred to new net-pens. During each sampling period, PIT-tagged fish not responding with a tag code when interrogated were sacrificed and dissected to determine if they had either retained a malfunctioning tag or had lost a tag.

Without replication, the container-related effects prevented statistical analyses from being applied to the biological (growth, survival, and maturation) data in this study.

Results

Length- In March 1988, the test groups within the YTS ranged in mean fork length from 63.2 mm to 63.9 mm (Table 9). When the YTS was terminated (May 1988), the mean lengths ranged from 86.8 mm to 89.3 mm with fish within the PIT-tagged group being slightly smaller than those in other treatment groups.

When the OTS groups were established in March 1988, the mean fork lengths ranged from 68.6 mm to 71.7 mm (Table 10). When examined just

Table 9.--Mean fork length (mm) for the five treatments in the young treatment series (YTS) fish at each sampling period.

	Treatment				
Period	Control	PIT-tag	Sham-PIT	CW-tag	Sham-CW
March 1988					
Number	300	300	300	300	300
Mean	63.9	63.9	63.7	63.2	63.7
SD	2.8	3.0	2.8	2.6	2.8
May 1988					
Number	297	297	306	292	299
Mean	87.1	86.8	88.6	87.1	89.3
SD	4.7	5.0	4.6	4.8	5.2

Table lO.-- Mean fork length (mm) for the five treatments (see text for definitions of abbreviations) of the old treatment series (OTS) fish at each sampling period.

	Treatment				
Period	Control	PIT-tag	Sham-PIT	CW-tag	Sham-CW
March 1988					
Number	300	300	300	300	300
Mean	70.3	71.7	71.1	68.9	68.6
SD	3.2	3.8	3.7	3.2	3.3
May 1988					
Number	295	295	299	297	293
Mean	87.4	88.5	86.3	87.9	88.2
SD	4.5	5.0	5.2	5.1	4.5
October 1988					
Number	240	243	262	255	242
Mean	156.2	157.6	160.0	160.7	160.4
SD	19.3	17.3	14.4	16.6	16.8
March 1989					
Number	210	207	249	232	186
Mean	222.6	221.3	229.3	234.2	228.3
SD	26.1	25.0	23.9	22.6	21.0
August 1989					
Number	141	188	148	166	158
Mean	298.8	285.9	299.4	300.2	306.1
SD	32.7	47.6	29.4	29.5	27.5
October 1989					
Number	129	135	113	106	145
Mean	345.0	324.5	352.2	337.3	349.7
SD	35.0	32.3	35.9	35.5	26.2

before transfer to seawater in May 1988, the mean length ranged from 86.3 mm to 88.5 mm. During the 18 months of seawater net-pen rearing, the relative order of the OTS groups for mean fork lengths varied at each sampling period (Table 10 and Fig. 1).

Maturity schedule--As expected, few OTS fish matured as precocious, l-year-old fish. Of the survivors (October 1988), only 1.9% of the sham-PIT-tagged, 2.4% of the CW-tagged, 2.9% of the control, 3.3% of the sham-CW-tagged, and 4.5% of the PIT-tagged fish were maturing (Table 11).

In October 1989, the percentage of the surviving fish maturing as 2-year-olds was considerably higher. The highest percentage of fish showing early maturation occurred in the sham-CW-tagged treatment (22.1%) followed by CW-tagged (19.8%), PIT-tagged (17.0%), sham-PIT-tagged (13.3%), and control (12.4%) treatments.

PIT-tag retention--Two fish from both the YTS and OTS groups combined had lost PIT tags by May 1988 (Table 12). From then on, all surviving tagged fish retained their tags, giving a tag loss of 0.3% (2/600) over 19 months.

PIT-tag malfunction--In May 1988, the PIT tags in four fish from both the YTS and OTS groups combined, were unreadable (Table 12). When examined in October 1988, two fish from the YTS group and one fish from the OTS group possessed tags that had failed to function. This gave an accrued 1.2% PIT-tag failure. In March 1989, 17 tags were unreadable, but it was determined that the interrogation equipment was malfunctioning, and not the tags.

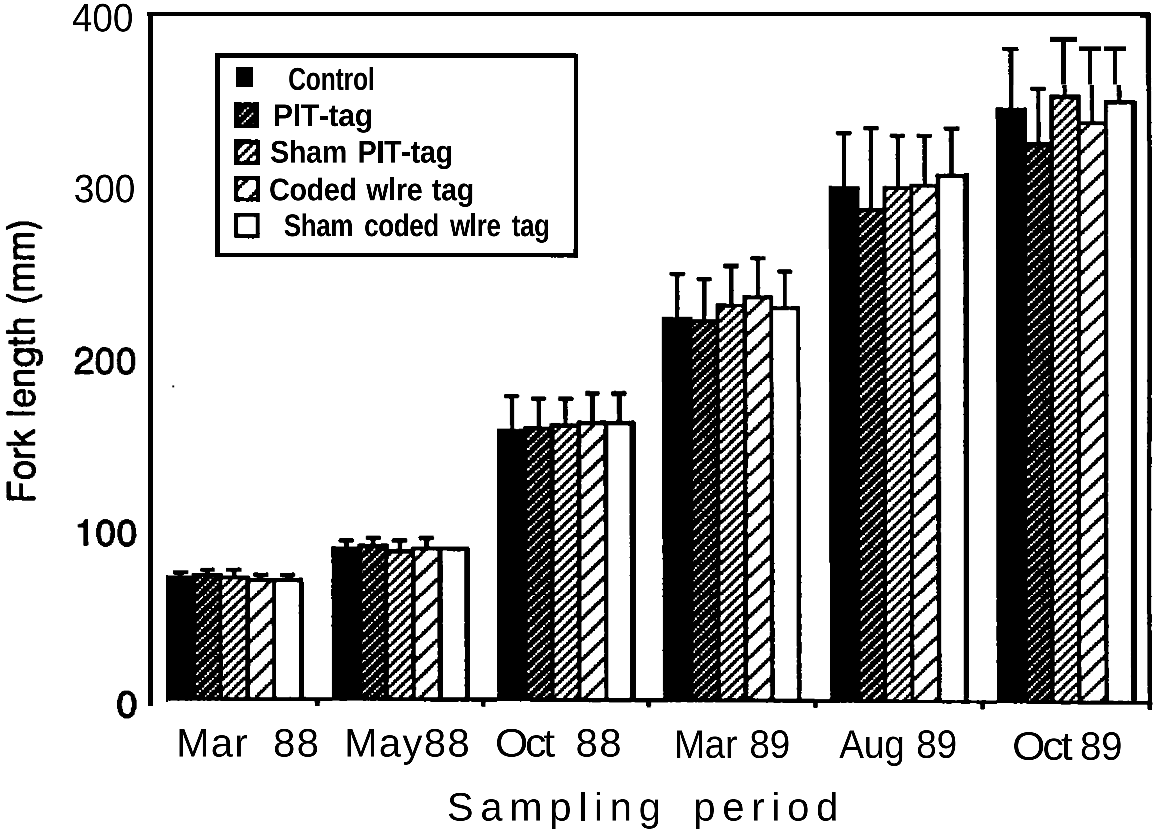

Figure 1.--Mean size of the old treatment series (OTS) chinook salmon at each of the six sampling periods.

Table 11.--Percent mature fish observed in each of the old treatment series (OTS) groups in October of each study year.

Age at maturity	Treatment				
	Control	PIT-tag	Sham-PIT	CW-tag	Sham-CW
One year	2.9	4.5	1.9	2.4	3.3
Two years	12.4	17.0	13.3	19.8	22.1

Table 12.--Number of PIT tags lost or malfunctioning at each examination period for both young and old treatment series (YTS and OTS) fish.

	PIT tags	
Period	Lost	Failed
May 1988	2	4
October 1988	0	3
March 1989	0[a]	0[b]
August 1989	0	0
October 1989	0	0

[a] Due to a weak PIT-tag interrogation loop, three fish were sacrificed and subsequently determined to have intact functional tags.

[b] Due to a weak PIT-tag interrogation loop, 14 fish with tags could not be read at the time of interrogation.

Survival-- Overall, survival was high in fresh water for both the YTS and OTS groups. When the YTS was terminated in May 1988, all of the sham-PIT-tagged fish, 99.7% of the sham-CW-tagged fish, 99.0% of the PIT-tagged and control fish, as well as 97.7% of the CW-tagged treatment fish had survived (Table 13). For the OTS treatments, survival also ranged from 97.7 to 100.0% until May 1988 (Table 14).

After transfer to seawater, the entire OTS began to show reduced survival. In October 1988, the sham-PIT-tagged fish showed the highest survival at 87.3%, followed by the CW-tagged (85.0%), PIT-tagged (80.7%), sham-CW-tagged (80.7%), and control (80.0%) fish (Table 14). When reexamined in March 1989, larger differences were detected in the survival of the five OTS treatments: The sham-PIT-tagged fish had the highest survival (83.0%), followed by the CW-tagged (77.3%), control (70.0%), PIT-tagged (69.6%), and sham-CW-tagged (62.0%) fish. When next examined in August 1989, large differences in survival were again observed. At this point, however, the PIT-tagged fish exhibited the highest survival (62.9%), followed by CW-tagged (55.5%), sham-CW-tagged (52.7%), sham-PIT-tagged (49.3%), and the control (47.0%) fish. When last examined in October 1989, the sham-CW-tagged (48.3%) and PIT-tagged (44.8%) fish had survived best, and the CW-tagged (35.5%) and sham-PIT-tagged (37.7%) fish had survived poorest, while the control fish (43.0%) showed intermediate survival.

Looking at the overall picture, the relative order for the survival of the groups seemed to vary at each sampling period (Fig. 2). One trend in the OTS data was for the PIT-tagged fish to show slightly better survival than the control fish. Generally, the sham-PIT-tagged

Table 13.-- Percent survival of fish in the five treatments of group young treatment series (YTS) adjusted for sacrifices and known escapes.

	Treatment				
Period	Control	PIT-tag	Sham-PIT	CW-tag	Sham-CW
March 1988	100.0	100.0	100.0	100.0	100.0
May 1988	99.0	99.0	100.0	97.7	99.7

Table 14.-- Percent survival of fish in the five treatments of the old treatment series (OTS) adjusted for sacrifices and known escapes.

	Treatment				
Period	Control	PIT-tag	Sham-PIT	CW-tag	Sham-CW
March 1988	100.0	100.0	100.0	100.0	100.0
May 1988	98.3	98.3	100.0	99.0	97.7
October 1988	80.0	80.7	87.3	85.0	80.7
March 1989	70.0	69.6	83.0	77.3	62.0
August 1989	47.0	62.9	49.3	55.5	52.7
October 1989	43.0	44.8	37.7	35.5	48.3

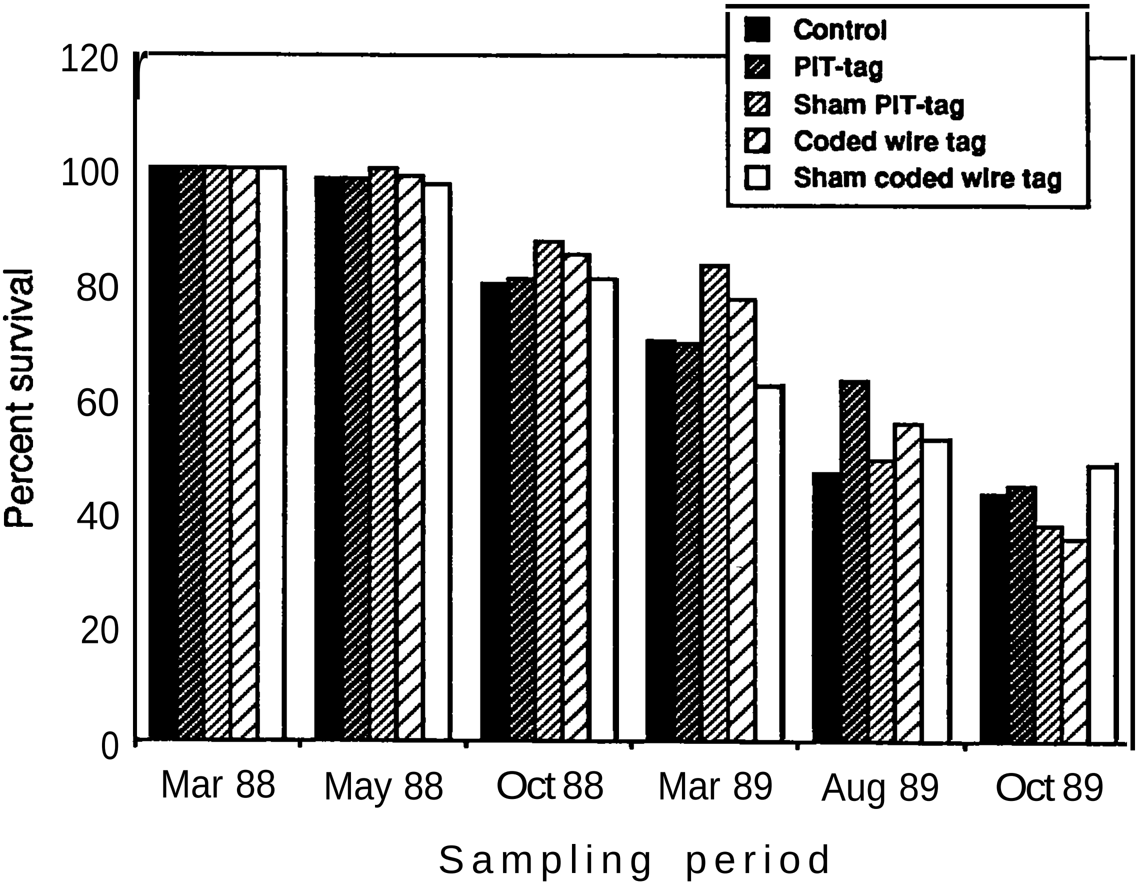

Figure 2. --Percent survival of the old treatment series (OTS) chinook salmon at each of the six sampling periods. Error bars indicate one standard deviation.

and CW-tagged fish survived better than the control fish until the last sampling in October 1989. The sham-CW-tagged fish generally survived as well as or better than the control fish.

Discussion

For the reasons presented in the caveat at the beginning of this section, any conclusions drawn in regard to the effects of PIT tags on growth or other biological variables are suspect.

Length--In this and the 1987 study (Prentice et al. 1987), the PIT-tag groups grew slower than the control groups. One can speculate that the reduced growth of PIT-tagged fish as compared to controls has to do with either the presence of PIT tags within the coelomic cavity or the stress from tagging. The observation that sham-PIT-tagged treatment fish in this study are not similarly affected suggested the effect was due to tag presence rather than the tagging procedure. As there was no consistent trend with the CW-tagged treatment, sham-CW-tagged, and control fish over time, it appeared that the CW tagging did not impact growth here as it had in the earlier study reported by Jefferts et al. (1963).

Maturity schedule--Hager and Noble (1976), Eriksson et al. (1987), and this report indicated that larger salmonid parr have a greater probability of maturing at a younger age. In an earlier chinook salmon study, Prentice et al. (1987) observed that fewer precocious males and jacks were produced in a smaller cultured PIT-tagged population than in the controls. However, in this study there were no differences in the number of l-year-old precocious and

2-year-old jacks among the smaller PIT-tagged and larger control and sham-PIT-tagged treatment fish.

Survival--The PIT-tagged fish survived as well as the control fish over 19 months, which suggested that tagging did not adversely affect the survival of cultured salmonids. The Prentice et al. (1987) study also found comparable survival. In addition, the lack of a consistent trend in the survival of PIT-tagged fish compared to CW-tagged fish suggested that PIT tags did not affect survival during culture any more than CW tags. Because there was no apparent trend for either type of tagged fish to survive better or worse than the two sham-tagged groups, the tagging itself did not appear to affect survival.

Tag retention and malfunction--The tag loss of 0.3% over 19 months was relatively low and believed to be within acceptable levels. Even when combined with the tag malfunction of 1.2%, total combined failure was only 1.5% in 19 months. This is considerably less than the 5% loss of CW tags reported for wild chinook salmon by Jefferts et al. (1963) during their pioneering studies with that tag. It should be noted that tag malfunction is affected by quality control during manufacturing and may increase or decrease with alterations in design and manufacturing procedures. An excellent example of this was reported in Prentice et al. (1987), in which switching from polypropylene to glass encapsulation decreased tag malfunction by more than 10%.

Results from this study permit changing the study design to address specifically some of the remaining questions on PIT-tag effects on biological variables. This study plus previous studies on chinook salmon (Prentice et al. 1987) and sockeye salmon (this report) have given us the ability to estimate tag retention. This ability enables us to combine treatments and therefore eliminate container-related effects. In addition, replication of the groups becomes practical. Both of these design changes allow statistical analyses to be applied to the data.

Summary, Conclusions, and Recommendations for the Laboratory Studies

Experimental Design Caveat

Conclusions drawn from past and the following PIT-tag studies that addressed the effects of the tag on growth, survival, and maturation should be viewed with caution because their experimental designs violated the assumption of independence by rearing treatment groups in separate containers. Furthermore, they were not replicated.

The Effects of PIT Tags on Cultured Sockeye Salmon

1. A PIT tag can be successfully injected and retained in the body cavity of juvenile sockeye salmon. The tagging wounds of small parr healed at a slightly greater rate than those of larger parr or smolts. Tag loss and failure among juvenile sockeye salmon was an acceptable 0 to 5% over 182 days. This result is comparable to that seen by other investigators with coded-wire tags.
2. Nearly 100% of the implanted PIT tags were operational after 907 days.
3. Survival was high in all sockeye salmon groups, never falling below 95%. Growth was similar for all three sizes of PIT-tagged and control fish.
4. The use of the PIT tag for identifying ripe female sockeye salmon may be limited by high tag loss (21%, N = 4).

The Effects of PIT Tags on Cultured Chinook Salmon

1. PIT-tag loss (0.3% over 19 months) was low and acceptable for juvenile chinook salmon. Even when combined with tag malfunction (1.2%), the total combined failure was an acceptable 1.5%.
2. The relative order of the different groups for mean fork length varied throughout the 19-month study. The presence of PIT tags within the coelomic cavity of juvenile chinook salmon appeared to reduce growth. The observation that sham PIT-tagged fish are not similarly affected suggested the effect was due to tag presence rather than the tagging procedure. Species differences may account for the difference the PIT tag has on growth between juvenile sockeye salmon and chinook salmon.
3. The lack of a consistent trend in the survival of PIT-tagged fish compared to coded-wire-tagged fish suggested that PIT tags do not affect survival during culture any more than coded-wire tags. Based on the similar survival of untagged control and PIT-tagged juvenile chinook salmon over 19 months, we concluded PIT tagging does not adversely affect the survival of this species during culture.
4. The ability to estimate tag retention permits combining treatment groups; this will eliminate container-related effects. Replication also becomes practical. Thus, future studies can be designed to get statistically significant results for growth, survival, and maturation of tagged fish.

FIELD STUDIES

The Effects of the Geometric, Electromagnetic, and Light Properties of PIT-Tag Passageways on Chinook Salmon Smolt Movement

Introduction

Accurate and precise information on the natural behavior of fish can only be obtained with noninvasive systems. Present tagging and marking techniques (coded-wire tags, anchor tags, freeze brands, etc.) require that the movement of fish be interrupted so that tags or marks can be read. This requires fish to be stalled in fyke nets, smolt traps, seines, or the holding facilities of dams until they can be reinterrogated. The turbulence and predation in the live boxes of smolt traps and fyke nets may reduce survival of the stalled fish. Maule et al. (1988) showed that fish collection facilities and associated handling procedures led to increased cortisol levels, which may also impact the survival of smolts.

The use of the PIT-tag system provides a noninvasive approach for reinterrogating tag codes as fish move out of hatcheries and through stream and river systems, thereby obtaining accurate and precise information (such as time of movement, relative success of early and late migrants, and overwinter survival) without altering the behavior of fish. This study evaluated the impact of the tunnel-type PIT-tag monitoring system described in Prentice et al. (1990b) on the volitional movements of ocean-type chinook salmon smolts. The passage of smolts through channels, clear and opaque (gray and white) tubes, and tubes with a 400-kHz electromagnetic field either present or absent were compared to determine how these factors altered smolt behavior. This information is used to derive principles for the development of less disruptive PIT-tag monitoring systems, smolt traps, and smolt passage facilities.

Methods and Materials

Tests were conducted with the progeny of adult chinook salmon returning to Big Beef Creek, Washington in the fall of 1988. The fish were maintained according to standard hatchery practices and tested from May through July 1989 when they began to exhibit smolt behavior.

The passageway preference of smolts was determined with the system illustrated in Figure 3. The prechoice holding chamber measured 43-cm long by 90-cm wide by l-m deep (375 1). The chamber was made of perforated aluminum plate and was placed in the downstream end of a 4-m long by 2-m wide by l-m deep fiberglass raceway. Fish could exit the prechoice holding chamber downstream via either of two passageways having l0-cm diameter orifices. A remotely operated gate was placed upstream from the orifices to block fish movement before and after trials. A translucent 300-l postchoice collection tank was attached to the downstream end of each passageway.

Trials were initiated by placing 30 to 50 fish in the holding area for a minimum of 15 minutes to adapt to their new surroundings and to recover from handling. The gate was then opened (time = 0), giving smolts the opportunity to remain in the holding area or to move downstream through one or the other of the passageways. As smolts emerged into the postchoice collection tanks, their time of

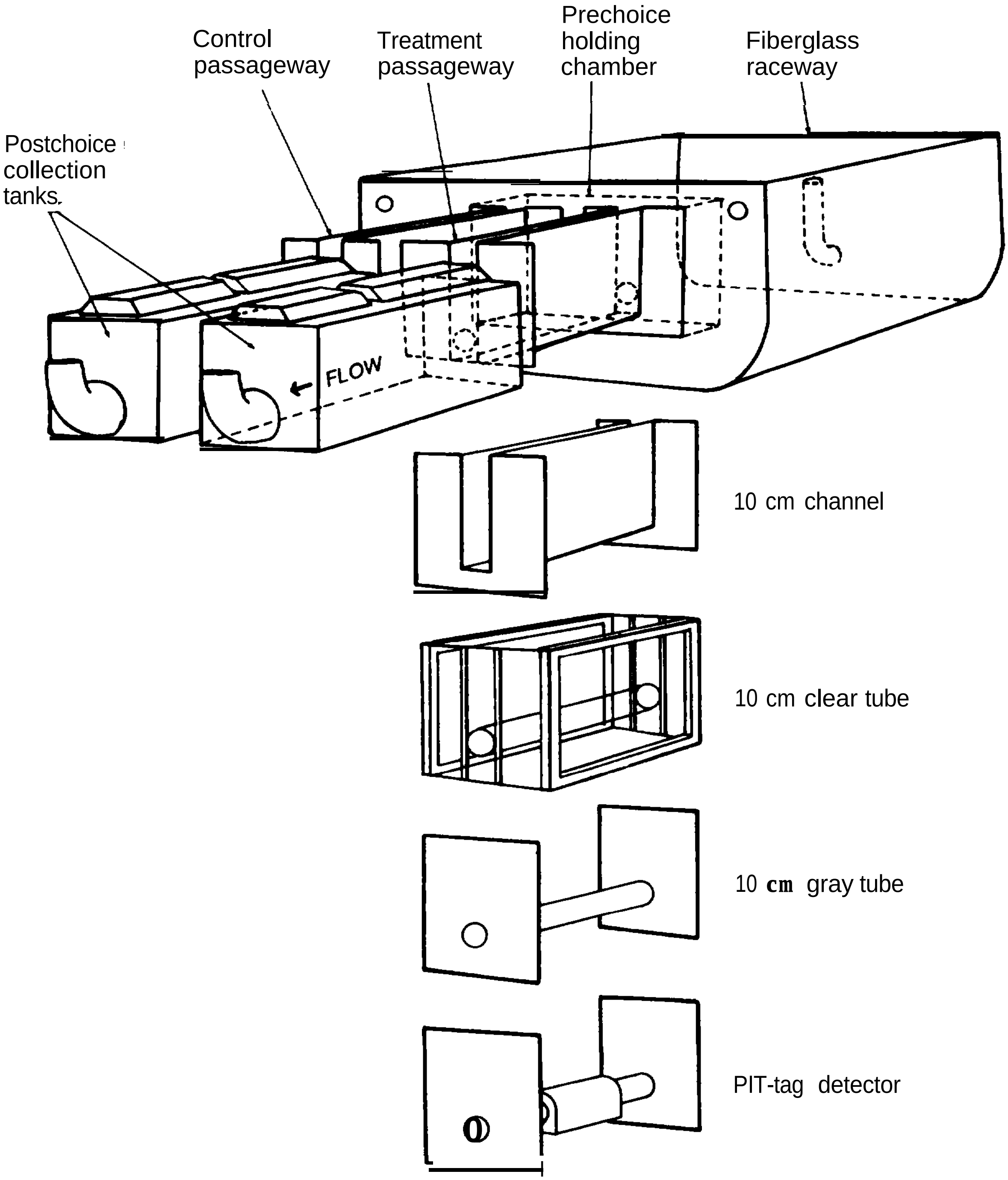

Figure 3.--Test system for determining passageway preference of juvenile salmon.

entry (= completion time) and number of fish in their "school" were scored. A "school" of fish was defined as a group of fish that had less than a 5-second gap between fish. After 1 hour, the gate was closed and the numbers of fish remaining in the holding area, each passageway, and the collection tanks were counted.

Four passageway types were used in the primary test period, with a fifth (gray tube) being added at the end of the study. A pair of three-sided, l0-cm wide by 152-cm long flat-bottomed channels that were constructed from gray opaque PVC determined the left and right preference of smolts. The channel treatment represented a more natural passageway and therefore was considered the control condition. The second type of passageway was an inactive PIT-tag detector which is a l0-cm diameter white, opaque tube (Prentice et al. 1990b). The third treatment was this PIT-tag detector energized with a 400-kHz electromagnetic field within the passageway. The fourth treatment was a l0-cm diameter transparent, acrylic tube. At the conclusion of the main study, a series of trials was run with a l0-cm diameter gray, opaque tube.

In all trials, the right passageway remained the control channel, while the left passageway was varied by treatment. On any given day, trials were conducted with each of the four main treatments. The time at which a treatment was conducted was varied daily so that all treatments were run an equal number of times in each time slot. The impact of the 400-kHz electromagnetic field on fish passage was determined by comparing the percentage of fish choosing passage through the left passageway with the field present or absent.

The effects of individual parameters on fish passage were discerned by statistically comparing the treatment types using two analyses of variance (ANOVA). Then, either Newman-Keuls tests or Tukey HSD analyses were used to determine groupings. With this approach, the effects of geometry (tubes and channels), light (hue and light intensity) and a 400-kHz electromagnetic field on fish passage ("school" size and time) were examined.

Results

Although it appeared that the smolts in this experiment did not have a preference for the right or left channels, all the comparisons were on fish moving through the left passageway. A one-way analysis of variance on the percentages of smolts using the left passageway indicated significant (P = 0.000) differences among the four main treatments (Table 15). The gray-tube-treatment data were not included in this first analysis of variance. A Newman-Keuls test arranged the data into three groups: channel, inactive detector = active detector, and clear tube. The highest percentage of smolts (48.3%) moved through the left passageway when it was a l0-cm wide channel. Installation of a white tube reduced the average percentage of smolts choosing the left passageway to 31.0% (inactive detector) and 28.8% (active detector). Therefore, the 400-kHz electromagnetic field did not significantly affect the preference of smolts for the left passageway. Only 16% of the downstream migrants used the left passageway when it was a transparent or clear tube. A second one-way analysis of variance incorporating the gray-tube data was significant (P = 0.000), and a

Table 15.--Mean percent of fish choosing to move through the test rather than the control passageway for each treatment. The probability values are based on a one-way ANOVA with groups distinguished by Newman-Keuls tests.

	Treatment				
		White tube			
Statistic	Left channel	Detector off	Detector on	Clear tube	Gray tube
Replicates	24	25	24	24	13
Mean (%)	48.3	31.0	28.8	16.0	8.7
SD (%)	16.6	22.0	19.1	20.7	6.6

Main four treatments: P = 0.000

Groupings: Channel White-off White-on Clear

All treatments: P = 0.000

Groupings: Channel White-off White-on Clear Gray

Newman-Keuls test indicated that the gray (8.7%) and clear tubes were not significantly different from one another; however, both differed significantly from the other three treatments (Table 15). These three treatments were separated by shape into two more groups (i.e., channel and the two tube treatments). It should be noted that the white and gray tubes were run at different times.

The "school" size of smolts moving through the left passageway significantly (P = 0.000) differed among the four treatments in the main study (Table 16). A Tukey HSD analysis arranged the treatments into one group consisting of channel treatment and another group consisting of the three tube treatments (i.e., clear tube = inactive detector = active detector). From the number of fish scored per "school," on average there were 2.5 fish per "school" moving through the channel treatment, and only 1.3, 1.2, and 1.3 fish per "school" moving through the clear-tube, inactive-detector, and active-detector treatments, respectively.

The time it took smolts to complete their movement through the different passageways was significant (P = 0.001). A Tukey test separated the clear tube from the other three treatment types (Table 17). On average, a fish took only 870 seconds to complete its movement through the transparent tube compared to the 1,480, 1,348, and 1,348 seconds required by a fish moving through the channel, the inactive detector, and the active detector, respectively.

Fish spent about 2 seconds in the clear tube and would rapidly swim out of one of the two ends. It was not observed how long fish remained in the three opaque-treatment passageways. However, at the

Table 16.--Average number of fish in "schools" of smolts moving through the test passageway for each treatment. The probability value is based on a one-way ANOVA with groups distinguished by a Tukey HSD analysis.

	Treatment			
		White tube		
Statistic	Left channel	Detector off	Detector on	Clear tube
Replicates	89	33	26	34
Mean	2.48	1.24	1.30	1.30
SD	2.52	0.50	0.62	0.58
P = 0.000				
Groupings:	Channel	White-off	White-on	Clear

Table 17.--Average time (seconds) required for smolts to complete movement through test passageway for each treatment. The probability value is based on a one-way ANOVA with grouping determined by a Tukey HSD analysis.

	Treatment			
		White tube		
Statistic	Left channel	Detector off	Detector on	Clear tube
Fish (N)	220	36	45	44
Mean	1,480	1,348	1,348	870
SD	744.2	1,103.6	901.6	1,159.2
P = 0.001				
Groupings:	Channel	White-off	White-on	Clear

end of tests, many more fish were found in the opaque tubes (inactive and active detectors) than in the transparent tube or channel.

Discussion

Tubes differ from channels in both geometric and light characteristics. If shape is a factor in the avoidance of tubes, smolts should strongly avoid tubes regardless of their light properties (e.g., hue or intensity). Because more'smolts swam through the channel passageway and avoided all three tubes to some degree, geometry did appear to affect fish behavior.

If the avoidance of tubes by smolts is only due to shape, then fish should respond the same to opaque or transparent tubes. In contrast, if light intensity is also an important factor, smolts should vary their response based on the light properties of the tubes. Because smolts preferred opaque to clear tubes and white to gray tubes, we concluded that both light and geometry are affecting the response of smolts to tubes.

It appeared that light intensity was more important than the hue of passageways. The preference of smolts for the channel over the gray tube was probably due to shape and light intensity as both passageways were the same hue. Because both the gray and white (inactive and active monitor) tubes had the same shape, fish preference for the white tubes may be due to the higher light intensity. Studies by Maynard (1980) and Prentice et al. (this report), in which shape and color were controlled, also found that reduced light intensity significantly decreased salmonid use of passageways. As explained below, the smolts did not use the well-lighted transparent tubes because of their unfamiliarity with translucent material.

The preference of smolts for passageways with ambient light may be related to the physiological mechanisms involved in dark adaptation. The typical vertebrate eye requires at least 30 minutes to develop complete dark adaptation and only seconds for complete light adaptation (Riggs 1972, Munz and McFarland 1973). As Munz and McFarland (1973) pointed out, a fish moving from a light area to a dark area faces a reduced probability of visually detecting a predator or other hazards. Thus, it is in the interest of moving fish to choose passageways with ambient lighting. If passageways have greater light intensity than the areas into which fish exit, the dark adaptation problem occurs. Munz and McFarland (1973) have applied this concept to the diurnal migration of fishes. Given the reluctance of smolts to enter darkened passageways, forcing them into such passageways may cause stress.

The reluctance of smolts to use the clear tube is due more to their inexperience with transparent material than to illumination. When smolts entered the tube, most attempted to swim through it to the ground below. After making several fruitless attempts to reach the ground, many would swim back upstream into the holding area. The few smolts that completed passage swam parallel to the tube wall without touching its sides. We have frequently observed this behavior in aquariums when fish are first introduced. Although clear passageways are the easiest technical means of matching ambient lighting, they are unsatisfactory from a biological perspective. However, the problems encountered with the transparent passageways may be overcome by darkening the bottom portion.

The PIT-tag detector generates a tag-energizing magnetic field that oscillates at 400 kHz. Juvenile salmonids have been shown to orient to magnetic fields (Rommel and McCleave 1973, Quinn 1980, Quinn et al. 1981, Quinn and Brannon 1982, Chew and Brown 1989). Therefore, there was some concern that the magnetic field in the detector might attract or repel smolts. However, no evidence was found to support this concern.

The greater volume of the channel compared to the tubes may explain why "school" size is significantly greater in the former. An alternative explanation is that when pioneer fish began to move through the channel, they were joined by more compatriots because there was less reluctance to move through the channel than the tubes, possibly due to shape.

The reduced number of fish in "schools" volitionally moving through tubes rather than channels raises serious concern about tubes for volitional fish passage. There is considerable evidence indicating that the smaller the school size the greater the risk of predation for its members (Radkov 1973, Neil1 and Cullen 1974, Poole and Dunstone 1975, Milinski 1979, Tremblay and Fitzgerald 1979, Pitcher 1986). The situation is compounded when fish passage systems release fish at locations predators can use as optimal foraging habitat.

The reduced time it takes smolts to move through the clear tube, again suggested a possible aversion to this structure. The increased number of smolts remaining in the opaque tubes, compared to results for the clear tube and channel, may stem from some smolts preferring to remain under cover,

As open channels are preferred by smolts and interfere less with social behavior, they should be used to pass volitionally moving smolts whenever possible. In addition, these channels should be either naturally or artificially illuminated to match ambient environmental light levels. It is recommended that an open-channel PIT-tag detector be developed and tested for detecting the volitional movement of smolts from hatcheries, in streams, and in rivers.

A Comparison of the Marine Survival, Maturation Strategies, Growth, and Tag Retention of Coho Salmon Tagged with PIT or Coded-Wire Tags

Introduction

Tagged and marked fish must be extensively evaluated to ensure that their biology has not been altered. Currently, the CW tag is the only widely used tag that has undergone this extensive evaluation (Bergman 1968, Blankenship 1981, Opdycke and Zajac 1981, Quinn and Groot 1983, Thrower and Smoker 1984, Morrison and Zajac 1987).

This study will provide some of the baseline information necessary for using the PIT tag as a tool to index populations. We will evaluate the effect of the tag on the survival, growth rate, age of maturity, marine distribution, and return time of hatchery coho salmon released to the ocean. We also will determine the durability of the tag in these ocean-going fish. The effect of a measuring and data-logging system on salmon biology will also be evaluated. Previous work (Prentice et al. 1987) as well as the present report showed that growth and survival were comparable for PIT-tagged and control cultured chinook salmon.

To address the above objectives, a multiyear study is being conducted. Juvenile coho salmon were tagged in two consecutive years (1989 and 1990), and ocean and hatchery return data will be gathered until 1992. This report covers the first year (1989) of the study.

Methods and Materials

Study design--The study employed a 2 x 3 design, with the effect of tagging determined by comparison among PIT-tagged-only fish, CW-tagged-only fish, and fish tagged with both tag types. The effect of the fish-measuring and data-logging system was determined by subjecting half of each tag group to the measuring and data-logging process. The number of fish in each treatment group is shown in Table 18.

Tagging--The study fish were 1987-brood Clark Creek coho salmon, reared to smoltification at the Washington State Department of Fisheries (WDF) Skagit River Hatchery near Marblemount, Washington. These fish, which are part of the Clark Creek broodstock program, are historically released in June as yearlings. Clark Creek fish typically return as 2-, 3-, and 4-year-old adults from October through December.

In January 1989, more than 20,000 fish were removed from the main hatchery population and transferred to their own raceway prior to tagging. These fish were taken off feed at least 1 day prior to tagging and were not fed again until at least 2 days after tagging. Subsamples for tagging were removed by crowding the fish within the raceway and then dipnetting lots of 600-800 fish. Each subsample was placed into one of two compartments of a holding trough. One compartment of the trough was used for fish to be PIT tagged while the second was for fish to be CW tagged. Fish receiving both tag types were the remaining fish from both compartments plus another new lot of 600-800 fish distributed between the two compartments.

Taggers removed fish from the holding compartments in groups of 100 or less and anesthetized them in MS 222. The fish were measured (fork length) using a digitizer according to their treatment (Table 18). Only fish larger than 80 mm were tagged. The procedure used for PIT tagging is described in Prentice et al. (1990c); the method for CW tagging is described in Jefferts et al. (1963). All fish receiving a CW tag were adipose-fin clipped. Fork length, CW-tag or PIT-tag codes, and fish condition were recorded using the digitizer data-logging system described in Prentice et al. (1990c). This measuring and data-logging process was only used on half of the fish in each treatment group (Table 18).

Separate PIT- and CW-tag teams were established and worked simultaneously during the single tag/fish sessions. In the double tag/fish sessions, the taggers would combine into one team with fish being first PIT tagged and then CW tagged. It was left to the discretion of the tagger to reject fish unacceptably injured during the tagging or data-logging process.

After tagging, all fish were placed in an outlet chute leading from the tagging building to a posttagging raceway. A CW-tag quality-control device (QCD) was located within the outlet chute. Fish lacking a CW tag were rejected by the QCD at this point. These fish were retagged and again passed through the QCD.

During each tagging session, 2.5% of the fish were subsampled and transferred to hatchery troughs to determine initial posttagging mortality and tag loss. These subsamples (approximately 80 fish each) were kept in these troughs until 7 April, when they were interrogated for tag presence, combined, and transferred to a seawater net-pen at Manchester, Washington. These fish are being used to index latent tag failure under culture conditions and were first reinterrogated in seawater for tag presence in August 1989.

An additional quality-control check to verify tag presence was conducted 1 month after tagging at the hatchery. A sample of 2,000 plus fish were transferred to hatchery troughs. The tag types expected to be found in the fish were determined from tagging scars and adipose-fin clips and by the use of PIT- and CW-tag detection equipment. After examination, the fish were returned to the raceway. These were then a part of the 97.5% of the tagged fish that were released in June along with the rest of the Clark Creek coho salmon yearlings.

Tag recovery--All coho salmon dispatched at the hatchery rack in the fall of 1989 were examined for the presence of PIT and CW tags. Fish that died in the adult holding pond or passed through the WDF facility during floods were examined during pond mortality and stream surveys.

On an intermittent basis, coho salmon were also interrogated for the presence of PIT tags with a prototype picket, V-lead, monitoring system as they entered the adult holding pond. This system was installed in the downstream end of the central runway of the adult return pond to interrogate fish passively as they entered. However, it was only intermittently operational because its effects on fish passage were being evaluated. Results for the picket system will be reported in the next annual report.

Prior to spawning, all coho salmon were individually passed through a dual-coil, 31-cm diameter, PIT-tag monitoring system. When the system identified a PIT-tagged adult, the tag code, sex, length, and recovery date of the fish were recorded. In addition, all jacks returning to the hatchery were interrogated with a hand-held PIT-tag scanner.

Following standard WDF procedures, the length and sex of each adipose-fin-clipped adult were determined and its head was removed. A label was attached to the head containing all data including the PIT-tag code when appropriate. The individually bagged and labeled heads were transferred to the WDF coded-wire-tag reading facility in Olympia, Washington for CW-tag code determination.

Adult coho salmon bypassing the hatchery during floods were sampled for tag presence in stream surveys. These were begun after the first flood and were conducted at least once a week in Washington Creek, Clark Creek, and a nearby water diversion channel. Surveyors interrogated all coho salmon carcasses with an intact body cavity for PIT-tag codes using a hand-held scanner. If the carcass was adipose-fin clipped and the head intact, the head was removed, labeled, and bagged for transfer to the WDF coded-wire-tag reading laboratory. The head labels for these fish were marked "stream survey." The length and sex of each tagged fish were recorded in field notebooks and on head labels. After sampling, the tail of all carcasses was cut so these individuals would not be counted on subsequent surveys. Live and dead counts were made on these sampling trips. Fish dying in the adult return pond before they could be spawned were designated as "pond mortalities." Fish dying in other areas were referred to as "supplementary-pond mortalities."

The WDF coded-wire-tag reading facility also reports the return of tags from the fishery. This information is made available to NMFS personnel on a trimonthly basis.

For treatments in which fork lengths were determined, probability values were based on one-way analyses of variance (ANOVA) on the growth data. Subsequent treatment grouping patterns were determined using a Tukey HSD analysis. Survival data were analyzed statistically using contingency table analyses.

Results

When examined for tag retention in late February 1989, 100% of the PIT-tagged-only group, CW-tagged-only group, and the group with both tags had retained their tags. When examined in August 1989, the subsample of fish transferred to the Manchester seawater net-pens had tag-failure rates of 1 and 2% for the PIT and CW tags, respectively.

In January 1989, the ANOVA was significant (P = 0.000) and a Tukey test separated the double-tagged fish ($\bar{x}$ = 104.5 mm) from the PIT-tagged ($\bar{x}$ = 104.9 mm) and the CW-tagged ($\bar{x}$ = 105.2 mm) fish (Table 18). All three tag treatments had relatively uniform lengths (SD = 0.1 mm).

Only 0.03% or six study fish returned as 2-year-old jacks in 1989. With so few, it was not surprising that the proportion of jacks returning in each treatment category was not significantly (P = 0.304) different (Table 19). The total study jack return was equal to or

Table 18.--Number (N) and mean fork length (mm) at tagging of yearling coho salmon in the treatment groups established in January 1989 and released in June 1989. The probability value is based on an one-way ANOVA for the three digitized treatments. A Tukey HSD analysis is used to distinguish the grouping pattern. N/A indicates lengths were not recorded.

	Digitized			Not digitized		
Statistic	PIT tag	cw tag	PIT+CW tags	PIT tag	cw tag	PIT+CW tags
N released"	3,218	3,232	3,223	3,218	3,217	3,302
N subsample	80	82	83	83	83	83
N analyzed	3,298	3,245	3,301	N/A	N/A	N/A
Mean length	104.9	105.2	104.5	N/A	N/A	N/A
SD	0.1	0.1	0.1	N/A	N/A	N/A

F (2, 9841) = 7.824

P = 0.000

Groupings: PIT cw PIT+CW

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[a] The total number of fish released and the number of fish in the subsample transferred to seawater net-pens does not equal the number of fish used in length analysis due to the failure of digitizer operators to manually accept the length of CW-tagged fish at the time of tagging.

Table 19.--Number (N) and mean fork length (cm) of recovered 1987-broodyear jacks in the adult return pond and stream survey between September 1989 and January 1990. Probability value is from a contingency table analysis. N/A indicates lengths were not recorded.

Statistic	Digitized			Not digitized		
	PIT tag	CW tag	PIT+CW tags	PIT tag	CW tag	PIT+CW tags
Original N	3,218	3,232	3,223	3,218	3,217	3,302
N returning jacks	0	0	3	1	1	1
Mean length	N/A	N/A	33	36	30	30

Chi square = 6.026

P = 0.304

greater than the estimated jack return rate for all the 1987-broodyear Clark Creek Hatchery stock. The number of jacks was insufficient to evaluate statistically the fork-length data of the returning fish. The longest (37 cm) and shortest (29 cm) returning fish were from the treatment with both tags. All four returning jacks in the double-tagged group possessed functional PIT-tags. Two heads of this group were examined by the WDF coded-wire-tag reading laboratory; the fish had retained their CW tags.

The only study fish that was recovered from the fishery to date belonged to the group with both tags.

In the subsample of fish transferred to the Manchester seawater net-pens, contingency table analysis determined that double-tagged fish exhibited significantly (P = 0.001) lower survival (46%) than the PIT-tagged (66%) or CW-tagged (71%) coho salmon, when examined in August 1989 (Table 20). The survival of PIT-tagged and CW-tagged fish did not significantly (P = 0.622) differ from each other. Results from an ANOVA showed no significant (P = 0.281) difference in mean size among these groups (Table 21).

Discussion

Although small (< 0.7 mm), the difference in size among the three 1989 tag categories may be biologically meaningful for the subsample transferred to the seawater net-pen facility near Manchester, Washington.

The smaller average size of the double-tagged group may account for its lower survival rate in the seawater net-pens compared with

Table 20.--Survival of fish transferred to Manchester seawater net-pens as of August 1989. Probability value is derived from contingency table analysis and a Tukey HSD analysis is used to distinguish the grouping pattern.

Statistic	PIT tag	CW tag	PIT+CW tags
Number (%) alive	108 (66)	117 (71)	77 (46)
Number (%) dead	55 (34)	48 (29)	89 (54)

Chi square = 23.633

P = 0.001

Groupings: PIT cw PIT+CW

Table 21.--Mean fork length (mm) of fish transferred to Manchester seawater net-pens as of August 1989. The probability value is based on a one-way ANOVA.

Statistic	PIT tag	CW tag	PIT+CW tags
Number	108	115	77
Mean length	160.2	159.3	157.0
SD	14.0	14.3	12.0

F (2, 297) = 1.275

P = 0.281

those of the single-tagged groups. Premature seawater entry of all groups may have also contributed to their reduced seawater survival. Zaugg and McLain (1972) reported that larger coho salmon have higher Na^+ and K^+ ATPase-stimulated activity than smaller members of their cohort. Mahnken et al. (1982) observed that the survival of smaller fish is lower than that of larger fish in seawater-challenge tests. In a review of the literature on the physiological adaptation for life in seawater, McCormick and Saunders (1987) noted that smaller coho salmon are less salinity tolerant than larger coho salmon. Hreha (1967) observed that within a season, smaller coho salmon migrated later than larger members of their cohort. Recently, Matthews and Ishida (1989) observed that smaller coho salmon had lower survival than larger coho salmon when released into Coos Bay, Oregon and challenged to return as adults.

Another possible explanation for the poorer survival in seawater net-pens of the group with both tags is their possession of two tags. The low number of jacks returning in 1989 provided insufficient data to determine the effects of the three treatments on the marine survival, age of maturity, or growth of coho salmon.

Juvenile PIT-Tag Monitors at Lower Granite, Little Goose, and McNary Dams: Systems Description and Reliability

Introduction

During 1988, the electronics in the monitoring systems were modified to improve tag-reading efficiency and system reliability. The systems used prior to 1989 are described in Prentice et al. (1984, 1985, 1986, 1987, 1990b). In 1989, the Lower Granite Dam PIT-tag monitoring facility was also modified to accommodate a prototype PIT-tag diversion system (Matthews et al. 1990, and some test results presented in another section of this report). During the 1989 field season, prototype PIT-tag monitoring equipment that incorporated the modifications was operated under field conditions in the Columbia River Basin at Lower Granite, Little Goose, and McNary Dams (Fig. 4). These new systems were evaluated for reliability of the systems and tag-reading efficiencies using direct and indirect methods. In this paper, we describe the new systems and report on their reliability; in the next section, we cover their tag-reading efficiencies.

Methods and Materials

<u>Lower Granite Dam</u>--One PIT-tag monitoring site was located at Lower Granite Dam on the Snake River approximately 54 km downstream from Clarkston, Washington (Fig. 4). Here six PIT-tag monitoring systems were installed in the discharge flumes and pipes of the juvenile fish and debris separator (Fig. 5). The A-Main and B-Main monitors each consisted of two adjacent, independent dual-coil assemblies measuring 15.2-cm high by 45.7-cm wide by 122-cm long. The

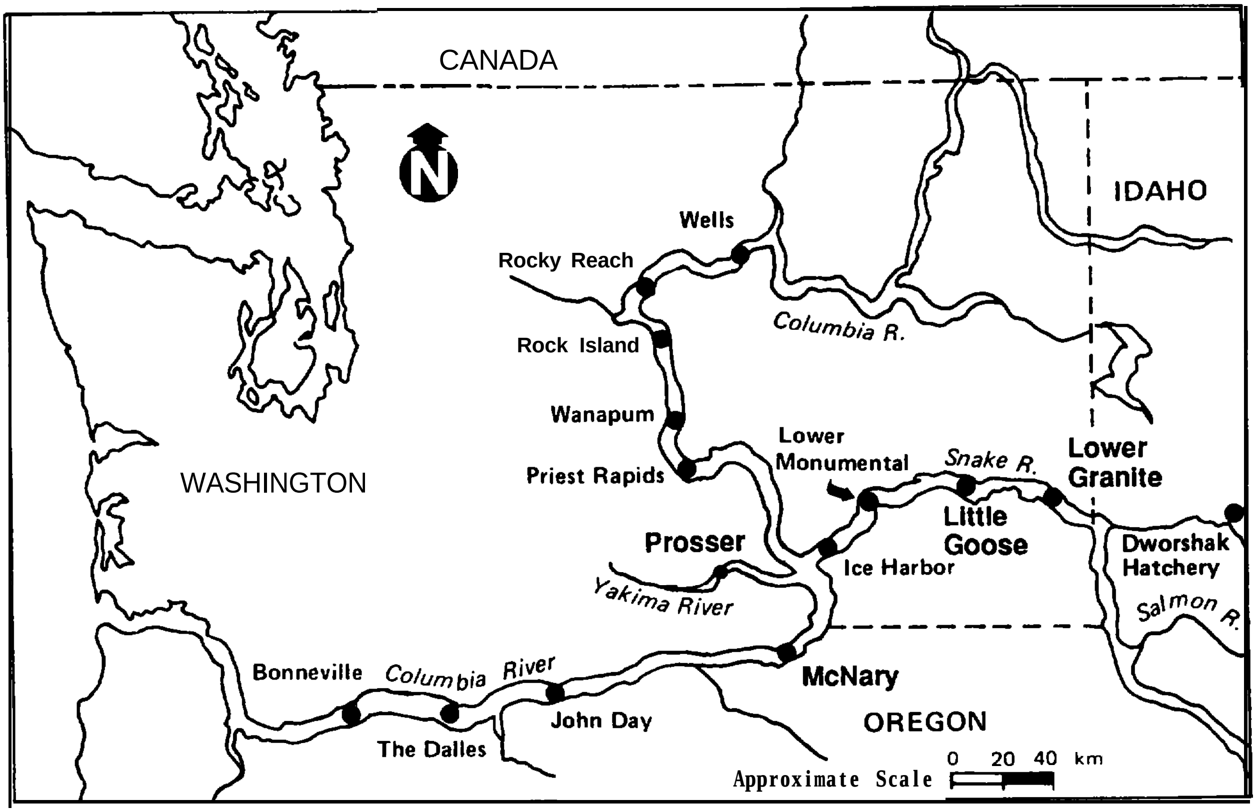

Figure 4. --Major hydroelectric facilities within the Columbia River Basin.

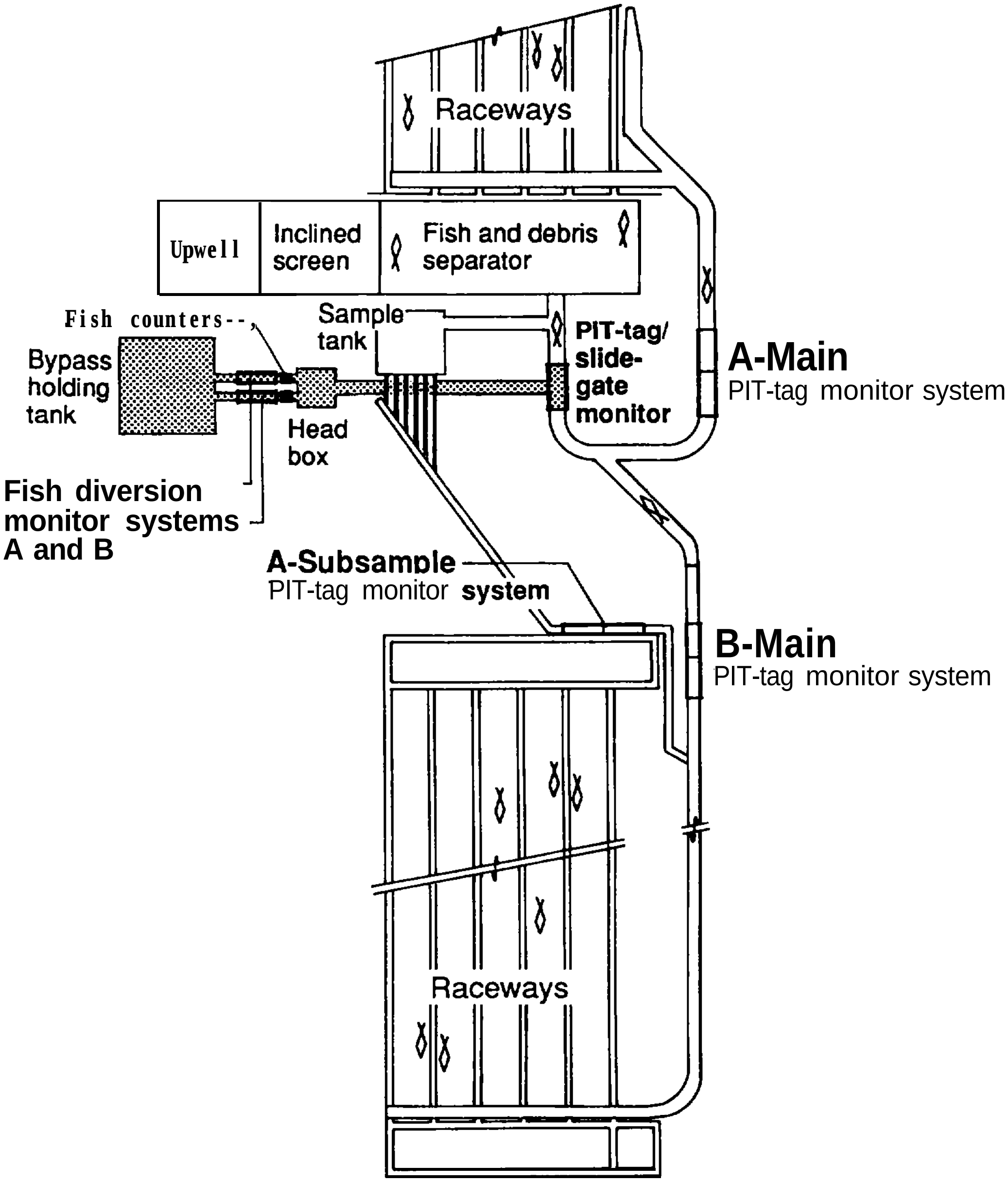

Figure 5.--Juvenile salmon PIT-tag monitoring systems at Lower Granite Dam, 1989. The shaded portion indicates the fish diversion system.

A-Subsample monitor consisted of two adjacent, independent dual-coil assemblies that measure 25.4-cm in diameter by 150-cm in length. Combined, these three systems monitored all exiting fish. When it became operational, the fish entered the fourth system, a prototype PIT-tag monitor system that controlled a slide gate which separated (diverted) PIT-tagged from untagged fish (Fig. 5). This PIT-tag monitor consisted of a single dual-coil assembly similar in measurement to those of the A- and B-Main assemblies. Any diverted tagged fish were then reinterrogated by two, independent three-coil monitors measuring 10 cm in diameter by 150 cm in length (diversion monitor systems A and B).[1]

For monitoring returning adult salmon, two PIT-tag monitoring systems (A and B) are located at Lower Granite Dam (Fig. 6). As with the juvenile monitoring systems, all returning fish pass through these monitors. Each of these adult monitoring systems consisted of two dual-coil monitors measuring 31 cm in diameter by 122 cm in length. These systems were installed in a test section of the fish ladder downstream from the coded-wire tag detection equipment.

Little Goose Dam--A second PIT-tag monitoring site was located at Little Goose Dam on the Snake River approximately 90 km downstream from Clarkston, Washington (Fig. 4). At the Little Goose facility, there were also six (A through F) monitoring systems (Fig. 7). Each consisted of dual-coil PIT-tag monitors that measured 10 cm in diameter

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[1] No further discussion of the prototype diversion system will be provided in this report since both the biological and technical evaluations of the system are discussed in a separate report prepared by Matthews et al. (1990).

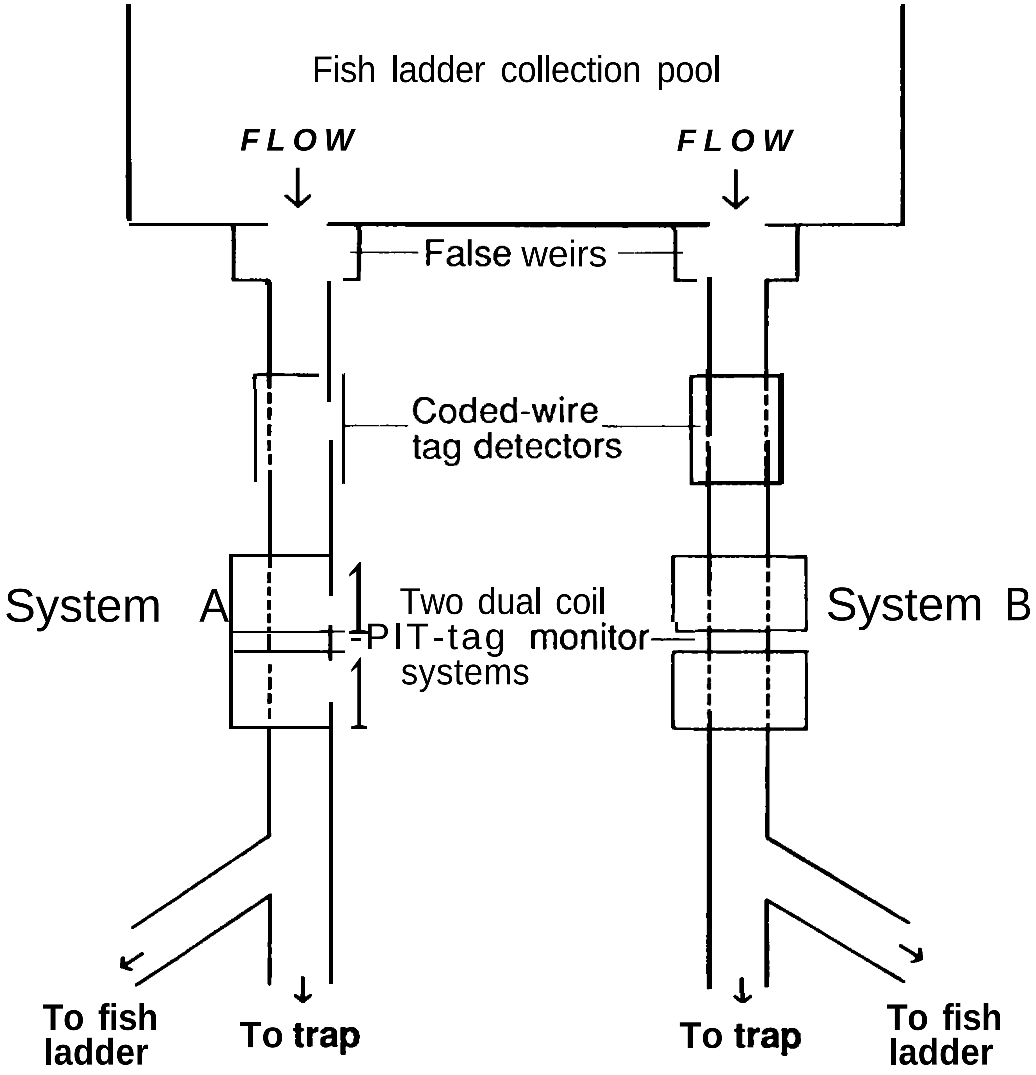

Figure 6.--Adult salmon PIT-tag monitoring systems at Lower Granite Dam, 1989.

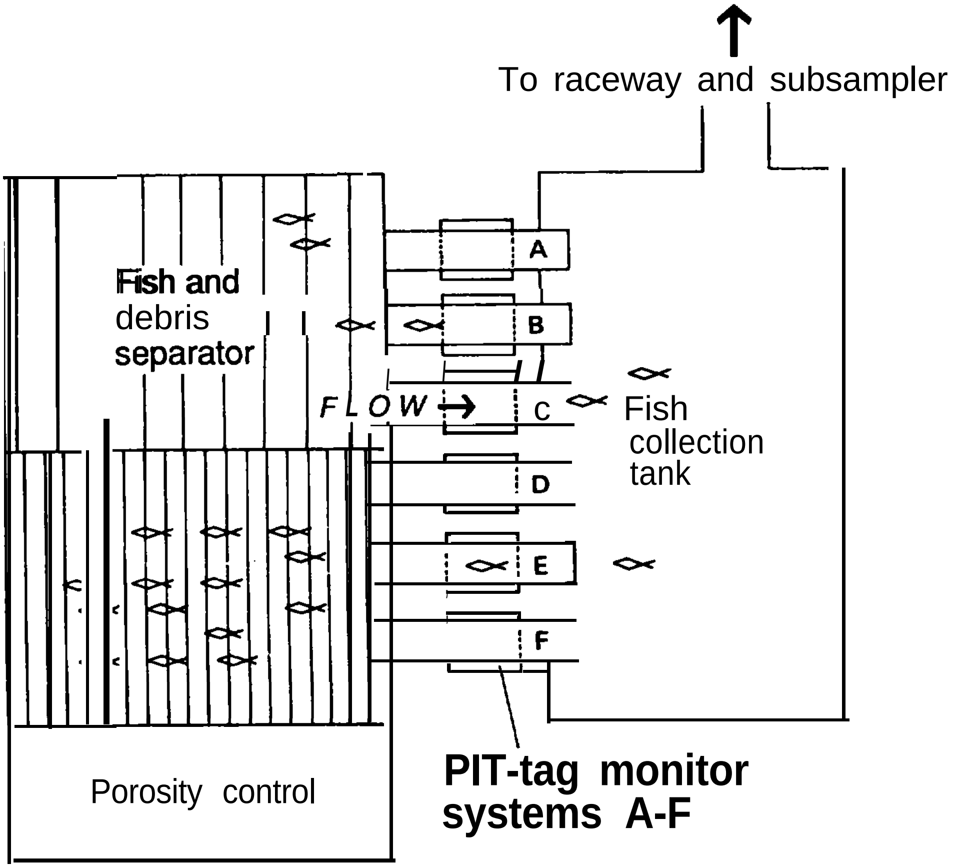

Figure 7.--Juvenile salmon PIT-tag monitoring systems at Little Goose Dam, 1989.

by 91 cm in length and are attached to the exit orifices of the fish and debris separator. A Smith-Root' model 1100 fish-counter assembly was located between the two coils of each PIT-tag monitor. Each fish counter assembly recorded the total number of fish (both tagged and untagged) passing out of each fish and debris separator orifice. The fish counts are used by the U.S. Army Corps of Engineers (COE) to determine total fish passage and raceway loading density, and are not directly associated with the PIT-tag monitoring system.

McNary Dam--The third monitoring site was located at McNary Dam on the Columbia River near Umatilla, Oregon (Fig. 4). Three PIT-tag monitoring systems were installed in the discharge flumes of the juvenile fish and debris separator (Fig. 8). Each of the A-Main, B-Main, and A-Subsample monitors had two adjacent, independent dual-coil assemblies;' they measured 15.2-cm high by 122-cm long by 25.4-cm, 35.5-cm, and 45.7-cm wide, respectively.

Monitoring systems--All PIT-tag monitors used at dams are constructed with the following: 1) an aluminum shield to control errant radio emissions and to provide weather protection for electronic components, 2) two or three tag excitation/detection coils, 3) a dual power-filter, 4) a tuner for each coil within the shield box, and 5) a dual air- or water-cooled exciter housed within a shielded box.

The monitoring system at each site was divided into two independent subsystems to provide backup in case of component failure. A typical monitoring system included an instrument building that housed

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*Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA

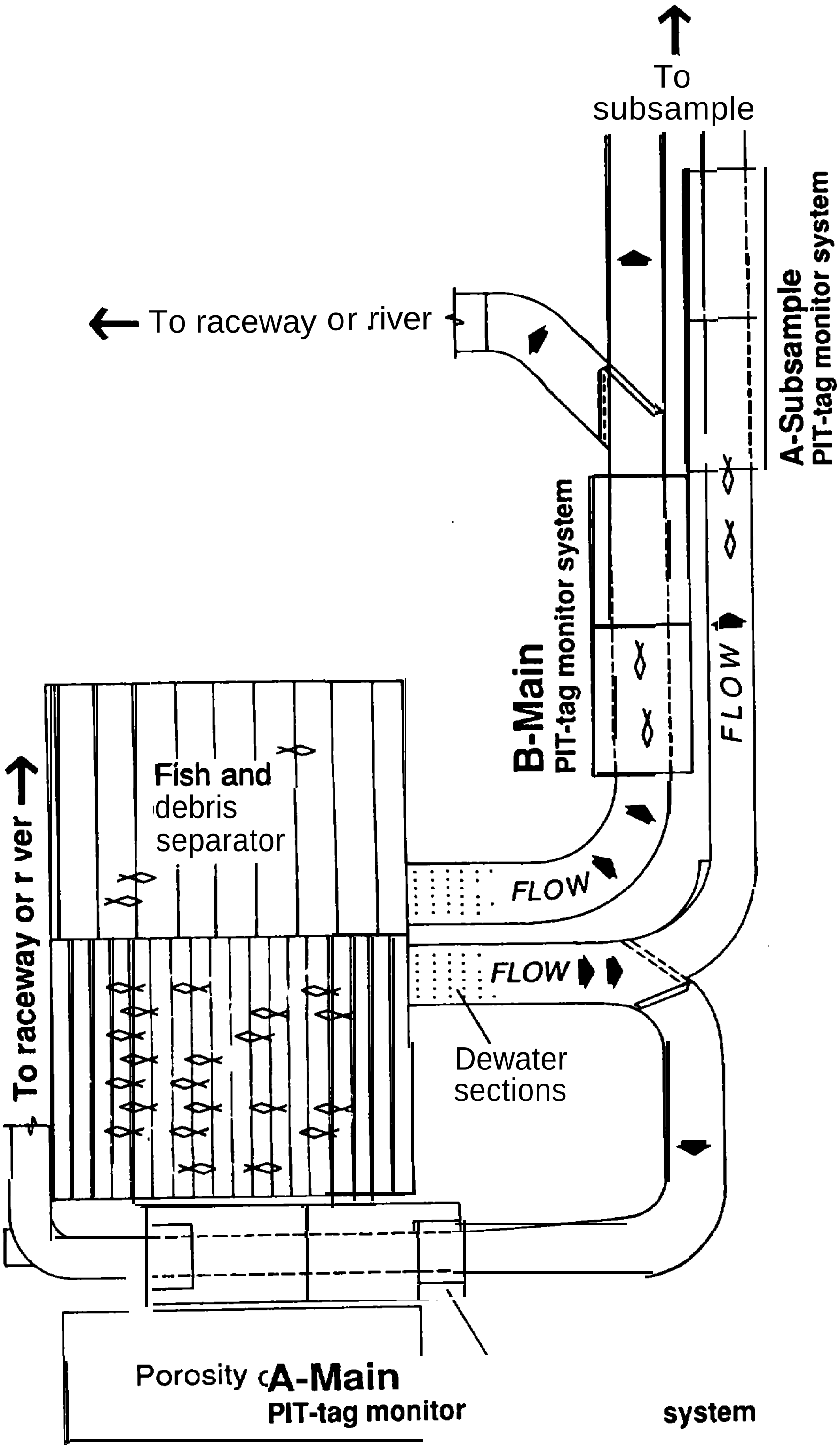

Figure 8.--Juvenile salmon PIT-tag monitoring systems at McNary Dam, 1989.

all the electronic equipment except for the exciters, coil tuners, power and signal filters, and monitor coils (Fig. 9). These buildings contained heaters and air conditioners to provide stable temperatures for the instruments. Power to the instrument building was supplied through a 15-kW isolation transformer. All computers and controllers were powered through a battery backup system.

Each dual-coil monitor had its own double-exciter power supply. One or two power supplies were connected to a voltage spike suppressor on a 20-amp circuit breaker. The exciters of upstream and downstream monitors were connected to separate controller units and printers. The subsystems were connected to a computer through a multiport and were on separate electrical circuits.

The monitoring systems were operated continuously during the field season to evaluate the operational longevity of the electronic components. The juvenile monitoring systems at Lower Granite Dam operated from 6 April to 27 July, at Little Goose Dam from 4 April to 10 July, and at McNary Dam from 24 March to 20 September 1989. The adult system at Lower Granite Dam was operated from 9 March to 7 August and from 23 August to 1 December 1989.

Results and Discussion

Reliabilitv of PIT-taq monitors--The monitoring equipment performed satisfactorily during the 1989 field season. Human operation error was the main factor that caused lost data, down time, or other problems (Table 22). Several incidents occurred during the field season at the Lower Granite Dam juvenile PIT-tag monitoring facility

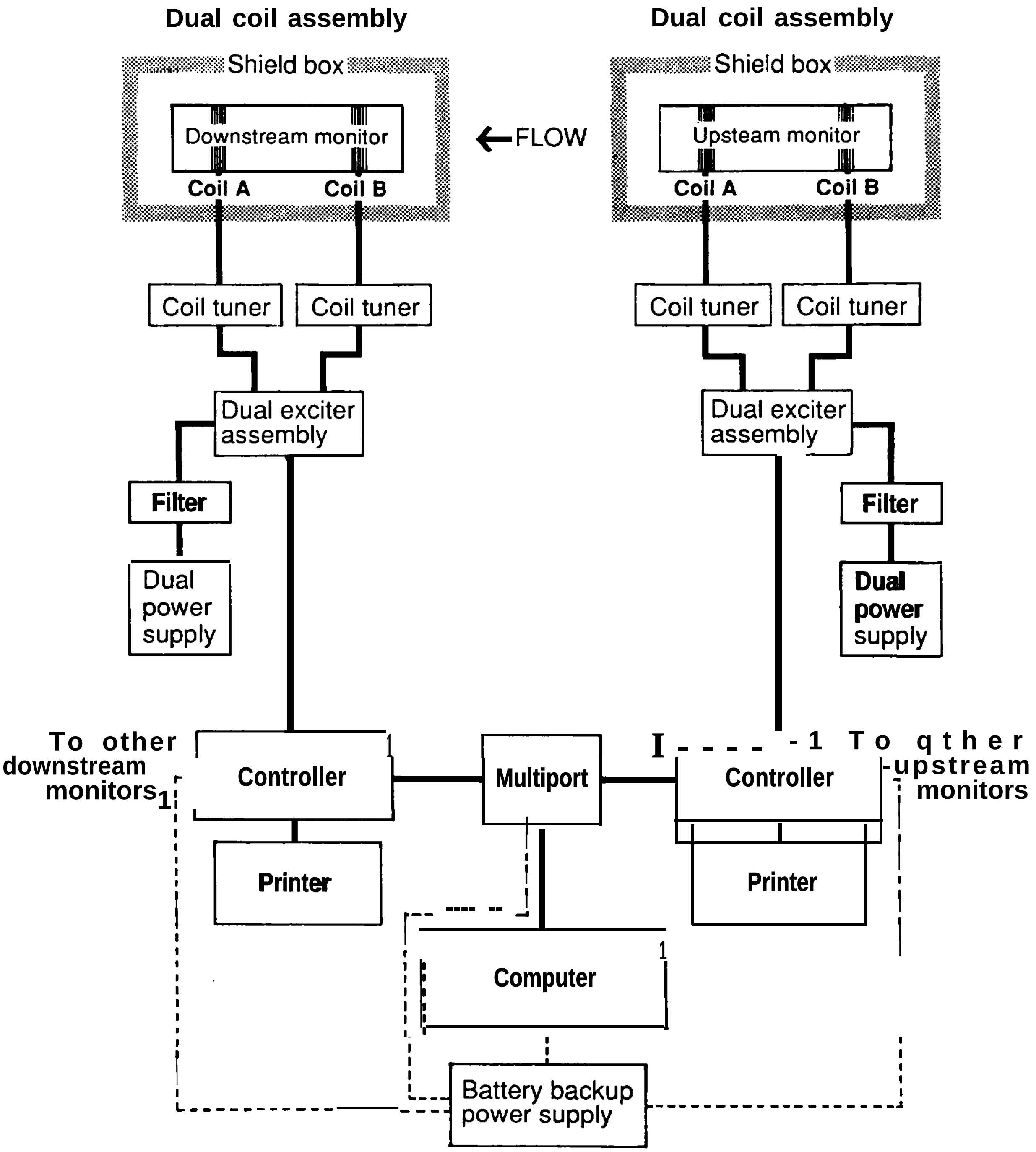

Figure 9.--PIT-tag monitoring systems at Columbia and Snake River dams, 1989.

Table 22.--Major events occurring at PIT-tag monitors in the Columbia River Basin, 1989.

Monitor Site	Date	Event
Lower Granite Dam (Juvenile facility)	25 Mar	System started.
	15 Apr	Computer power supply failed but no data were lost. The unit was replaced on 16 April.
	26 Apr	Two power supplies inadvertently turned off. Approximately 1 hour of data, from 1925 PST to 2032 PST, were lost.
	24 May	Air conditioning power interrupted. One computer failed because of excessive temperature. Other computer functioning properly. Reader cards for coils 28 and 3A failed-others check OK. Data were lost for 16 hours.
	25 May	Replaced failed computer and reader cards.
	26 May	Controller was accidentally left off after testing. No data lost.
	28 May	Multiport failed and replaced the same day. This failure is thought to be associated with the event of 24 May (high heat).
	27 Jul	Shut down system.
Lower Granite Dam (Adult facility)	9 Mar	Started system
	3 May	Problems with communication software. Monitor program and data OK.
	10 May	Reference tag indicated reader card OC weak. Replaced card OC.
	7 Aug	Adult trap shut down.
	22 Aug	Adult trap restarted.
	5 Sep	Computer hung up. No data lost.
	1 Dec	Shut down Adult system.
Little Goose Dam	4 Apr	Started system.
	6-7 May	Multiplexer became disconnected from the computer. Data entered by hand from hard copy.
	18 May	Changed exciter board 5A and replaced 5A/58 power supply.
	25 May	Replaced burned connector on 5A/58 exciter.
	1 Jun	Rebalanced coils 5A/58.
	10 Jul	Shut system down.

Table 22.--Continued.

Monitor Site	Date	Event
McNary Dam	24 Mar	System started up.
	27 Mar	Replaced reader card on coil 64.
	30 Mar	Replaced exciter board for B-Main downstream coils.
	29 Apr	Replaced exciter board on coil 68 and rebalanced system.
	14 May	Adjusted tuning on B-Main coils.
	18 May	Checked and adjusted entire system.
	20 May	Replaced reader card on coil 64.
	21 May	Replaced exciter board on coil 64.
	27 May	Air conditioner iced up. Temperature reached 36°C. No apparent damage to system.
	30 May	Replaced RF filters for coils 64 and 66.
	7 Jun	Replaced tuner on B-Main coil 66 and returned coil.
	23 Jun	Replaced tuner on coil 68.
	19 Jul	Returned coil 68.
	9 Aug	Replaced reader card on coil 74.
	20 Sep	Shut down system.

(Table 22). The first occurred when the computer's internal power supply malfunctioned. A spare computer was installed the following day. Because the data were recorded on a computer and on a printer file, no data were lost. On 26 April, two power supplies were inadvertently left off after testing. This error resulted in data being lost between the hours of 1925 and 2032. A third incident occurred at Lower Granite Dam when the master electrical breaker was tripped by an air conditioner in another building and 16 hours of data were lost. Future repetitions of this type of failure were avoided by moving the electrical supply for the PIT-tag monitoring system to an independent circuit. A fourth incident occurred when a switch for the downstream controllers was accidentally turned off. Because the monitors at the dam were configured into two completely, independent subsystems (upstream and downstream), no data were lost. The final event was the failure of a multiport. This failure is believed to be related to the excessive heat caused when the air conditioning system was shut off. Data were manually entered from the printed files and consequently no data were lost.

The adult PIT-tag monitoring system at Lower Granite Dam and the juvenile monitoring system at Little Goose Dam functioned throughout the season and required only minor periodic adjustments (Table 22).

The major problem encountered at the McNary Dam PIT-tag facility was the repeated failure of exciter units controlling the B-Main monitoring system (Table 22). Failures occurred on four separate occasions, but never simultaneously in both the upstream and downstream monitors. No explanation can be offered as to why this system caused problems.

To further improve the monitor system's overall reliability, we suggest the following measures be implemented for the 1990 field season. First, because human error is the major cause of system failure, all system operators should be required to complete a check list prior to leaving an instrument room. This will force the operator to confirm that all equipment is in the operating mode. Second, we suggest that back-up electrical components for all equipment be stored in the instrument room at each monitoring site. This will decrease the time needed to repair equipment that fails.

Juvenile PIT-Tag Monitors at Lower Granite, Little Goose, and McNary Dams: PIT-Tag Reading Efficiency Evaluated by Direct and Indirect Methods

Introduction

Probably the most accurate method for determining PIT-tag monitor reading efficiency is to introduce a known number of tagged fish directly upstream from the monitoring system. The tag-reading efficiency can then be obtained directly by comparing the number of fish released to the number observed. In 1985, PIT-tag monitors at McNary Dam were evaluated for their efficiency in detecting tagged juveniles using this method (Prentice et al. 1986). In this evaluation, tagged fish were released directly into the upwells of the fish and debris separator which is located upstream from the PIT-tag monitors. Results showed 97.1% of the yearling chinook salmon and 92.5% of the subyearling chinook salmon were detected.

In 1986, a PIT-tag monitoring system was installed and evaluated at Lower Granite Dam, and the system at McNary Dam was reevaluated (Prentice et al. 1987). Although a system was installed at Little Goose Dam, no evaluation was done that year. As in the 1985 test, both evaluations used live fish. Results at Lower Granite Dam showed a 98.5% reading efficiency for yearling chinook salmon and 98.7% for steelhead. At McNary Dam, 96.5, 99.0, and 96.0% of the yearling chinook salmon, subyearling chinook salmon, and steelhead, respectively, were detected.

Since 1986, the electronic equipment has been upgraded at all the monitoring sites to increase system efficiency and reliability.

Therefore, throughout the field season in 1989, system operational status and tag-reading efficiency of all PIT-tag monitoring systems on the Columbia and Snake Rivers were determined using two direct methods and an indirect statistical method.

Methods and Materials

First direct method--The first direct method involved the release of a known number of PIT-tagged fish directly into the fish and debris separator at each dam. The number of tagged fish detected was then compared to the number released. Fish for tagging were removed from a subsample of fish passing through the collection system of the dam being evaluated. Only fish having limited scale loss and no previous marks, tags, or injuries were used. The fish were PIT-tagged by the method described in Prentice et al. (1987, 199Oc). Twelve test groups of 39 to 60 fish were tagged and measured to the nearest 1 mm (fork length) for each species at Lower Granite and Little Goose Dams; at McNary Dam, 13 test groups were established for each species (Table 23). Length data were taken following standard Columbia Basin, PIT-tagging protocol (Pacific States Marine Fisheries Commission 1991); however, they were not used in this study. Each test group was held in a covered 132-1 portable container having flow-through aerated ambient-temperature river water.

The fish were held for 24 hours and then released directly into the upwells of the fish and debris separators. Prior to release, each group was examined for tag loss and mortality. All mortalities were replaced with fish from the 12th or 13th group of fish. The individual

Table 23.-- PIT-tag monitor reading efficiencies (percent) based upon the first direct method of calculation (tagged fish) at three hydroelectric dams in 1989.

	Lower Granite Dam						Little Goose Dam					
	Chinook yearling (21-22 April)			Steelhead (2 May)			Chinook yearling (9-10 May)			Steelhead (11-12 May)		
	Release	Numbers		Release	Numbers		Release	Numbers		Release	Numbers	
Group	time	Out	Obs[a]	time	Out	Obs	time	Out	Obs	time	Out	Obs
1	1600	40	40	1000	40	39	659	40	38	604	40	40
2	1630	40	40	1030	40	39	729	40	39	634	40	39
3	1700	40	37	1100	40	40	759	39	39	704	40	39
4	1730	40	39	1130	40	40	a29	40	39	734	39	38
5	1800	39	37	1200	40	40	a59	40	39	804	40	39
6	1830	40	39	1230	40	39	929	40	37	a34	40	40
7	1900	39	35	1300	40	40	959	40	39	904	40	40
a	1930	40	36	1330	40	40	1029	40	37	934	40	40
9	2000	40	31	1400	40	40	1059	40	35	1004	40	40
10	2030	40	35	1430	40	39	1129	39	37	1034	40	40
11	2100	40	34	1500	40	40	1159	42	41	1104	40	40
12[b]	2130	51	44	1530	59	59	1229	41	39	1134	60	60
Totals (N = 11)		438	403		440	436		440	420		439	435
Percent		92.0			99.1			95.5			99.1	

	McNary Dam								
	Chinook yearling (17 May)			Steelhead (24-25 May)			Chinook subyearling (14-15 June)		
	Release	Numbers		Release	Numbers		Release	Numbers	
Group	time	Out	Obs	time	Out	Obs	time	Out	Obs
1	700	40	40	700	40	39	710	39	39
2	730	40	38	730	40	40	730	40	39
3	800	41	41	800	40	40	800	40	38
4	830	40	39	a30	40	37	a30	40	38
5	900	40	40	900	40	40	900	40	40
6	930	40	40	930	40	39	930	40	38
7	1000	40	39	1000	40	40	1000	39	39
a	1030	40	40	1030	40	40	1030	40	40
9	1100	40	40	1100	40	39	1100	38	37
10	1130	40	37	1130	40	37	1130	40	38
11	1200	40	40	1200	40	40	1200	40	40
12[b]	1230	40	40	1230	40	39	1230	40	37
13[b]	1231	12	12	1231	20	20	1231	la	17
Totals (N = 11)		441	434		440	431		436	426
Percent		98.4			98.0			97.7	

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[a] Out = Number of tagged fish released; Obs = Number of tagged fish observed.

[b] Fish group released and interrogated, but not used in statistical evaluation.

PIT-tag code and length of the replacement fish were substituted for the removed mortalities. Fish remaining in groups 12 and 13 were not used in the statistical evaluations, but were released. Groups were released at 30-minute intervals until all were placed into the fish and debris separator.

All fish were allowed to pass through the fish and debris separator on their own volition. Following their exit from the fish and debris separator, fish were passively interrogated for tag presence. Upon detection of a PIT-tagged fish, the code of each PIT tag, monitor, and detection coil position, time of passage (day, hour, minute, and second), and date of passage (month, day, and year) were recorded into a computer and onto a printer file. Reading efficiency was compared within test groups with a one sample t-test. An acceptable detection efficiency of 95% or better was established. The observed efficiency rates were also compared to estimated probabilities for missing PIT tags.

The percent tag-reading efficiency for each release group and the overall system efficiency were calculated by dividing the number of tags observed from a single release (or total releases) by the number released and then multiplying by 100.

Three PIT-tag monitoring sites were evaluated for tag-reading efficiency in 1989: Lower Granite, Little Goose, and McNary Dams (Figs. 4, 5, 7, and 8). Two tests were conducted at Lower Granite Dam: yearling chinook salmon were evaluated on 21 and 22 April and steelhead were evaluated on 2 May. The B-Main monitors at Lower Granite Dam were not used during the evaluation period since insufficient numbers of fish were passing through the collection system to warrant the use of the additional fish-holding area offered by the upper set of raceways (Fig. 5). Two tests were conducted at Little Goose Dam: yearling chinook salmon were evaluated on 9 and 10 May and steelhead were evaluated on 11 and 12 May. Three tests were conducted at McNary Dam: yearling chinook salmon on 17 May, steelhead on 24 and 25 May, and subyearling chinook salmon on 14 and 15 June 1989.

Second direct method--This direct method used a series of reference tags that were passed through a monitoring system. Periodically, juvenile PIT-tag monitors were evaluated using this method by repeatedly passing a plastic tube containing PIT tags through the monitors. The adult monitoring system at Lower Granite Dam was also checked similarly: reference tags embedded in wooden blocks were passed through the system. In all cases, the number of tags detected was compared to the number that actually passed through the system. These tests helped confirm the proper operation of the electronic equipment.

Indirect method--Daily, for each dam, system status was determined using statistical analysis on data collected previously. The pattern of PIT-tag recordings at each coil of a monitor was used to determine whether a monitor needed adjustment. Then combining the coil-read information, the statistical probability of missing a fish was calculated for each monitor and for the entire system. (A detailed description of the method is presented in Appendix B.) For the statistical program to run an accurate analysis, the data needed to meet certain criteria. Optimally, data must be collected from a minimum of 15 fish passing through the system the day before. If fewer than 15 fish per day passed through a monitor system, then data for more than 1 day were combined. The program then used these data to calculate the overall system's tag-reading efficiency and each coil's efficiency. If these were below 95% or 50%, respectively, then adjustments were made to the monitoring system.

Results and Discussion

First direct method--Of the 3,455 fish tagged, 3,352 were detected, yielding an overall detection efficiency of 97.0% for all three monitoring sites (Table 24). PIT-tag reading efficiencies for individual systems ranged from 92.0 to 99.1% in tests conducted using the direct method of calculation (Tables 23-25; Fig. 10). With the exception of the yearling chinook salmon at Lower Granite Dam, all the group mean observations exceeded 95%. Following the yearling chinook salmon tests at Lower Granite Dam, it was noticed that a gate in the fish and debris separator was ajar, allowing some fish to bypass the PIT-tag monitoring system and directly enter the river. The number of tags from this inadvertent release that were subsequently observed at Little Goose and McNary Dams supports the conclusion that fish were bypassing the monitoring systems at Lower Granite Dam (Table 24). In addition, of the fish tagged for the Lower Granite Dam release and subsequently interrogated at Little Goose or McNary Dams, none had been recorded on the Lower Granite monitoring system. This inadvertent bypass of fish resulted in a lower than expected PIT-tag reading efficiency for the yearling chinook salmon (92.0%) at Lower Granite

Table 24.--Numbers of PIT-tagged fish released into the fish monitor and debris separators and subsequently observed at three hydroelectric dams.

	Lower Granite Dam		Little Goose Dam		McNary Dam		
	Yearling chinook	Steelhead	Yearling chinook	Steelhead	Yearling chinook	Steelhead	Subyearling chinook
Number of fish released	489	499	481	499	493	500	494
Observations at Lower Granite Dam	447	495					
Observations at Little Goose Dam	13	2	459	495	-		
Observations at McNary Dam	23	2	96	29	486	490	480

Overall efficiency of all releases immediately following initial release = 97%

Table 25.--The proportion of PIT-tagged juvenile chinook salmon and steelhead detected at three Columbia River Basin Dams following their release into the fish and debris separator as calculated using the direct method with tagged fish.

	Lower Granite Dam		Little Goose Dam	
Group	Chinook yearling (21-22 April)	Steelhead (2 May)	Chinook yearling (9-10 May)	Steelhead (11-12 May)
1	1.000	0.975	0.950	1.000
2	1.000	0.975	0.975	0.975
3	0.925	1.000	1.000	0.975
4	0.975	1.000	0.975	0.974
5	0.949	1.000	0.975	0.975
6	0.975	0.975	0.925	1.000
7	0.897	1.000	0.975	1.000
8	0.900	1.000	0.925	1.000
9	0.775	1.000	0.875	1.000
10	0.875	0.975	0.949	1.000
11	0.850	1.000	0.976	1.000
Mean	0.920	0.991	0.955	0.991
SD	0.070	0.013	0.035	0.013

	McNary Dam		
	Chinook yearling (17 May)	Steelhead (24-25 May)	Chinook subyearling (14-15 June)
1	1.000	0.975	1.000
2	0.950	1.000	0.975
3	1.000	1.000	0.950
4	0.975	0.925	0.950
5	1.000	1.000	1.000
6	1.000	0.975	0.950
7	0.975	1.000	1.000
8	1.000	1.000	1.000
9	1.000	0.975	0.974
10	0.925	0.925	0.950
11	1.000	1.000	1.000
Mean	0.984	0.980	0.977
SD	0.026	0.029	0.236

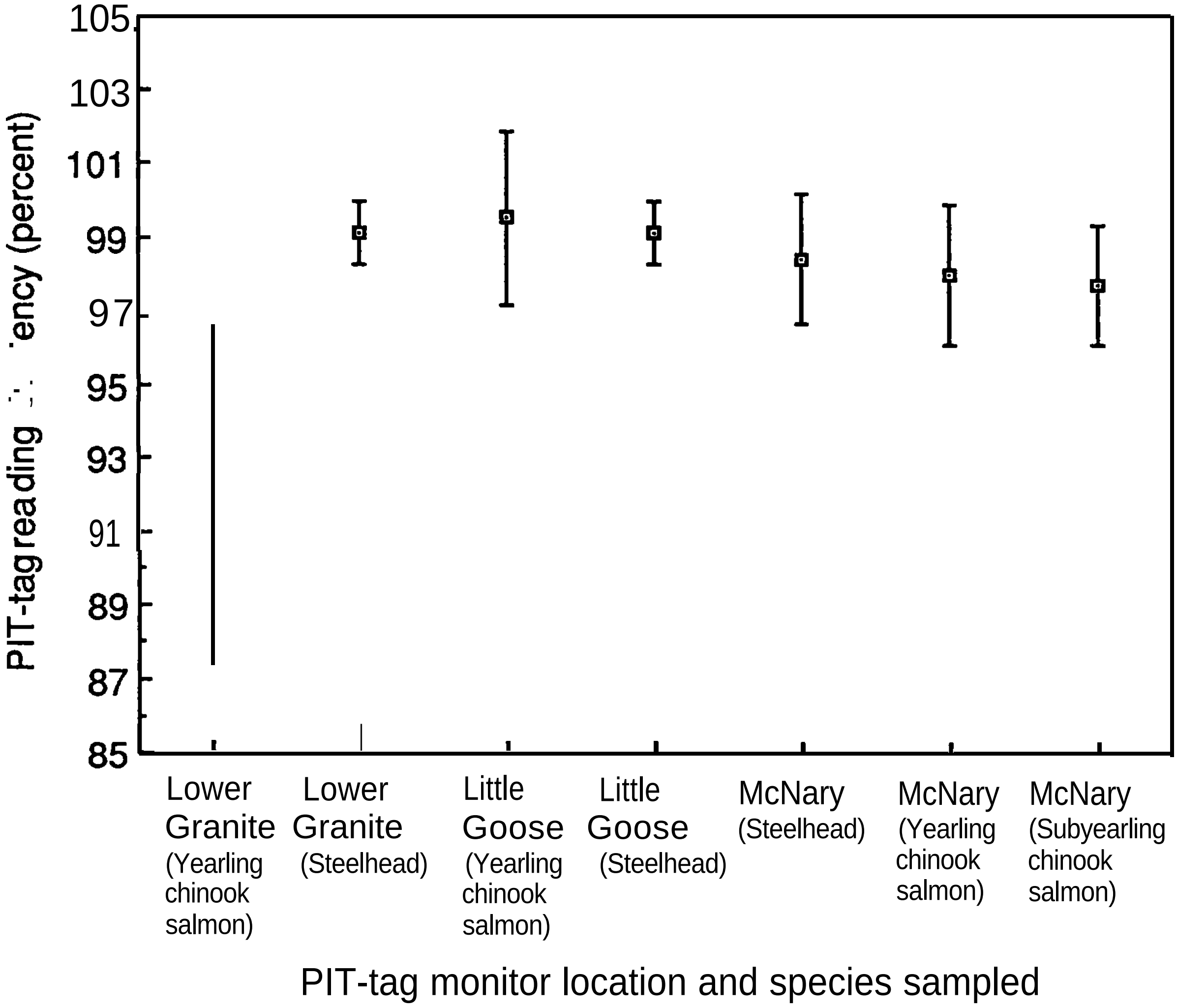

Figure 10.--Mean PIT-tag reading efficiencies for monitors at Columbia and Snake River dams, 1989 (95% confidence intervals shown by bars).

Dam. The gate problem was corrected by the COE prior to the steelhead study. The PIT-tag reading efficiency for steelhead was 99.1%.

At Little Goose Dam, tests with yearling chinook salmon and steelhead had 95.5 and 99.1% tag-reading efficiencies, respectively (Tables 23-25; Fig. 10).

Pit-tagged fish released at Little Goose Dam were observed not only at the dam of origin but also downstream at McNary Dam (Table 24). Generally, normal operating procedure of the juvenile collection facility is to collect and transport all juvenile salmonids exiting the fish and debris separator. However, under certain conditions the standard operating procedure requires the COE to redirect (bypass) certain species of salmonids back to the river rather than collect them for transport around the remaining hydroelectric dams. Fish are separated in the fish and debris separator automatically based solely on size (steelhead are normally much larger than the other species at the time of outmigration) and therefore any fish within a certain size category will be diverted regardless of species. This diversion process occurred during our tests and accounts for some PIT-tagged fish being interrogated at two sites.

PIT-tag reading efficiency was high at McNary Dam in all tests (Tables 23-25; Fig. 10). Direct reading efficiency was 98.4, 97.7, and 98.0% for yearling and subyearling chinook salmon and steelhead, respectively. No problems with the monitoring system were encountered during the evaluation period.

Second direct method-- This is a less expensive alternative to tagging individual fish, and results from tests conducted at Lower Granite Dam adult facility using reference tags showed that the system operated in a satisfactory manner. An example of data collected using this method is shown in Table 26. Care must be taken to get accurate results. Although it is more costly than using the indirect statistical method and cannot be done daily, it is the best method in cases where too few fish pass through the system for an accurate indirect statistical method.

Indirect method--The estimates of not reading (i.e., missing) a PIT tag passing through two dual-coil monitors (four coils total) using the indirect statistical method indicated a low probability for individual monitors to miss tags (Tables 27-33). The estimates tended to indicate a rate lower than the directly observed miss rate. In nearly all cases when the criterion of 95% tag-reading efficiency was not met, there were fewer than the 15-fish minimum needed for an accurate calculation of reading efficiency. For example, in the third release of yearling chinook salmon at Lower Granite Dam, the estimated probability of not reading a tag passing through bypass monitor A was 25% based on two fish (Table 27). This result demonstrates the need for caution when using the estimated value when N is low. On-site trials indicated that the estimate is usable if 15 or more fish pass through daily, or if data for more than 1 day are combined. The number of PIT-tags detected and the probability of not detecting a tag at the PIT-tag monitors for each day are presented in Tables l-3 of Appendix C.

Table 26.--Summary of the adult PIT-tag-read efficiencies at Lower Granite Dam using reference PIT tags, 1989.

	Monitor System A		Monitor System B	
Date	No. of reference tags	Percent detected	No. of reference tags	Percent detected
3/10	9	100	9	100
4/04	9	100	10	100
5/08	18	100	18	100
5/10	43	100	43	100
6/09	10	100	10	100
6/29	10	100	10	100
8/22	10	100	9	100
9/20	9	100	9	100
10/10	10	100	10	100
10/23	10	100	10	100
11/20	10	100	10	100

Table 27.-- PIT-tag reading efficiencies (given as probabilities of missing a PIT tag) were calculated using the indirect and direct methods for yearling chinook salmon at Lower Granite Dam in relation to the individual monitors.[a]

		Indirect statistical method											
		Diversion A		Diversion B		A Subsample		A Main		B Main		Direct method"	
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed'
1	1600	4	0.000	5	0.000	9	0.091	24	0.000	0	-	40	0.000
2	1630	4	0.000	4	0.000	9	1.176	26	0.000	0	-	40	0.000
3	1700	3	0.000	8	0.000	2	25.000	26	0.000	0	-	40	7.500
4	1730	1	0.000	8	0.000	6	0.000	24	0.000	0	-	40	2.500
5	1800	10	1.714	3	0.000	5	0.000	22	0.000	0	-	39	5.130
6	1830	5	0.000	3	0.000	6	0.154	26	0.000	0	-	40	2.500
7	1900	7	1.633	6	0.000	2	0.000	22	0.000	0	-	39	10.260
8	1930	4	0.000	3	0.000	6	0.000	23	0.000	0	-	40	10.000
9	2000	0	-	0	-	5	0.640	26	0.000	0	-	40	22.500
10	2030	0	-	0	-	9	0.784	26	0.005	0	-	40	12.500
11	2100	0	-	0	-	8	0.000	26	0.000	0	-	40	15.000

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Low reading efficiency resulted from a gate within the fish and debris separator being ajar which allowed tagged fish to bypass all PIT-tag monitors.

[c] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 28.--PIT-tag reading efficiencies (given as probabilities of missing a PIT tag) were calculated using the indirect and direct methods for steelhead at Lower Granite Dam in relation to the individual monitors."

		Indirect statistical method										Direct method[b]	
		Diversion A		Diversion B		A Subsample		A Main		B Main			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed
1	1000	0		0	-	4	0.000	34	0.094	0	-	40	2.500
2	1030	0	-	0	-	2	0.000	36	0.091	0	-	40	2.500
3	1100	0	-	0	-	3	0.000	37	0.038	0	-	40	0.000
4	1130	38	0.000	0	-	1	0.000	38	0.053	0	-	40	0.000
5	1200	36	0.000	0	-	2	0.000	38	0.035	0	-	40	0.000
6	1230	37	0.337	0	-	2	0.000	36	0.068	0	-	40	2.500
7	1300	40	0.000	0’	-	0		38	0.123	0	-	40	0.000
8	1330	35	1.515	2	0.000	1	0.000	37	0.000	0	-	40	0.000
9	1400	38	0.000	0	-	1	0.000	38	0.294	0	-	40	0.000
10	1430	25	0.000	1	0.000	3	0.000	35	0.064	0	-	40	2.500
11	1500	33	0.000	1	0.000	1	0.000	37	0.148	0	-	40	0.000

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[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 29.--PIT-tag reading efficiencies (given as probabilities of missing a PIT tag) were calculated using the indirect and direct methods for yearling chinook salmon at Little Goose Dam in relation to the individual monitors."

		Indirect statistical method												Direct method	
		Monitor A		Monitor B		Monitor C		Monitor D		Monitor E		Monitor F			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed[b]
1	659	9	0.000	9	6.250	8	2.041	6	0.000	1	0.000	5	16.667	40	5.000
2	729	13	1.515	5	0.000	8	2.041	4	0.000	3	0.000	6	0.000	40	2.500
3	759	13	0.000	6	0.000	6	0.000	3	0.000	4	0.000	7	0.000	39	0.000
4	829	10	0.000	4	0.000	5	0.000	6	0.000	3	0.000	11	3.750	40	2.500
5	859	6	0.000	9	0.000	10	1.235	8	4.762	1	0.000	5	0.000	40	2.500
6	929	5	0.000	8	0.000	8	0.000	9	0.000	3	0.000	4	0.000	40	7.500
7	959	9	0.000	5	6.250	13	1.515	8	0.000	1	0.000	3	0.000	40	2.500
8	1029	9	0.000	7	0.000	9	0.000	5	0.000	2	0.000	5	6.250	40	7.500
9	1059	12	0.000	9	0.000	3	0.000	7	6.667	1	0.000	3	0.000	40	12.500
10	1129	13	0.000	7	0.000	4	0.000	4	11.111	2	0.000	7	0.000	39	5.130
11	1159	12	0.000	8	0.000	5	0.000	5	0.000	6	0.000	5	0.000	42	2.380

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 30.--PIT-tag reading efficiencies (given as probabilities of missing a PIT tag) were calculated using the indirect and direct method for steelhead at Little Goose Dam in relation to the individual monitors.*

		Indirect statistical method												Direct method	
		Monitor A		Monitor B		Monitor C		Monitor D		Monitor E		Monitor F			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed[b]
1	604	4	0.000	4	0.000	0	-	12	0.000	4	0.000	16	0.952	40	0.000
2	634	3	0.000	6	0.000	0	-	15	0.000	7	0.000	8	0.000	40	2.500
3	704	2	0.000	1	0.000	2	0.000	13	0.000	11	0.000	10	0.000	40	2.500
4	734	0		0	-	1	0.000	8	0.000	8	0.000	21	1.176	39	2.560
5	804	2	0.000	0	-	2	0.000	15	0.000	8	0.000	12	0.000	40	2.500
6	834	0		0	-	0	-	14	0.000	9	0.000	17	0.000	40	0.000
7	904	2	0.000	2	0.000	0	-	11	0.000	11	0.000	14	0.000	40	0.000
8	934	1	0.000	0	-	0	-	12	0.826	10	0.000	17	0.000	40	0.000
9	1004	1	0.000	1	0.000	0	0.000	11	0.000	5	0.000	22	0.476	40	0.000
10	1034	1	0.000	3	0.000	0	-	13	0.000	5	0.000	18	0.000	40	0.000
11	1104	0		0	-	0	-	10	0.000	13	0.000	17	4.103	40	0.000

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 31.--PIT-tag reading efficiencies (given as the probabilities of missing a PIT tag) calculated using indirect and direct methods for yearling chinook salmon at McNary Dam in relation to the individual monitors."

		Indirect statistical method						Direct method	
		A Subsample		A Main		B Main			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed[b]
1	700	1	0.000	17	0.014	22	0.738	40	0.000
2	730	1	0.000	25	0.017	12	0.000	40	5.000
3	800	4	0.000	22	0.000	15	0.316	41	0.000
4	830	0	-	25	0.016	14	0.543	40	2.500
5	900	1	0.000	21	0.013	18	0.346	40	0.000
6	930	2	0.000	19	0.061	19	0.034	40	0.000
7	1000	2	0.000	18	0.058	20	1.901	40	2.500
8	1030	4	0.000	31	0.007	5	0.320	40	0.000
9	1100	1	0.000	33	0.010	6	0.000	40	0.000
10	1130	4	0.000	30	0.000	3	0.000	40	7.500
11	1200	3	0.000	33	0.065	4	1.563	40	0.000

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 32.--Estimated PIT-tag reading efficiency (given as the probabilities of missing a PIT tag) calculated using indirect and direct methods for sub-yearling chinook salmon at McNary Dam in relation to the individual monitors.[a]

		Indirect statistical method						Direct method	
		A Subsample		A Main		B Main			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed[b]
1	710	2	0.000	33	0.022	4	25.000	39	0.000
2	730	5	0.000	32	0.058	2	0.000	40	2.500
3	800	2	0.000	32	0.019	4	2.083	40	5.000
4	830	0		34	0.010	4	2.083	40	5.000
5	900	3	0.000	35	0.004	2	0.000	40	0.000
6	930	0		36	0.055	2	0.000	40	5.000
7	1000	0		36	0.031	3	0.000	39	0.000
8	1030	0	-	36	0.020	4	0.000	40	0.000
9	1100	0		31	0.000	6	4.000	38	2.630
10	1130	1	0.000	34	0.027	3	0.000	40	5.000
11	1200	1	0.000	36	0.023	3	0.000	40	0.000

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Table 33.--Estimated PIT-tag reading efficiency (given as the probabilities of missing a PIT tag) calculated using indirect and direct methods for steelhead at McNary Dam in relation to the individual monitors."

		Indirect statistical method						Direct method	
		A Subsample		A Main		B Main			
Group	Release time	N	Percent missed	N	Percent missed	N	Percent missed	N	Percent missed[b]
1	700	0		2	0.000	37	0.501	40	2.500
2	730	2	0.000	8	0.000	30	1.405	40	0.000
3	800	0		8	0.000	32	0.507	40	0.000
4	830	0		5	0.000	32	0.728	40	7.500
5	900	1	0.000	8	0.000	31	1.033	40	0.000
6	930	1	0.000	7	0.000	31	0.272	40	2.500
7	1000	0		9	0.000	31	0.286	40	0.000
8	1030	0		5	0.000	35	1.084	40	0.000
9	1100	2	0.000	12	0.069	25	0.350	40	2.500
10	1130	0		8	1.339	29	1.165	40	7.500
11	1200	0		9	0.000	31	0.043	40	0.000

[a] See Appendix B for formula to estimate the probability of not reading a PIT tag.

[b] Actual percent missed is equal to the absolute value of the number of tagged fish observed within a group divided by the number of fish released in a group times 100 (Table 24) minus 100.

Only six times during the field season were the calculated efficiencies less than 95% when adequate numbers of tagged fish were detected (Table 34). No reasons for the occurrences are immediately apparent for the five times at Little Goose Dam. The Little Goose Dam PIT-tag monitoring system is unlike other sites as there are only two tag-reading opportunities at each of the six monitors. Since only two coils are used for each monitor here instead of the normal four, the opportunity for a tag to be missed by one coil and still be detected by another coil is reduced, which then reduces the accuracy of the coil-efficiency calculation. However, if one combines the overall performance of the six monitors for any given day, tag-reading efficiency standards are met on all occasions. For the one occasion at McNary Dam (27 May), it is suspected that when the air conditioner was tripped off, the high heat caused the controllers within the instrument room to partially malfunction and thus their reading efficiencies were reduced (Table 34).

The indirect statistical method for determining tag-reading efficiency could not be conducted at Lower Granite Dam adult facility because too few fish passed through the system on a daily basis.

In conclusion, releasing tagged fish into the fish and debris separator is probably the most accurate direct method for evaluating the overall system operation and tag-reading ability. However, the problems associated with tagging and handling fish make it impractical to rely routinely on this method. The results obtained from the indirect method of calculating monitor tag-reading efficiency indicate that the accuracy of the probability formula increases both as the

Table 34.--Dates on which the juvenile PIT-tag monitor systems at each site did not meet the 95% reading efficiency criterion using the indirect statistical method in 1989.

Site	Monitor	Date	Cause
Little Goose Dam	A	2 May	Unknown
	E	18 April	Unknown
	F	12 May	Unknown
	F	18 May	Unknown
	F	30 May	Unknown
McNary Dam	A Subsample	18 May	Air conditioner

number of tagged fish passing and the number of coils passed is increased. The chances of missing a tagged fish are significantly reduced in systems having four or more coils. In addition to yielding good estimates of system (individual monitor) performance, the indirect method can be done daily at minimal cost. When too few fish pass, the most economical way to check the system is to use embedded reference tags.

Through daily calculation of individual monitor-reading performances (using the indirect method) for each monitor at a dam, an indication of tag-reading problems (such as electrical problems) can be determined at any site. This diagnostic procedure will enable technical personnel to identify problems in a timely manner, and thus aid in maintaining system reliability and accuracy.

Summary, Conclusions, and Recommendations for the Field Studies

The Effects of the Geometric, Electromagnetic, and Light Properties of PIT-Tag Passageways on Chinook Salmon Smolt Movement

1. Significantly fewer smolts chose passage through the tube-shaped passageways than through a square-bottomed, three-sided channel. In addition, these smolts exhibited longer passage times and traveled in smaller "schools" than fish passing through the channel. However, only tube-shaped monitors can presently be used to interrogate volitionally moving salmon. Thus, it is important for investigators to realize that the tunnels impact fish migration.
2. The light properties of the passageways affected fish passage: more fish passed through white tubes than through transparent tubes, and light intensity appeared to be more important than material hue.
3. The presence of the 400-kHz electromagnetic field needed to energize PIT-tags had no affect on passageway preference, passage time, or passage "school" size.
4. Based on our findings, we recommend illuminated open-channel PIT-tag detectors be developed and evaluated for use in monitoring the volitional movements of chinook salmon smolts.

A Comparison of the Marine Survival, Maturation Strategies, Growth, and Tag Retention of Coho Salmon Tagged with PIT or Coded-Wire Tags

1. The three main treatment groups (PIT-tagged only, CW-tagged only, and fish tagged with both PIT and CW tags) were tagged and then combined with the main hatchery population set for release in June 1989. The sampling design inadvertently resulted in the two-tag treatment fish being an average 0.5-mm shorter than either of the other two treatments.
2. In April 1989, a subsample of the study fish were transferred to the Manchester seawater net-pens. In August, the survival of fish in the two-tag group was found to be significantly lower than either of the single-tag fish. The two single-tag groups of fish had comparable survival.
3. Tag retention was nearly 100% when the fish were checked more than a month after tagging. After seven months, tag failure was 1 and 2% for PIT and CW tags, respectively.
4. Only six jacks returned in the fall of 1989, and there were no significant differences among return rates for the three treatments.

Juvenile PIT-Tag Monitors at Lower Granite, Little Goose, and McNary Dams: Systems Description and Reliability

1. The text contains a description of the monitoring sites and systems at Lower Granite, Little Goose, and McNary Dams.
2. Generally, the systems at all the dams were reliable and only 17 hours of data were lost. Human operator error was the main factor that caused lost data, down time, or other problems during 1989 at Lower Granite Dam. At McNary Dam, repeated electronic malfunction of exciter units contributed to the interruption of normal PIT-tag monitoring.

Juvenile PIT-Tag Monitors at Lower Granite, Little Goose, and McNary Dams: PIT-Tag Reading Efficiency Evaluated by Direct and Indirect Methods

1. The release of a known number of PIT-tagged fish directly into the fish and debris separator at each dam was used as the first direct method for determining tag-reading efficiencies. When the number of tagged fish detected was compared to the number released at the various monitoring sites, the overall detection efficiency was 97.0%.
   a. PIT-tag monitor reading efficiency at Lower Granite Dam was 92.0 and 99.1% for yearling chinook salmon and steelhead respectively. A gate in the fish and debris separator was found ajar that allowed the chinook salmon to bypass the PIT-tag monitor system and directly enter the river, and thereby lower the reading efficiency.

b. At Little Goose Dam, PIT-tag monitor reading efficiencies were 95.5 and 99.1% for chinook salmon and steelhead, respectively.

c. At McNary Dam, PIT-tag monitor reading efficiencies were 98.4, 97.7, and 98.0% for yearling and subyearling chinook salmon and steelhead, respectively.

2. The second direct method used a series of reference tags that were passed through a monitoring system. The number of tags detected was compared to the number that actually passed through the system. These tests were conducted periodically throughout the field season to help confirm the proper operation of the electronic equipment. This method was found to be less expensive than using tagged live fish and the best method when too few fish passed for the indirect method to be used.

3. An indirect statistical method for determining system operational status and tag-reading efficiency was used daily in 1989. The pattern of PIT-tag recordings at each coil of a monitor was used to determine whether a monitor required adjustment. Then combining the coil-read information, the statistical probability of missing a fish was calculated for each monitor and for the entire system. Whenever these were below 95 or 50%, respectively, then adjustments were made to the monitoring system. Most of the days when the indirect statistical method indicated less than 95% tag-reading efficiency, there were fewer than the 15-fish daily minimum needed for an accurate calculation of reading efficiency.

In only six cases was the calculated efficiency less than 95% when adequate numbers of tagged fish were detected. The five times at Little Goose Dam are probably due to the unique two-coil monitoring system because if one combines the overall performance of all six monitors for any given day, then tag-reading efficiency standards were met on all occasions. The one occasion at McNary Dam (27 May) was probably due to computer malfunctioning caused by high heat.

4. Releasing tagged fish into the fish and debris separator is probably the most accurate direct method for evaluating the overall system operation and tag-reading ability. The problems associated with tagging and handling fish, however, make it impractical to rely upon this method on a routine basis. We thus recommend that the detection efficiency of all monitor systems be calculated using the indirect statistical method, which can be done daily at minimal cost. The information will aid technical personnel to identify PIT-tag monitor problems in a timely manner.

SYSTEMS DEVELOPMENT

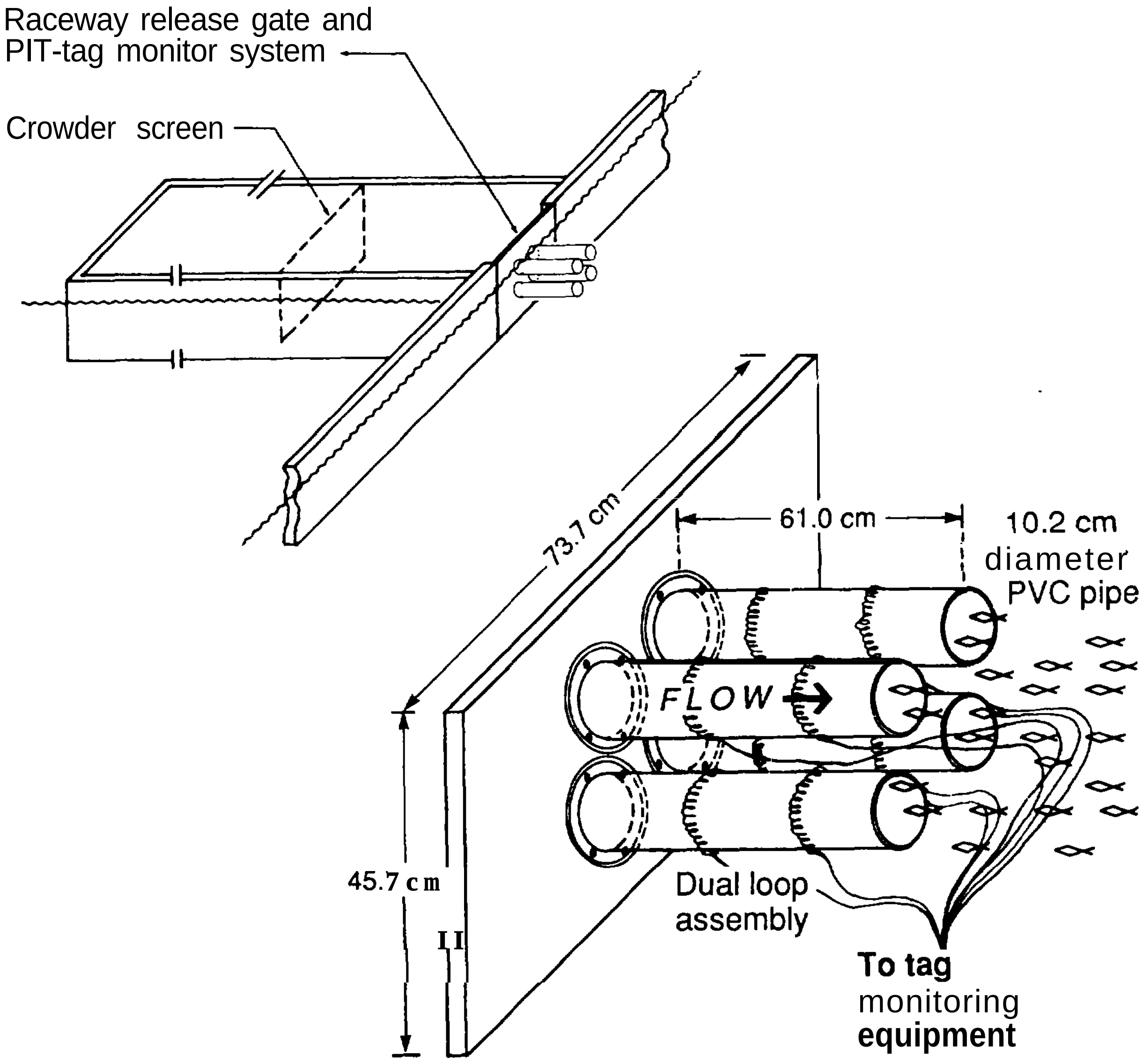
Development of Hatchery and Fish Pump PIT-Tag Monitoring Systems

Introduction

Mortality and tag loss can occur between the time fish are tagged and their subsequent release from the hatchery. In some studies, it is essential to know the identification of each fish at the time of release. One method of obtaining such information is to interrogate fish automatically for PIT tags as they are released from a hatchery or loaded into (or released from) a transport vehicle. This is challenging because the highest concentration of tagged fish will occur under these conditions which makes monitoring using present methods ineffective. Therefore, a new system needs to be designed that will rapidly monitor fish without stressing them, prevent tag-reading errors, and have a high tag-reading efficiency (over 95%).

In 1986, we began testing prototype hatchery-release monitors at Dworshak National Fish Hatchery (Prentice et al. 1987). The first system consisted of a battery of four, dual-coil PIT-tag monitors that were placed in a raceway exit (Fig. 11). Fish passed through the monitors at the time of release. The results were encouraging, but problems in the design were observed. Specifically, control over the rate of fish passage through the monitors was lacking and preferences for particular monitors were noted.

More studies were conducted in 1987 and 1988 (unpublished data) to address these specific problems. The tests were conducted at the NMFS Pasco Field Station and at the WDF Lyons Ferry Fish Hatchery. The



PIT-tag monitoring equipment

Description	Number
Dual power supplies	4
Exciter assemblies	4
Controllers	2
Multiport	1
Computer	1
Printers	2

Figure 11.--Hatchery PIT-tag monitoring system.

tests evaluated the tag-reading efficiency of dual-coil PIT-tag monitors alone or in tandem, attached at the raceway exit. In addition, PIT-tag monitors that measured 10 or 15 cm in diameter and were attached to the discharge of a fish pump were evaluated. The tag-reading efficiency for the single monitor was generally below 90%, while the tandem system averaged about 93%. A low percentage (<1%) tag-reading error was observed in the above tests.

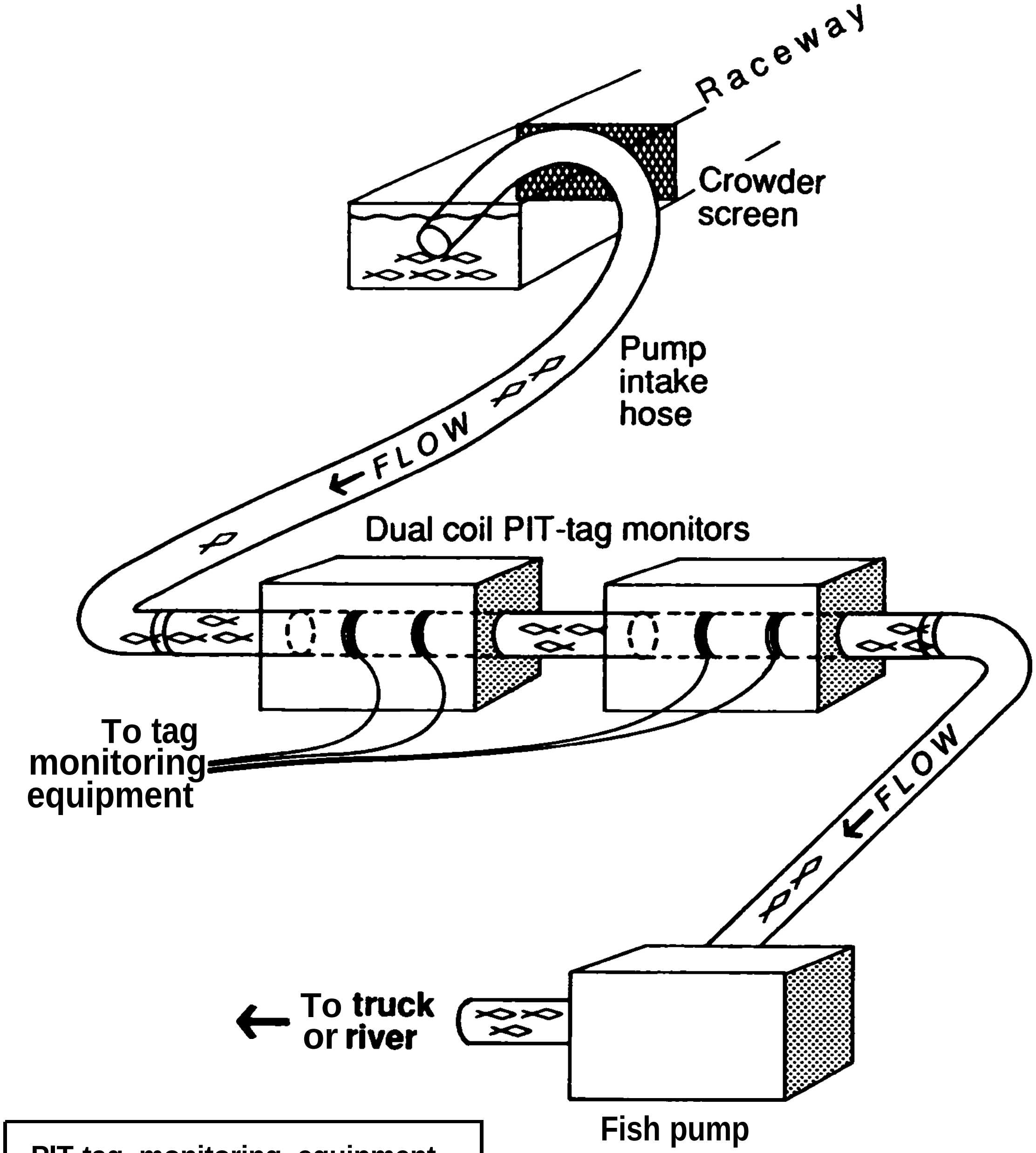
To reduce the error rate, tests were conducted with the above monitoring systems both with single- and double-read firmware within the tag-reader/code processor. The tag-reader/code processor is also referred to as a controller (see Prentice et al. 1990b for the description and operation of the controller). Using the single-read firmware, the tag-code sequence transmitted from the tag to the controller is directly processed without needing verification before acceptance. This is in contrast to the double-read firmware, where a tag-code sequence is verified by comparing two code sequences before acceptance.

Tag-reading efficiency was significantly better with the single-read firmware than with the double-read firmware. Although the tag-code error rate was lower for the double-read system than for the single-read system, it was concluded that fish pass much too quickly through this type of PIT-tag monitoring system to use the double-read firmware. This was substantiated by the higher number of total tags missed using the double-read firmware.

In final analysis, the above studies showed that one of the main limiting factors affecting the tag-reading efficiency of both the hatchery and fish-pump PIT-tag monitors was tag-reading speed. The problem was addressed by the NMFS Electronics Shop in cooperation with an instrument manufacturer. The above single-read firmware that controls the processing of the tag code was further modified to reduce code-processing time and should result in a controller able to process more tag codes over a unit of time. A series of tests were conducted to determine whether the new, faster, single-read, controller firmware would overcome problems encountered with the older firmware. The system was evaluated in the field using a fish-pump PIT-tag monitoring system.

Methods and Materials

Field evaluation of the new firmware took place in April 1989 at the Dworshak National Fish Hatchery. Juvenile chinook salmon from four raceways were pumped through two dual-coil, PIT-tag monitors (15-cm diameter by 122-cm length) placed in tandem, into a raceway bypass that leads to Clearwater River (Fig. 12). The fish were previously tagged as part of a different study using the method described in Prentice et al. (1990c). The monitors were positioned on the intake side of a standard fish pump. The monitoring equipment was similar to that described by Prentice et al. (1987), except for the modified controller firmware. Fish were crowded into the pump's intake using standard techniques developed for pumping fish. For each trial, the number of fish, time to interrogate the fish, and tag-reading efficiency were recorded (Table 34).



PIT-tag monitoring equipment

Description	Number
Dual power supplies	4
Exciter assemblies	4
Controllers	2
Multiport	1
Computer	1
Printers	2

Figure 12.--Diagram of a PIT-tag monitoring system connected to a fish pump.

Results and Discussion

The results show that tag-reading efficiencies were generally 95% or better (Table 35). Whether a 20- to 35-minute evacuation time for a raceway is acceptable to hatchery managers has not yet been examined. It is possible that the raceway evacuation time could be reduced if one additional dual-coil monitor were incorporated into the system. This modification could possibly reduce the evacuation time by 5 to 10 minutes; however, it would increase the size and expense of the system.

The exception to the 95% or greater reading efficiency was Trial 2, which was evacuated in 35 minutes and had a 90.1% reading efficiency (Table 35). Based upon the evacuation time, we would have expected a reading efficiency of over 95%. One possible explanation for the low reading efficiency in this trial is an observed high initial tag loss by the fish used. This observation was made on fish being held in transport containers immediately after tagging and prior to being transported to the hatchery raceway. This tag loss may have continued during the holding period prior to release.

We have concluded from the results of this and previous studies (Prentice et al. 1987) that it is practical to interrogate PIT-tagged fish successfully while they are pumped at high rates. Using the same firmware as in the pump tests, a hatchery release monitor should give acceptable results since fish movement through a hatchery monitor is normally slower than that in the pump system tested. However, with either system it is advisable to control the rate at which fish enter the monitoring system. Even with the fast firmware installed in the

Table 35.--Fish pump PIT-tag monitor study results.

Trial	Number of fish	Number of tagged fish[a]	Evacuation time (minutes)	Tag reading group (%)
1	35,986	2,265	23	95.5
2[b]	38,073	2,296	35	90.1
3	38,410	2,334	33	95.9
4	39,081	2,364	37	96.8

[a] The number of tagged fish has been corrected for mortalities.

[b] This group had a known high initial tag loss. The tag loss probably continued during the holding period prior to release, thus reducing the effective number of tagged fish available to be monitored.

controller, two PIT-tagged fish present simultaneously within the same monitor coil could not be read.

We also recommend, when feasible, that two dual-coil, PIT-tag monitors placed in tandem be used in either a pump or hatchery-release monitoring system. The tandem system will provide backup in case of a system failure. This is especially true if they are operated by separate controllers. The tandem monitors will also increase tag-reading efficiency two ways. First, it is less probable that two tagged fish will remain side-by-side during their passage through a series of independent monitoring coils than through a single coil, and therefore the probability of reading the tag is increased as more monitoring coils are added. Second, the probability of reading a tag is increased as more monitoring coils are added to the system. The disadvantage of adding more monitoring coils to the system is that the cost and size of the system increases.

Future PIT-Tag Monitoring Systems

Introduction

Development of PIT-tag systems for the Columbia River Basin was continued in 1989. The projects varied in scope, complexity, purpose, time to completion, and cost. A brief description of the developmental projects follows.

Extended-Range PIT-Tag Monitor for Adult Salmon

At present, PIT-tag monitors used at dams can detect tags within an 18-cm radius. This range is sufficient to monitor both juvenile salmonids exiting a fish and debris separator and adult salmon passing through a Denil fish ladder. However, modifications to the present PIT-tag monitoring system may be possible that would extend the interrogation range. By extending the detection range of the system from an 18-cm radius to a 30-cm radius, the underwater orifice or the viewing and counting window at a fish ladder might be monitored. Such an extended-range monitoring system should enable investigators to monitor 100% of PIT-tagged adult salmon passing through the fish ladder using special underwater orifices. As with existing PIT-tag interrogation systems, the time, date, location, and unique tag code of each PIT-tagged salmon would be automatically recorded without handling the fish or delaying its passage.

To achieve this objective, a research and development contract was issued to Destron-Identification Devices Inc. (D/IDI), the manufacturer of the PIT tag and tag-interrogation equipment presently used in the Columbia River Basin. D/ID1 worked closely with the NMFS Electronics Shop to develop an improved system.

The improved system was initially tested in 1989 at the NMFS Pasco Field Station. Problems encountered in the development and testing of the system included: 1) meeting Federal Communications Commission (FCC) requirements (because of its increased power, the system has the potential to produce too much radio-frequency interference); 2) equipment overheating; 3) creating sufficient signal amplification; and 4) electronic noise. After several electronic changes are made to the system, it will be further tested from a technical standpoint in 1990. Due to the complexity of the problems associated with this project, we do not believe a system for actual evaluation with fish will be available until 1993.

Lower Granite Dam PIT-Tag Diversion System

PIT-tagged fish are now processed at juvenile collection facilities in the same manner as all other fish. However, because PIT-tagged fish are electronically monitored, they could be diverted mechanically into special holding areas or back into the river. If the tagged fish are returned to the river (e.g., below Lower Granite Dam), they could subsequently be reinterrogated at downstream PIT-tag monitoring sites. This diversion can be accomplished without handling the fish while recording time, date, and location of individual fish as they pass through a juvenile collection facility.

With this objective in mind, a prototype PIT-tag diversion or separation system was designed, constructed, and evaluated at the NMFS

Pasco Field Station in 1988. This system, in part, simulated the flume dimensions and hydraulic conditions of the fish and debris separator system at Lower Granite Dam. The prototype diversion system design permitted the number of PIT-tagged fish in the test population to be selected (from all or zero to every eighth fish) and allowed some control over the activation time and length of time that the diversion system remained open.

Three types of fish diversion systems--flip gate, sliding bottom flume, and rolling vinyl diverter--were evaluated from both biological and technical standpoints. Our criteria for acceptable operation of the system included high mechanical reliability (99%) and high efficiency in diverting PIT-tagged fish (95%). In addition, the system could not injure the fish nor cause delays in their passage through the system.

Based upon the results of the 1988 Pasco tests, a PIT-tag diversion system was constructed and installed at Lower Granite Dam in the spring of 1989 (Figs. 5 (shaded area) and 13). This system was installed off the flume just beyond the exit port of the fish and debris separator within the fish collection facility at the dam. The first part of this system consisted of a dual-coil PIT-tag monitor (slide-gate monitor) just upstream of a slide gate, which was mounted within the bottom of the flume. The slide-gate monitoring system was of the same design and operation as those described in Prentice et al. (1990b). The slide-gate monitoring system was connected to custom-made electronics that controlled the operation of the hydraulically activated slide gate. The length of time the slide gate remained open

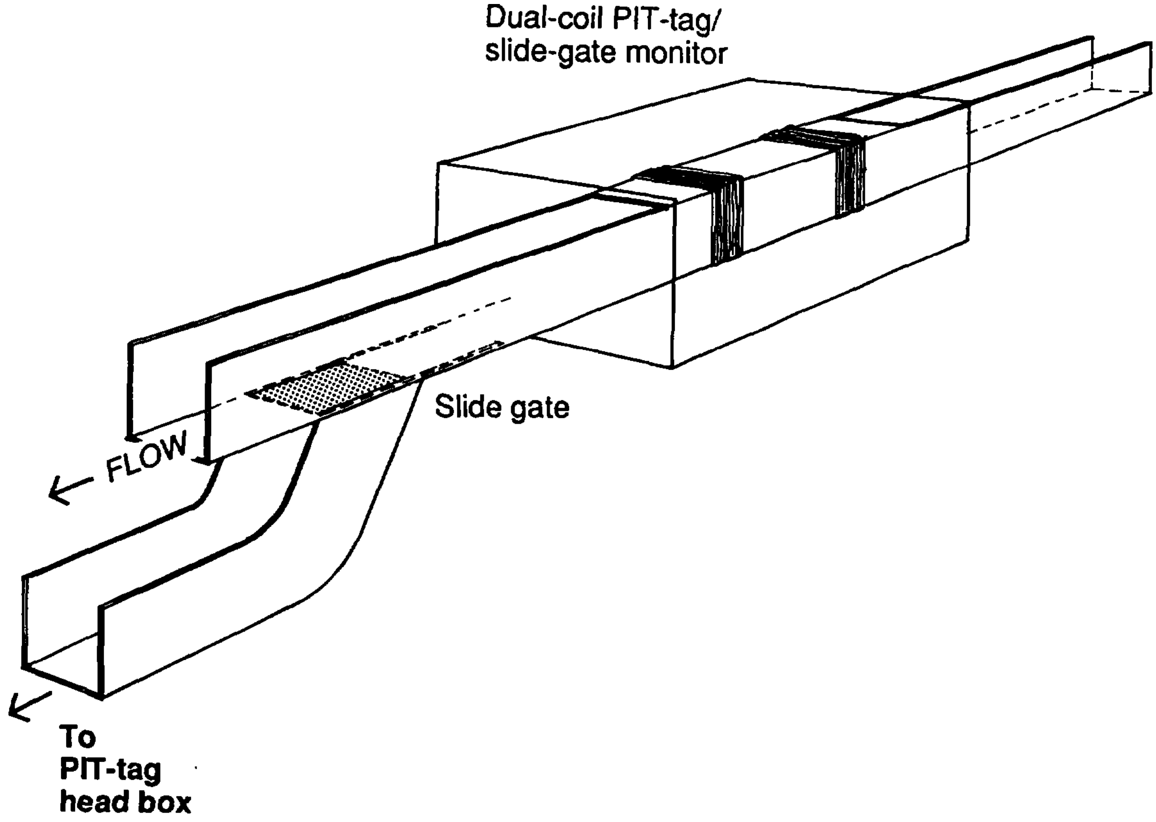


Figure 13.--PIT-tag detection and fish-diversion system at Lower Granite Dam, 1989.

and the speed that it moved were set according to the velocity of water in the flume (1 to 3 m/second). PIT-tagged fish passing through an open (activated) slide gate dropped into a second flume located below the primary flume that led to a common PIT-tag head box (Fig. 5). After remaining open for a predetermined time, the slide gate closed in the same direction and at the same velocity as the water flow. From the PIT-tag head box, the PIT-tagged fish and any incidental untagged fish moved in pipes through Smith-Root electronic fish counters, a second set of PIT-tag monitors (fish diversion monitor systems A and B), and into a partitioned bypass holding tank for inspection (Fig. 5).

Biological and mechanical evaluation of the system at Lower Granite Dam is discussed in detail by Matthews et al. (1990). They identified several problems with the prototype system that need to be modified before the system will perform as designed. Water-flow problems were identified as having the greatest adverse effect on the system's operation. Slow water-flow enabled strong-swimming fish to reenter the slide-gate entrance from the downstream side of the slide gate when it was opened, or remain in the area of the slide gate while it was open. This intrusion of untagged fish reduced the effectiveness of the separation between fish, and therefore reduced reading accuracy.

Fish descaling and injuries from the prototype system at Lower Granite Dam were also documented in Matthews et al. (1990). The primary causes of fish descaling and injury resulted from fish reentering or remaining in the slide-gate area and from the reexamination of fish in the collection tank. Descaling and injury attributable to the separation system varied from 2.7 to 5.9% depending on the species. Mortality caused by the system ranged from 0.1% for spring/summer chinook salmon to 3.2% for steelhead.

The system's efficiency at separating PIT-tagged from untagged fish was about half of the theoretical value for a given fish density (Matthews et al. 1990). The system was more efficient at separating tagged from untagged fish when smaller numbers of fish were present. For instance, the separation ratio (number of untagged fish diverted per PIT-tagged fish) varied from 0.7 to 2.5 depending upon the number of fish passing through a flume (<5,000 to 15,000 fish per hour, respectively).

It was concluded by Matthews et al. (1990) that in spite of the initial problems, the system showed great promise, and it should be further evaluated after making the suggested modifications. Modifications to the system will be made prior to the 1990 field season and the system reevaluated during fish outmigration.

Little Goose Dam Pit-Tag Monitoring and Diversion System

A new fish collection facility with a standard PIT-tag monitoring system similar to the one at McNary Dam is scheduled for 1990 at Little Goose Dam. The electronic equipment required for this PIT-tag monitoring system will come primarily from the PIT-tag detection system at the dam. However, this system will be modified and other equipment added in anticipation of unique requirements for this new facility.

A PIT-tag diversion system (similar to the one described above for Lower Granite Dam) has been requested for use at Little Goose Dam by the Fish Passage Advisory Committee and by several NMFS investigators. The proposed system will incorporate some of the modifications suggested by the fishery agencies, other modifications recommended following the test results from the Lower Granite Dam PIT-tag diversion system, as well as those dictated by site characteristics. The design will be available to the appropriate agencies for review prior to making the final design decisions. Scheduling indicates the diversion system will be retrofitted to the new fish collection facility at Little Goose Dam in the early 1990s.

Bonneville Dam Fish Collection and PIT-Tag Monitoring System

Bonneville Dam is approximately 61 km east of Portland, Oregon on the Columbia River (Fig. 4). Bonneville's First Powerhouse and spillway are on the south side of the river, while the Second Powerhouse is on the north side of the river.

In the powerhouses, upstream from the turbines, juvenile salmon are intercepted and diverted away from the turbines through a traveling screen system and into a fish bypass system. The fish are returned to the river downstream through flumes or pipes. At both powerhouses, there are facilities for sampling the diverted fish prior to their reentry to the river. The sampling is done to read brands, obtain counts, and to examine individual fish to determine species composition and physical condition. These sampling data are essential for monitoring the effectiveness and status of the bypass system and for many biological studies. These sampling facilities, however, have not proven to be totally satisfactory from either biological or datagathering standpoints. Furthermore, the facilities are not presently designed to detect PIT-tagged fish.

In light of these shortcomings, new sampling and fish interrogation facilities are being planned for both powerhouses at Bonneville Dam. A contract was issued to a private engineering firm to develop several concepts for construction and/or modification of the existing sampling and interrogation facilities at each powerhouse. Concept designs are scheduled for completion in 1991.

Summary, Conclusions, and Recommendations for Systems Development

Development of Hatchery and Fish Pump PIT-Tag Monitoring Systems

1. The results showed that tag-reading efficiencies were generally 95% or better when fish in a raceway were evacuated within 20-35 minutes. This evacuation time could be reduced if an additional dual-coil monitor were incorporated into the system.
2. Tag-reading efficiency was substantially better with the single-read firmware than with the double-read firmware. Although the rate of tag-reading error was lower for the double-read system than for the single-read system, it was concluded that the fish pass too quickly through fish pumps and during hatchery releases for a PIT-tag monitoring system to use the double-read firmware.
3. We recommend two, double-coil PIT-tag monitors placed in tandem be used in pump or hatchery-release monitoring systems. This will provide backup in case of system failure and also increase the tag-reading efficiency.

Future PIT-Tag Monitoring Systems

1. Extended-Range PIT-Tag Monitor for Adult Salmon--A prototype PIT-tag monitoring system designed to extend the detection range of tagged adult salmon from an 18-cm radius to a 30-cm radius was evaluated. The problems encountered in the initial development and testing of the system included: 1) meeting Federal Communications Commission requirements, 2) equipment overheating, and 3) electronic noise. The system's electronics will be further evaluated in 1990 after modifying several key components. Due to the problems with the system electronics, field tests at hydroelectric facilities are not anticipated until 1993.
2. Lower Granite Dam PIT-Tag Diversion System--A prototype PIT-tag diversion system to mechanically divert PIT-tagged juveniles at Lower Granite Dam was designed, constructed, and evaluated in 1989. The separation efficiency of the system, based on fish density, was determined to be half of the theoretical value. Although it did increase when smaller numbers of fish passed through the system (i.e., <5,000 compared to 15,000 fish per hour). Several modifications will be made in 1990 to correct technical problems (e.g., dealing with low-water velocities) and consequently increase the reliability and efficiency of the system.

3. Little Goose Dam Pit-Tag Monitoring and Fish Diversion System--The design of a new PIT-tag detection systems for the new Little Goose Dam juvenile salmonid collection facility was completed in 1989.

4. Bonneville Dam Fish Collection and PIT-Tag Monitoring System--Several preliminary concept designs for new fish collection facilities and PIT-tag monitoring systems at Bonneville Dam's powerhouses were started in 1989. These facilities will include capabilities for passively interrogating PIT-tagged fish. The concept designs are scheduled for completion in 1991.

INFORMATION TRANSFER

PIT-Tag Database Management

Introduction

The timely management and analyses of large volumes of data produced by the Columbia Basin PIT-tag project require a computer database system. The existing microcomputer data management programs are not satisfactory because they have problems with storage limitations, system flexibility, and slow operational speed (e.g., up to 3 hours to conduct a data intersect with a 30,000 record PIT-tag file using Microrim's R-base on a 8-MHz 8086 microcomputer vs. several minutes using a mainframe computer). In addition, the information obtained from individual PIT-tag monitoring sites requires some editing to prepare it for expedient data processing. This is best accomplished by a single database manager rather than by a number of individual users.

We concluded that a professionally designed and managed PIT-tag database residing on a mainframe computer was required to meet contractual and verbal agreements with BPA and various fishery agencies. In 1988, a cooperative agreement was made with the Pacific States Marine Fisheries Commission to develop and manage a prototype PIT-tag database. The development of the database occurred in two phases during 1988-1989. Phase I involved design and testing of the system, while Phase II involved implementation and refinement.

System Description

The PIT-tag database consists of four subsystems: tagging, interrogation, central processing, and data transfer. Together, the subsystems are referred to as the PIT-tag information system (PTAGIS).

Tagging--The tagging subsystem consists of tagging files created at the time fish are PIT tagged. Some elements of each record file are created electronically, while other elements are entered by fishery biologists. After creation, these files are sent (up-loaded) to a Burroughs B7800 computer located at NOAA facilities in Seattle, Washington.

Interrogation--The interrogation subsystem consists of data files that are created as fish pass through a PIT-tag monitoring system located at a dam, hatchery, fish trap, or other site. These data files are made up of records containing tag code, date and time of interrogation, and other relevant information. A PIT-tag monitoring system is made up of one or more detector arrays, which pass information to a personal computer for temporary storage. These files are up-loaded daily to the Burroughs B7800 in Seattle.

Central processing--On the Burroughs B7800 computer, both tagging and interrogation files are rigorously examined and edited for accuracy before being added to the PIT-tag database for central processing. In addition, the interrogation files are used daily with the "indirect method" statistical program to determine if the PIT-tag monitoring systems are functioning properly. This database was constructed on the Burroughs B7800 computer using its DMSII program. From remote locations, PIT-tag users with personal computers can access this DMSII database using a second program called Extended Retrieval and Graphics Output (ERGO). ERGO provides quick, on-line access to the DMSII database in tabular and graphic forms.

Data transfer--The data-transfer subsystem involves both data acquisition to, and retrieval from, PTAGIS. This can be accomplished by oral or written request, or remotely by computer modem. Examples of data being sent to the database are tagging files, mortality files, or interrogation files, and examples of data acquisition include fish-release information or downstream-recovery information.

Modifications

The above database is considered both a prototype system to meet BPA and NMFS's immediate needs and a framework for a permanent Columbia River Basin database system. This system was designed to handle tagging, release, and interrogation files, and to conduct system-operation analyses. The prototype database system was available to all users of the PIT-tag system in 1989. Continued development, refinement, and implementation of the prototype system will take place during the 1990 field season. A permanent Columbia River Basin database is being negotiated based on the NMFS prototype.

The primary criticism of the prototype system is that it is not "user friendly." During the 1990 field season, to meet this criticism, modifications will be made to the PTAGIS system. Training sessions will be offered at a number of locations to familiarize users with the database system's operation. Any new database system must take the concern of "user friendly operation" very seriously. If system users have difficulty in extracting their information, the PIT-tag database system will only be accessed by a few sophisticated users, thus defeating a major purpose of the system.

Summary, Conclusions, and Recommendations for Information Transfer

1. NMFS established a cooperative agreement with the Pacific States Marine Fisheries Commission to develop a prototype PIT-tag database for tagging, release, and interrogation files, as well as for system analyses. The prototype database system was available to all users of the PIT-tag system in 1989. We recommend that the database be further refined during 1990. In addition, users should be trained on how to use this system.
2. We recommend a permanent Columbia River Basin PIT-tag database that would be a refinement of the NMFS prototype and be managed by a service organization.

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APPENDIX A

NMFS PIT-Tag Experiment

by

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INTRODUCTION

The Passive Integrated Transponder (PIT) tag is a relatively recent innovation that can be used to identify (mark) individual fish. The tag, which is encased in a non-toxic glass tube, consists of a 40-bit computer chip that is attached to a very thin antenna. Since it measures only 12 mm x 2.1 mm, it can be injected into the peritoneal cavity using a 12 gauge hypodermic needle. PIT tags can be interrogated using a hand held scanner or using scanners that are attached to fish passageways. The new tag offers advantages over previous marking techniques because each tag carries a unique identification number which can be read quickly, the tag can be interrogated in situ without having to kill the fish, and the tag is reusable.

During the summer of 1987 a study was undertaken to examine the pathological effects that might be induced by intraperitoneal injection of the tag. The results of that study are described in this report.

MATERIALS AND METHODS

During the summer of 1987, PIT tags were implanted intraperitoneally into 60 juvenile sockeye salmon (Oncorhynchus nerka). Ten fish were sacrificed at each of six intervals (0, 5, 10, 15, 20, 47 days) post implantation. At sacrifice, the body wall was incised (to allow for adequate fixative penetration) and the fish were preserved in Bouin's solution.

Following fixation, whole body cross sections were collected at the injection site. These cross sections were dehydrated through a series of graded ethanol solutions, cleared in xylene, and embedded in paraffin. Four skip sections (cut one **5-µm** section, skip ten) were prepared from each paraffin block using **a** rotary microtome. The tissues were then stained with hematoxylin and eosin. For histopathological examination, the slides were consistently placed on the microscope stage with the slide label located to the pathologist's left. This procedure allowed the pathologist to identify problematic or interesting fields (by recording their coordinates on the Vernier scale) for subsequent re-examination or for photography. The entire cross section was examined; however, particular attention was paid to those tissues actively involved in the reaction to injury. Tissue alterations were evaluated using subjective pathological descriptors.

RESULTS

Day- -The **epidermis** was disrupted over the injection site. The dermis was also disrupted and contained bits of necrotic debris. Inflammatory changes were not noted in either of these tissues.

The **musculature** surrounding the injection site was markedly altered. Damaged fibers were hypertrophic, densely eosinophilic and less prominently striated than adjacent undamaged fibers. Damaged fibers bore myocyte nuclei which were small and densely basophilic (pyknotic) and which contained no discernable nucleoli. These contrasted with the nuclei of undamaged fibers which were oval vesicular structures with prominent, centrally placed nucleoli. In addition, damaged muscle fibers were separated from one another by amorphous, lightly eosinophilic material which, presumably, represented proteinaceous exudate.

Blood vessels in the area of injury were congested and showed margination of polymorphonuclear leukocytes (PMNs). A few PMNs were also present within the injured tissue. These cells probably migrated from the adjacent blood vessels. Hemorrhage was noted in some areas.

The visceral organs, pancreatic tissue and coelomic adipose tissue were unremarkable.

Day 5--The wound was completely covered by a layer of **epidermal** cells. The epidermis over the wound was thicker than that over adjacent areas. This increased thickness arose both from an increased number of cell layers and from an increase in component cell size. In addition, the cells were separated by wide intercellular spaces. The epithelial cell layers extended to the underlying musculature and filled the space normally occupied by **dermal** elements. Whereas the epidermis was fully reformed by Day 5, the dermis remained disrupted and was represented only by necrotic debris.

Damaged fibers remained the most prominent component of the body **musculature.** Separated by inflammatory exudate and petechial hemorrhages, the fibers were infiltrated by PMNs (primarily) and some mononuclear cells (macrophages, lymphocytes). Interspersed among the damaged fibers were muscle fibers that were frankly necrotic. Mononuclear cells were often aligned near such necrotic fibers and sometimes contained eosinophilic intracytoplasmic inclusions that resembled phagocytized muscle tissue.

In several specimens the **pancreatic/adipose tissue** was infiltrated by hemorrhagic foci, PMNs and mononuclear cells. Ascites and fibrin deposition were present in some specimens. In at least **one** fish, there also appeared to be an adhesion forming between these tissues and the damaged muscle fibers.

Day 10--The **epidermis** had an appearance similar to that seen at Day **5.** The epidermal layer was thickened over the injection site and the epidermal plug extended to the damaged muscle fibers. As on Day **5,** the cells were separated by prominent intercellular spaces. The dermis showed no evidence of regeneration and was represented only by necrotic debris.

Damaged and necrotic fibers were prominent in the **musculature.** The fibers were surrounded by large numbers of macrophages, most of which contained eosinophilic, intracytoplasmic inclusions. Fibroblasts were also present and fibrin deposition was noted. While a few PMNs were present, the inflammatory response was predominated by mononuclear cells and could best be described as fibrogranulation tissue. The most obvious changes in the musculature were degenerative; however, a few isolated myoblasts were present signalling the onset of regeneration.

In several fish the **pancreatic/adipose tissue** was infiltrated **by** fibrogranulation tissue, fibrin deposition and small hemorrhagic foci. Fully formed granulomas were also present. Although they were encased by this inflammatory exudate, the pancreatic acinar cells appeared viable.

Day 15--The **epidermis** was intact and somewhat thicker than adjacent epidermal elements. The **dermis** was absent at the penetration point.

Damaged/necrotic fibers had been removed by macrophages and the **musculature** at the injection site was completely replaced by fibrogranulation tissue. Although inconspicuous, a few myoblasts were present adjacent to muscle fibers that were not damaged during the injection procedure.

An exuberant inflammatory response was noted in the **pancreatic/adipose tissue** of some fish. This response resembled that seen on Day 10, consisting of hemorrhage, fibrogranulation tissue, fibrin deposition and formation of adhesions between pancreatic elements as well as adhesions to the body wall. As before, the affected pancreatic acinar cells appeared viable.

Day 20--The **epidermis** and dermis had an appearance identical to that seen at Day **15.**

As before, the **musculature** was completely replaced by fibrogranulation tissue. Although not abundant, myoblasts were more frequently encountered than they were at Day 15. These cells were recognizable both by their location (adjacent to viable fibers) and by their morphology. The cells were irregularly shaped with dark grey cytoplasm. They had spherical clear nuclei which contained **a** prominent centrally placed nucleolus. In more mature myoblasts, brightly eosinophilic fibers were present within the cytoplasm.

Pronounced inflammatory changes identical to those noted on previous days were present in the **pancreatic/adipose tissue.** Adhesions were noted between these tissues and the body wall.

Day 47--The **epidermis** was fully reformed and only slightly thicker than adjacent tissue. By Day 47 the **dermis** was reformed and was generally intact. Although the dermis was intact, the stratum compactum covering the wound was not as densely fibrous as the stratum compacturn in adjacent dermal tissue, nor was scale formation noted.

Some residual fibrosis was present in the **musculature;** however, the tissue was overwhelmingly populated with myoblasts that were regenerating new muscle tissue. The myoblasts had prominent intracellular fibers and appeared to be forming muscle bundles.

Residual foci of chronic inflammation were noted in the **pancreatic/adipose tissue.** These foci were small and appeared to be resolving rather than progressing. In one fish, an island of pancreatic tissue that had been incorporated into an adhesion was attached to the body wall.

DISCUSSION

The results of this study indicate that intraperitoneal injection of a PIT tag causes damage to the epidermis, dermis and musculature at the site of the injection. This damage appears to result directly from penetration by the 12 guage hypodermic needle, and does not reflect chronic damage induced by the tag itself. In the present study the epidermis regenerated quickly, completely covering the wound by Day 5. The dermal and muscular elements were much slower to regenerate. Fully restored dermis was first seen on Day 47. Full restoration of skeletal muscle was never observed; however, regeneration and healing were nearly complete at the time the study was terminated (Day 47).

Acute inflammatory lesions were noted in pancreatic and adipose tissues at the implantation site. The changes were reversible and were resolved by Day 47 post implantation.

Morphological changes were also observed in other visceral organs, notably the components of the gastrointestinal tract; however, these were artifacts resulting from incomplete penetration of the fixative. There was no convincing evidence that presence of the PIT tag caused adverse effects on organs other than those that were physically damaged by the hypodermic needle.

Finn and Nielsen (1971) described the inflammatory response of rainbow trout (0. <u>mykiss</u>) following intramuscular injection with staphylococci. Muscle necrosis was noted within hours of injury, as was a marked increase in the number of PMNs and macrophages in the lumen of blood vessels. The leukocytes exited the vessels, migrated into the injured tissue by Day 1 (PMNs) or Day 2 (macrophages), and phagocytosed the necrotic debris. Fibroblasts appeared in the area of injury on Day 4, but intense fibroplasia did not commence until Day 8. Muscle regeneration, as evidenced by the presence of myoblasts, was observed on Day 16. The study conducted by Finn and Nielsen (1971) involved injection of a living microorganism and was of shorter duration (16 days) than the present study. Nonetheless, the major events in the reaction to injury were similar.

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APPENDIX B

Statistical Method of Determining PIT-Tag Coil Reading Efficiency

by

Benjamin Sandford

DISCUSSION

Direct and indirect methods can be used to determine PIT-tag monitor tag-reading efficiency. The direct method compares the number of tagged fish monitored to that of a known number of tagged fish released directly into the monitoring system. This method is only accurate for the time and conditions of the test and does not necessarily represent reading efficiency over a prolonged period. The indirect method is a statistical method based upon the number of tagged fish monitored while not knowing the actual number of fish passing through the system. The following is a description of the derivation of a point estimator, with its associated estimated variance, for the probability of missing a PIT tag with a PIT-tag monitor unit.

Consider a PIT-tag monitor unit consisting of k coils. An unbiased maximum likelihood estimate (MLE) for P,, the probability of detection on coil i (i = l,...,k), can be obtained under the following two assumptions:

A1) P_i and P_j are independent for $i \neq j$.

A2) P_i is the same for all PIT tags.

Under A2, we can treat the tags detected on coil i as a random sample of all tags passing through the unit. Incorporating Al as well, we can treat the tags detected on all other coils as a random sample of all tags passing through the unit independent of whether those tags were detected on coil i.

Let $P_{i|j}$ equal the probability of detection on coil i given detection on at least one other coil. A1 implies that $P_{i|j} = P_i$.

Let n_i equal the number of unique tags detected on coil i and at least one other coil.

Let M_i equal the total number of unique tags detected on at least one other coil.

It is then reasonable to assume that n_i is binomially distributed with parameters M_i and $P_{i|j} = P_i$.

The unbiased MLE for P_i is then (Mood et al. 1974)

$$p_i = n_i / M_i \tag{1}$$

The estimated variance of p_i is

$$p_i (1 - p_i) / M_i = n_i (M_i - n_i) / M_i^3 \tag{2}$$

This method can be repeated for each coil in the unit. Thus, estimates p_i, $i = 1,...,k$ can be obtained for the detection efficiencies of the k coils in a unit. These estimates are independent. Therefore, P_o, the probability of a tag passing a unit undetected, is the product of the probabilities of the tag passing all k coils undetected, i.e., the product of the $(1-P_i)$s. An unbiased estimate for P_o is then

$$p_o = \Pi_{i=1}^{k} (1 - p_i) \tag{3}$$

The in-variance property of MLEs implies that p_o is the MLE for P_o. The estimated variance of p_o can be approximated using a Taylor series expansion, i.e., the Delta method (Mood et al. 1974), as follows:

$$\mathrm{var}(p_o) = \mathrm{var}\left(\Pi_{i=1}^{k} (1 - p_i)\right) \approx \Sigma_{i=1}^{k} \mathrm{var}(p_i) \{ \delta P_o/\delta P_i(p_1, \ldots, p_k) \}^2$$

$$\delta P_o/\delta P_i(p_1, \ldots, p_k) = -\Pi_{j=1}^{k} (1 - p_j)/(1 - p_i) = -p_o / (1 - p_i)$$

$$\text{Thus, } \mathrm{var}(p_o) \approx \Sigma_{i=1}^{k} [p_i (1 - p_i)/M_i] [-p_o / (1 - p_i)]^2$$

$$= p_o^2 \Sigma_{i=1}^{k} p_i/[M_i (1 - p_i) 1 \qquad (4)$$

$$= p_o^2 \Sigma_{i=1}^{k} n_i/[M_i (M_i - n,) \qquad (5)$$

An approximate $(1 - \alpha)100\%$ confidence interval for the probability of missing a tag for a PIT tag monitor unit is:

$$p_o \pm z_{\alpha/2} p_o \left(\Sigma_{i=1}^{k} p_i/[M_i(1 - p_i)]\right)^{1/2} \qquad (6)$$

where α is the desired significance level and $z_{\alpha/2}$ is a standard normal deviate corresponding to $\alpha/2$ (e.g., α=0.05, $z_{\alpha/2}$= 1.96).

The estimated probability of missing a tag for an overall monitor system, Π_o say, is a weighted average of the probabilities for each unit provided the units cover mutually exclusive routes. The estimate, for u units in a system, is

$$\Pi_o = \Sigma_{i=1}^{u} p_{oi} w_i \qquad (7)$$

where p_{oi} is the estimate, p,, for unit i, (i = 1,...,u), and w_i is the weight for unit i.

The estimated variance of Π_o is

$$\text{var}\ (\Pi_o) = \Sigma_{i=1}^{u}\ \text{var}\ (p_{oi})\, w_i^2 \qquad (8)$$

An approximate (1 - α)100% confidence interval for the true system probability of missing a tag is

$$\Pi_o \qquad z_{\alpha/2}[\text{var}(\Pi_o)]^{1/2} \qquad (9)$$

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APPENDIX C

The Probability of Missing a PIT Tag by Juvenile PIT-Tag Monitors at Lower Granite, Little Goose, and McNary Dams, 1989.

by

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and
Earl F. Prentice

DISCUSSION

The following data were obtained for PIT-tag monitoring systems at Lower Granite, Little Goose, and McNary Dams. The data presented in Tables 1-3 reflect PIT-tag-reading status determined using the indirect statistical approach described in Appendix B for each monitor.

Table 1.--The probability of missing a PIT tag on juvenile monitors at Lower Granite Dam, 1989.

Date	MONITOR SYSTEM - A MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
03/25	3	0.000	0.000
03/26	1	[1]	
03/27	6	0.000	0.000
03/28	14	0.000	0.000
03/29	16	0.020	0.055
03/30	17	0.015	0.043
03/31	19	0.000	0.000
04/01	24	0.087	0.168
04/02	30	0.000	0.000
04/03	39	0.003	0.007
04/04	51	0.002	0.005
04/05	76	0.000	0.000
04/06	55	0.000	0.000
04/07	55	0.000	0.001
04/08	70	0.000	0.001
04/09	74	0.000	0.001
04/10	51	0.002	0.003
04/11	51	0.001	0.001
04/12	68	0.000	0.000
04/13	77	0.002	0.003
04/14	114	0.000	0.000
04/15	153	0.000	0.000
04/16	146	0.000	0.000
04/17	220	0.000	0.000
04/18	262	0.000	0.000
04/19	213	0.000	0.000
04/20	333	0.000	0.000
04/21	850	0.000	0.000
04/22	961	0.000	0.000
04/23	652	0.000	0.000
04/24	669	0.000	0.000
04/25	494	0.000	0.000
04/26	248	0.001	0.001
04/27	640	0.036	0.015
04/28	423	0.114	0.046
04/29	339	0.042	0.022
04/30	254	0.013	0.010
05/01	317	0.035	0.020
05/02	928	0.058	0.018
05/03	493	0.011	0.006

Table 1.--Continued.

	MONITOR SYSTEM - A MAIN		
Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/04	546	0.009	0.005
05/05	447	0.008	0.005
05/06	484	0.010	0.005
05/07	429	0.032	0.016
05/08	707	0.015	0.007
05/09	670	0.009	0.004
05/10	976	0.017	0.006
05/11	563	0.026	0.012
05/12	319	0.032	0.018
05/13	271	0.039	0.024
05/14	115	0.035	0.034
05/15	253	0.019	0.013
05/16	244	0.031	0.021
05/17	105	0.004	0.005
05/18	259	0.022	0.015
05/19	219	0.023	0.017
05/20	193	0.016	0.013
05/21	90	0.014	0.017
05/22	114	0.095	0.078
05/23	92	0.012	0.016
05/24	92	0.047	0.049
05/25	105	0.029	0.030
05/26	169	0.014	0.013
05/27	137	0.026	0.023
05/28	133	0.005	0.006
05/29	76	0.013	0.018
05/30	104	0.020	0.021
05/31	167	0.080	0.055
06/01	111	0.062	0.061
06/02	95	0.003	0.005
06/03	112	0.009	0.010
06/04	79	0.008	0.013
06/05	144	0.001	0.002
06/06	124	0.014	0.014
06/07	89	0.006	0.009
06/08	134	0.006	0.007
06/09	93	0.018	**0.021**
06/10	60	0.004	0.008
06/11	84	0.038	0.040
06/12	62	0.002	0.004
06/13	43	0.003	0.008
06/14	55	0.057	0.071
06/15	30	0.007	0.019
06/16	29	0.005	0.014
06/17	36	0.000	0.000

Table 1. --Continued.

Date	MONITOR SYSTEM - A MAIN Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/18	33	0.047	0.083
06/19	29	0.092	0.153
06/20	19	0.154	0.300
06/21	12	0.000	0.000
06/22	6	0.000	0.000
06/23	13	0.000	0.000
06/24	11	0.015	0.052
06/25	4	0.000	0.000
06/26	5	0.000	0.000
06/27	3	0.000	0.000
06/28	2	0.000	0.000
06/29	3	0.000	0.000
06/30	5	0.000	0.000
07/01	3	0.000	0.000
07/02	2	0.000	0.000
07/03	1	0.000	0.000
07/04	3	0.000	0.000
07/05	0		
07/06	0		
07/07	0		
07/08	1	0.000	0.000
07/09	3	0.000	0.000
07/10	0		
07/11	0		
07/12	1	0.000	0.000
07/13	2	0.000	0.000
07/14	1	0.000	0.000
07/15	1	0.000	0.000
07/16	1	0.000	0.000
07/17	0		
07/18	0		
07/19	2	0.000	0.000
07/20	0		
07/21	0		
07/22	1	0.000	0.000
07/23	0		
07/24	0		
07/25	0		
07/26	0		
07/27	1	0.000	0.000

Table 1.--Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
03/25	3	0.000	0.000
03/26	3	33.333	53.344
03/27	0		
03/28	0		
03/29	3	0.000	0.000
03/30	1	0.000	0.000
03/31	1	0.000	0.000
04/01	3	0.000	0.000
04/02	5	0.000	0.000
04/03	5	0.000	0.000
04/04	4	0.521	1.743
04/05	1	0.000	0.000
04/06	31	0.316	0.418
04/07	22	0.236	0.389
04/08	14	0.273	0.554
04/09	19	0.000	0.000
04/10	35	0.268	0.358
04/11	28	0.356	0.475
04/12	40	1.066	0.993
04/13	58	0.259	0.255
04/14	34	0.227	0.301
04/15	67	0.264	0.257
04/16	67	0.370	0.320
04/17	87	1.023	0.664
04/18	73	0.281	0.243
04/19	60	0.501	0.428
04/20	83	0.709	0.497
04/21	149	0.853	0.429
04/22	91	0.242	0.193
04/23	91	0.271	0.210
04/24	105	0.161	0.126
04/25	88	0.428	0.311
04/26	66	0.074	0.082
04/27	35	0.096	0.167
04/28	6	0.463	1.336
04/29	13	0.168	0.372
04/30	35	0.318	0.402
05/01	30	0.175	0.263
05/02	**56**	**0.402**	**0.372**
05/03	35	0.087	0.128
05/04	18	0.957	1.363
05/05	23	0.131	0.230
05/06	14	0.362	0.705
05/07	12	0.000	0.000
05/08	28	0.055	0.100

Table 1. --Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/09	26	0.527	0.681
05/10	16	2.074	2.743
05/11	10	0.000	0.000
05/12	14	0.083	0.214
05/13	14	1.121	1.883
05/14	7	0.000	0.000
05/15	30	0.192	0.316
05/16	10	0.000	0.000
05/17	14	0.067	0.177
05/18	23	0.177	0.319
05/19	16	0.049	0.128
05/20	19	0.032	0.084
05/21	10	0.000	0.000
05/22	27	0.068	0.131
05/23	5	0.000	0.000
05/24	10	0.222	0.583
05/25	20	0.489	0.744
05/26	27	0.545	0.727
05/27	12	0.316	0.743
05/28	15	0.076	0.196
05/29	30	0.159	0.237
05/30	19	0.440	0.734
05/31	23	0.137	0.235
06/01	4	0.000	0.000
06/02	14	0.000	0.000
06/03	12	1.929	3.176
06/04	10	0.000	0.000
06/05	14	1.030	1.697
06/06	10	0.200	0.561
06/07	7	2.799	5.360
06/08	10	1.481	2.695
06/09	3	5.556	14.744
06/10	8	1.488	3.439
06/11	8	0.335	0.943
06/12	5	0.000	0.000
06/13	7	0.125	0.407
06/14	7	0.486	1.382
06/15	7	0.583	1.507
06/16	4	0.000	0.000
06/17	1		
06/18	1	0.000	0.000
06/19	5	6.000	11.361
06/20	5	9.000	17.786
06/21	2	0.000	0.000
06/22	3	0.000	0.000

Table 1. --Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/23	1	0.000	0.000
06/24	3	0.000	0.000
06/25	1	0.000	0.000
06/26	1	0.000	0.000
06/27	1	0.000	0.000
06/28	1	0.000	0.000
06/29	1	0.000	0.000
06/30	0		
07/01	1	0.000	0.000
07/02	0		
07/03	0		
07/04	0		
07/05	1		
07/06	0		
07/07	0		
07/08	0		
07/09	0		
07/10	0		
07/11	0		
07/12	0		
07/13	2	0.000	0.000
07/14	0		
07/15	0		
07/16	0		
07/17	0		
07/18	0		
07/19	0		
07/20	0		
07/21	0		
07/22	0		
07/23	0		
07/24	0		
07/25	0		
07/26	0		
07/27	0		

Table 1.--Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
03/25	0		
03/26	3		
03/27	0		
03/28	0		
03/29	0		
03/30	0		
03/31	0		
04/01	0		
04/02	0		
04/03	0		
04/04	0		
04/05	0		
04/06	0		
04/07	0		
04/08	0		
04/09	0		
04/10	0		
04/11	0		
04/12	0		
04/13	0		
04/14	0		
04/15	0		
04/16	0		
04/17	0		
04/18	0		
04/19	0		
04/20	0		
04/21	0		
04/22	0		
04/23	0		
04/24	0		
04/25	0		
04/26	75	0.007	0.011
04/27	0		
04/28	0		
04/29	0		
04/30	0		
05/01	0		
05/02	0		
05/03	0		
05/04	0		
05/05	167	0.002	0.003
05/06	22	0.007	0.020
05/07	617	0.047	0.019
05/08	143	0.034	0.030

Table 1.--Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/09	104	0.025	0.026
05/10	0	-	-
05/11	83	0.003	0.005
05/12	278	0.090	0.048
05/13	265	0.019	0.013
05/14	298	0.037	0.022
05/15	184	0.021	0.017
05/16	17	0.172	0.344
05/17	189	0.011	0.010
05/18	0	-	-
05/19	0	-	-
05/20	0	-	-
05/21	122	0.005	0.006
05/22	0	-	-
05/23	0	-	-
05/24	0	-	-
05/25	0	-	-
05/26	0	-	-
05/27	0	-	-
05/28	0	-	-
OS/29	0	-	-
05/30	0	-	-
05/31	0	-	-
06/01	0	-	-
06/02	0	-	-
06/03	0	-	-
06/04	0	-	-
06/05	0	-	-
06/06	0	-	-
06/07	0	-	-
06/08	0	-	
06/09	0	-	-
06/10	0	-	-
06/11	0	-	-
06/12	0	-	-
06/13	0	-	-
06/14	0	-	-
06/15	0	-	-
06/16	0	-	-
06/17	0		-
06/18	0	-	
06/19	0		
06/20	0	-	
06/21	0		
06/22	0		

Table 1. --Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/23	0	-	-
06/24	0	-	-
06/25	0	-	-
06/26	0	-	-
06/27	0	-	-
06/28	0	-	-
06/29	0	-	-
06/30	0	-	-
07/01	0	-	-
07/02	0	-	-
07/03	0	-	-
07/04	0	-	-
07/05	0	-	-
07/06	0	-	-
07/07	0	-	-
07/08	0	-	-
07/09	0	-	-
07/10	0	-	-
07/11	0	-	-
07/12	0	-	-
07/13	0	-	-
07/14	0	-	-
07/15	0	-	-
07/16	0	-	-
07/17	0	-	-
07/18	0	-	-
07/19	0	-	-
07/20	0	-	-
07/21	0	-	-
07/22	0	-	-
07/23	0	-	-
07/24	0	-	-
07/25	0	-	-
07/26	0	-	-
07/27	0	-	-

[1] '-' indicates that there was insufficient data to calculate.

Table 2.--The probability of missing a PIT tag on juvenile monitors at Little Goose Dam, 1989.

Date	MONITOR A		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
04/04	2	-[1]	
04/05	0	-	
04/06	0	-	
04/07	1	0.000	0.000
04/08	0	-	
04/09	0	-	
04/10	0	-	
04/11	0	-	
04/12	4	0.000	0.000
04/13	2	0.000	0.000
04/14	6	0.000	0.000
04/15	10	2.778	6.121
04/16	6	0.000	0.000
04/17	14	2.778	4.970
04/18	16	0.000	0.000
04/19	24	1.299	2.190
04/20	26	1.087	1.843
04/21	54	1.176	1.463
04/22	68	2.246	2.120
04/23	139	1.355	0.928
04/24	122	1.032	0.821
04/25	104	0.707	0.833
04/26	65	0.323	0.504
04/27	69	0.337	0.517
04/28	53	1.451	1.640
04/29	116	1.002	0.885
04/30	80	0.839	0.920
05/01	79	1.250	1.314
05/02	39	5.714	5.710
05/03	58	0.241	0.496
05/04	73	1.034	1.074
05/05	54	0.816	1.024
05/06	5	0.000	0.000
05/09	168	0.915	0.695
05/10	50	0.000	0.000
05/11	57	0.202	0.353
05/12	57	0.000	0.000
OS/13	37	0.893	1.400
05/14	30	0.510	0.964
05/15	28	0.617	1.309
05/16	13	0.000	0.000

Table 2.--Continued.

Date	MONITOR A		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/17	15	0.510	1.363
05/18	24	3.030	4.467
05/19	17	1.339	2.875
05/20	17	0.000	0.000
05/21	17	1.923	3.972
05/22	16	0.952	2.178
05/23	7	0.000	0.000
05/24	13	0.000	0.000
05/25	7	0.000	0.000
05/26	3	0.000	0.000
05/27	9	0.000	0.000
05/28	11	0.000	0.000
05/29	17	1.778	3.244
05/30	9	1.563	4.051
05/31	7	0.000	0.000
06/01	6	0.000	0.000
06/02	4	0.000	0.000
06/03	1		
06/04	6	0.000	0.000
06/05	12	3.030	6.317
06/06	5	16.667	31.276
06/07	8	0.000	0.000
06/08	10	2.778	6.121
06/09	7	2.778	7.029
06/10	4	0.000	0.000
06/11	10	0.000	0.000
06/12	8	0.000	0.000
06/13	2	0.000	0.000
06/14	4	0.000	0.000
06/15	1	0.000	0.000
06/16	4	11.111	25.147
06/17	1		
06/18	0		
06/19	1		
06/20	0		
06/21	0		
06/22	0		
06/23	2	0.000	0.000
06/24	1	0.000	0.000
06/25	0		
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	0		

Table Z.--Continued.

	MONITOR A		
Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
07/01	0	0.000	0.000
07/02	0		
07/03	0		
07/04	1		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		
	MONITOR B		
04/04	1		
04/05	0		
04/06	0		
04/07	2	0.000	0.000
04/08	1	0.000	0.000
04/09	1	0.000	0.000
04/10	4	0.000	0.000
04/11	2	0.000	0.000
04/12	10	0.000	0.000
04/13	12	0.000	0.000
04/14	12	0.000	0.000
04/15	9	0.000	0.000
04/16	3	0.000	0.000
04/17	8	0.000	0.000
04/18	33	0.313	0.690
04/19	24	1.299	2.190
04/20	26	1.087	1.843
04/21	65	0.189	0.389
04/22	70	0.578	0.740
04/23	96	0.805	0.855
04/24	134	1.180	0.913
04/25	99	0.694	0.824
04/26	89	0.824	0.977
04/27	79	0.686	0.776
04/28	54	2.174	2.127
04/29	115	1.159	1.008
04/30	83	0.314	0.625
05/01	73	0.500	0.733
05/02	68	0.932	1.328
05/03	51	0.759	1.135
05/04	38	1.042	1.592
05/05	76	0.842	0.935

Table 2. --Continued.

Date	MONITOR B		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/06	8	0.000	0.000
05/09	130	0.447	0.430
05/10	41	0.606	1.229
05/11	61	0.182	0.379
05/12	46	0.000	0.000
05/13	30	0.000	0.000
05/14	25	0.362	0.845
05/15	10	6.250	10.609
05/16	8	0.000	0.000
05/17	9	0.000	0.000
05/18	26	0.000	0.000
05/19	19	0.000	0.000
05/20	15	0.510	1.363
05/21	15	0.000	0.000
05/22	6	0.000	0.000
05/23	9	0.000	0.000
05/24	6	0.000	0.000
05/25	8	0.000	0.000
05/26	**10**	0.000	0.000
05/27	3	0.000	0.000
05/28	12	0.000	0.000
05/29	8	0.000	0.000
05/30	3	0.000	0.000
05/31	3	0.000	0.000
06/01	9	0.000	0.000
06/02	2	0.000	0.000
06/03	5	0.000	0.000
06/04	3	0.000	0.000
06/05	4	0.000	0.000
06/06	1	0.000	0.000
06/07	2	0.000	0.000
06/08	7	0.000	0.000
06/09	6	0.000	0.000
06/10	1	0.000	0.000
06/11	9	0.000	0.000
06/12	2	0.000	0.000
06/13	2	0.000	0.000
06/14	2	0.000	0.000
06/15	4	0.000	0.000
06/16	1	0.000	0.000
06/17	5	0.000	0.000
06/18	0		
06/19	4	0.000	0.000
06/20	3	0.000	0.000
06/21	4	0.000	0.000

Table 2.--Continued.

Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
	MONITOR B		
06/22	2	0.000	0.000
06/23	1	0.000	0.000
06/24	0		
06/25	1	0.000	0.000
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	2	0.000	0.000
07/01	1	0.000	0.000
07/02	0		
07/03	1	0.000	0.000
07/04	1		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		
	MONITOR C		
04/04	3	25.000	49.000
04/05	0		
04/06	0		
04/07	0		
04/08	1	0.000	0.000
04/09	2	0.000	0.000
04/10	2	0.000	0.000
04/11	4	0.000	0.000
04/12	4	11.111	25.147
04/13	16	0.000	0.000
04/14	12	0.826	2.184
04/15	21	0.833	1.810
04/16	5	37.500	56.137
04/17	21	0.000	0.000
04/18	30	0.794	1.357
04/19	26	0.333	0.778
04/20	29	0.549	1.035
04/21	36	0.000	0.000
04/22	57	0.274	0.454
04/23	122	0.766	0.655
04/24	108	0.111	0.175
04/25	74	0.818	0.996
04/26	59	0.390	0.565
04/27	55	0.070	0.166

Table 2.--Continued.

Date	MONITOR C		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
04/28	33	0.000	0.000
04/29	109	0.261	0.313
04/30	74	0.241	0.353
05/01	84	0.185	0.271
05/02	45	0.216	0.414
05/03	36	0.461	0.964
05/04	50	1.039	1.338
05/05	69	0.882	0.964
05/06	12	0.000	0.000
05/09	118	1.059	0.863
05/10	33	0.416	0.789
05/11	50	0.568	0.879
05/12	43	0.238	0.455
05/13	42	0.665	1.340
05/14	27	0.000	0.000
05/15	12	1.818	4.077
05/16	11	0.000	0.000
05/17	12	0.000	0.000
05/18	19	0.000	0.000
05/19	13	0.694	1.843
05/20	8	2.041	5.237
05/21	15	0.000	0.000
05/22	5	0.000	0.000
05/23	5	0.000	0.000
05/24	5	0.000	0.000
05/25	6	0.000	0.000
05/26	8	0.000	0.000
05/27	8	0.000	0.000
05/28	8	2.041	5.237
05/29	7	2.778	7.029
05/30	6	0.000	0.000
05/31	3	0.000	0.000
06/01	10	0.000	0.000
06/02	1	0.000	0.000
06/03	8	0.000	0.000
06/04	11	0.000	0.000
06/05	4	0.000	0.000
06/06	4	0.000	0.000
06/07	4	0.000	0.000
06/08	6	0.000	0.000
06/09	2	0.000	0.000
06/10	2	0.000	0.000
06/11	3	0.000	0.000
06/12	4	0.000	0.000

Table 2. --Continued.

Date	MONITOR C Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/13	4	0.000	0.000
06/14	2	0.000	0.000
06/15	0		
06/16	2	0.000	0.000
06/17	2	0.000	0.000
06/18	6	0.000	0.000
06/19	2	0.000	0.000
06/20	0		
06/21	1	0.000	0.000
06/22	0		
06/23	1	0.000	0.000
06/24	1	0.000	0.000
06/25	2	0.000	0.000
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	0		
07/01	0		
07/02	0		
07/03	0		
07/04	0		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		

Table 2.--Continued.

Date	MONITOR D		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
04/04	1		
04/05	2	0.000	0.000
04/06	0		
04/07	2	0.000	0.000
04/08	0		
04/09	2	0.000	0.000
04/10	6	0.000	0.000
04/11	3	0.000	0.000
04/12	2	0.000	0.000
04/13	13	0.000	0.000
04/14	17	1.339	2.875
04/15	26	2.118	4.176
04/16	5	0.000	0.000
04/17	10	0.000	0.000
04/18	26	0.333	0.778
04/19	39	2.078	2.436
04/20	32	2.897	3.598
04/21	62	1.148	1.227
04/22	105	1.619	1.229
04/23	165	1.279	0.823
04/24	201	1.642	0.937
04/25	137	1.073	0.791
04/26	93	1.263	1.084
04/27	70	1.563	1.483
04/28	39	0.952	1.355
04/29	74	1.632	1.474
04/30	71	1.010	1.044
05/01	63	0.714	0.865
05/02	46	1.161	1.443
05/03	46	2.317	2.529
05/04	51	1.729	1.851
05/05	84	1.370	1.222
05/06	12	4.000	7.012
05/09	136	1.510	1.022
05/10	76	0.564	0.667
05/11	240	0.288	0.241
05/12	111	0.416	0.441
05/13	112	0.102	0.150
05/14	109	0.929	0.814
05/15	37	1.379	1.858
05/16	27	0.308	0.719
05/17	55	0.218	0.381
05/18	46	0.487	0.751
05/19	33	2.463	2.975
05/20	17	0.391	1.048

Table 2.--Continued.

Date	MONITOR D		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/21	17	2.604	5.241
05/22	10	0.000	0.000
05/23	9	1.563	4.051
05/24	10	0.000	0.000
05/25	8	0.000	0.000
05/26	8	4.762	10.184
05/27	6	0.000	0.000
05/28	9	0.000	0.000
05/29	6	0.000	0.000
05/30	11	1.000	2.630
05/31	7	0.000	0.000
06/01	8	0.000	0.000
06/02	6	4.000	9.917
06/03	5	0.000	0.000
06/04	11	0.000	0.000
06/05	11	0.000	0.000
06/06	14	0.592	1.576
06/07	4	0.000	0.000
06/08	9	0.000	0.000
06/09	9	1.563	4.051
06/10	7	0.000	0.000
06/11	12	0.000	0.000
06/12	5	0.000	0.000
06/13	7	6.667	13.911
06/14	6	0.000	0.000
06/15	4	0.000	0.000
06/16	1	0.000	0.000
06/17	2	0.000	0.000
06/18	3	0.000	0.000
06/19	4	0.000	0.000
06/20	0		
06/21	0		
06/22	3	0.000	0.000
06/23	2	0.000	0.000
06/24	0		
06/25	2	0.000	0.000
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	0		
07/01	0		
07/02	0		
07/03	1	0.000	0.000
07/04	0		

Table 2. --Continued.

	MONITOR D		
Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		
	MONITOR E		
04/04	0	-	-
04/05	0	-	-
04/06	1	-	-
04/07	1	0.000	0.000
04/08	0	-	-
04/09	0		
04/10	5	0.000	0.000
04/11	3	0.000	0.000
04/12	5	0.000	0.000
04/13	9	10.000	18.851
04/14	6	0.000	0.000
04/15	9	0.000	0.000
04/16	7	6.667	13.911
04/17	13	5.455	8.569
04/18	16	5.325	7.475
04/19	20	0.585	1.352
04/20	17	0.000	0.000
04/21	27	1.391	2.226
04/22	42	1.563	2.258
04/23	80	1.051	1.242
04/24	89	1.364	1.399
04/25	60	0.516	1.027
04/26	25	0.000	0.000
04/27	33	0.694	1.426
04/28	20	0.585	1.352
04/29	46	0.000	0.000
04/30	37	3.733	4.368
05/01	48	1.754	2.133
05/02	30	0.000	0.000
05/03	44	0.000	0.000
05/04	44	1.384	1.768
05/05	52	1.643	1.983
05/06	6	0.000	0.000
05/09	80	1.116	1.185
05/10	60	0.154	0.326
05/11	148	0.179	0.198

Table 2. --Continued.

Date	MONITOR E Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/12	115	0.000	0.000
05/13	103	0.186	0.252
05/14	89	0.177	0.357
05/15	42	0.000	0.000
05/16	20	0.277	0.747
05/17	12	0.000	0.000
05/18	36	0.735	1.197
05/19	42	0.330	0.692
05/20	11	0.000	0.000
05/21	19	0.000	0.000
05/22	11	0.000	0.000
05/23	9	1.563	4.051
05/24	10	0.000	0.000
05/25	6	4.000	9.917
05/26	6	0.000	0.000
05/27	7	0.000	0.000
05/28	3	0.000	0.000
05/29	7	2.778	7.029
05/30	5	0.000	0.000
05/31	6	20.000	35.062
06/01	8	0.000	0.000
06/02	9	0.000	0.000
06/03	15	3.846	6.185
06/04	13	0.000	0.000
06/05	8	8.571	16.720
06/06	5	0.000	0.000
06/07	4	0.000	0.000
06/08	8	0.000	0.000
06/09	6	0.000	0.000
06/10	2	0.000	0.000
06/11	5	0.000	0.000
06/12	6	0.000	0.000
06/13	6	0.000	0.000
06/14	4	11.111	25.147
06/15	4	0.000	0.000
06/16	2	0.000	0.000
06/17	4	11.111	25.147
06/18	2	0.000	0.000
06/19	0		
06/20	3	0.000	0.000
06/21	1	0.000	0.000
06/22	3	0.000	0.000
06/23	3	25.000	49.000
06/24	2	0.000	0.000
06/25	1	0.000	0.000

Table 2.--Continued.

Date	MONITOR E		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/26	0		
06/27	1		
06/28	1	0.000	0.000
06/29	0		
06/30	0		
07/01	0		
07/02	0		
07/03	0		
07/04	0		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	1	0.000	0.000
	MONITOR F		
04/04	1	-	-
04/05	0	-	
04/06	2	-	
04/07	1	0.000	0.000
04/08	0	-	
04/09	3	0.000	0.000
04/10	4	33.333	53.344
04/11	2	0.000	0.000
04/12	4	0.000	0.000
04/13	13	0.000	0.000
04/14	12	4.000	7.012
04/15	8	0.000	0.000
04/16	8	4.762	10.184
04/17	11	2.222	4.945
04/18	13	3.704	7.458
04/19	12	0.826	2.184
04/20	23	4.167	5.341
04/21	22	4.938	6.036
04/22	43	1.663	1.967
04/23	66	3.490	2.844
04/24	63	1.848	2.154
04/25	51	2.340	2.490
04/26	26	0.000	0.000
04/27	22	1.401	2.871
04/28	30	0.794	1.357
04/29	61	2.955	2.619
04/30	64	4.000	3.122

Table 2.--Continued.

	MONITOR F		
Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/01	58	1.576	1.878
05/02	50	1.909	2.100
05/03	56	2.736	2.470
05/04	32	1.235	1.920
05/05	66	1.290	1.400
05/06	9	3.571	7.770
05/09	158	3.438	1.869
05/10	64	2.825	2.625
05/11	252	1.143	0.660
05/12	116	7.503	3.965
05/13	110		
05/14	94		
05/15	47		
05/16	34		
05/17	38		
05/18	56	5.270	5.816
05/19	39	1.515	1.974
05/20	25	0.794	1.676
05/21	24	0.000	0.000
05/22	20	1.235	2.281
05/23	15	1.099	2.504
05/24	15	1.099	2.504
05/25	12	0.000	0.000
05/26	12	0.000	0.000
05/27	10	11.111	20.532
05/28	6	0.000	0.000
05/29	14	0.000	0.000
05/30	20	9.091	12.146
05/31	6	0.000	0.000
06/01	9	1.563	4.051
06/02	3	0.000	0.000
06/03	15	3.571	7.099
06/04	13	1.515	3.419
06/05	10	0.000	0.000
06/06	9	0.000	0.000
06/07	6	0.000	0.000
06/08	6	0.000	0.000
06/09	8	0.000	0.000
06/10	6	0.000	0.000
06/11	2	0.000	0.000
06/12	7	0.000	0.000
06/13	8	0.000	0.000
06/14	4	0.000	0.000
06/15	4	0.000	0.000
06/16	3	0.000	0.000

Table 2.--Continued.

Date	MONITOR F		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/17	1	0.000	0.000
06/18	0		
06/19	1	0.000	0.000
06/20	0		
06/21	1		
06/22	2	0.000	0.000
06/23	4	0.000	0.000
06/24	0		
06/25	1	0.000	0.000
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	1	0.000	0.000
07/01	1	0.000	0.000
07/02	0		
07/03	0		
07/04	0		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		

Table 3.--The probability of missing a PIT tag on juvenile monitors at McNary Dam, 1989.

	MONITOR SYSTEM - A MAIN		
Date	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
03/24	1	[1]	
03/25	0	-	-
03/26	0	-	-
03/27	0	-	-
03/28	0	-	-
03/29	0	-	-
03/30	2	-	-
03/31	0	-	-
04/01	0	-	-
04/02	0	-	-
04/03	0	-	-
04/05	0	-	-
04/06	0	-	-
04/07	0	-	-
04/08	0	-	-
04/09	0	-	-
04/10	0	-	-
04/11	0	-	-
04/12	0	-	-
04/13	0		
04/14	5	0.000	0.000
04/15	1	0.000	0.000
04/16	1	0.000	0.000
04/17	4	0.000	0.000
04/18	5	0.000	0.000
04/19	6	0.000	0.000
04/20	6	0.000	0.000
04/21	12	0.000	0.000
04/22	16	0.000	0.000
04/23	28	0.121	0.200
04/24	34	0.020	0.047
04/25	37	0.334	0.426
04/26	87	0.413	0.316
04/27	107	0.143	0.116
04/28	131	0.495	0.299
04/29	163	0.536	0.281
04/30	203	0.689	0.309
05/01	178	0.577	0.283
05/02	251	0.226	0.109
05/03	86	0.507	0.370
05/04	149	0.167	0.109

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[1] - Indicates that there was insufficient data to calculate.

Table 3.--Continued.

Date	MONITOR SYSTEM - A MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/05	184	0.302	0.166
05/06	144	0.376	0.223
05/07	461	0.170	0.063
05/08	123	0.139	0.108
05/09	528	0.068	0.027
05/10	110	0.067	0.059
05/11	484	0.069	0.029
05/12	605	0.052	0.020
05/13	410	0.048	0.023
05/14	342	0.044	0.023
05/15	618	0.047	0.018
05/16	885	0.041	0.013
05/17	703	0.025	0.010
05/18	242	0.097	0.054
05/19	231	0.084	0.049
05/20	466	0.084	0.034
05/21	378	0.082	0.038
05/22	172	0.096	0.063
05/24	286	0.115	0.058
05/25	200	0.131	0.077
05/26	145	0.114	0.081
05/27	171	0.257	0.147
05/28	231	0.053	0.033
05/29	133	0.063	0.050
05/30	64	0.073	0.082
05/31	53	0.403	0.384
06/01	27	0.183	0.282
06/02	21	0.107	0.204
06/03	16	0.081	0.205
06/04	4	0.000	0.000
06/05	4	0.000	0.000
06/06	8	0.670	1.642
06/07	11	0.000	0.000
06/08	8	0.000	0.000
06/09	6	0.000	0.000
06/10	14	0.302	0.622
06/11	7	0.000	0.000
06/12	6	0.000	0.000
06/13	9	0.617	1.495
06/13	9	0.617	1.495
06/14	436	0.052	0.025
06/15	10	0.494	1.196
06/16	8	0.000	0.000
06/17	6	0.000	0.000

Table 3.--Continued.

Date	MONITOR SYSTEM - A MAIN Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/19	3	0.000	0.000
06/20	2	0.000	0.000
06/22	11	5.657	8.522
06/23	7	27.551	29.459
06/24	4	4.167	9.720
06/25	1	0.000	0.000
06/26	1	0.000	0.000
06/27	1	0.000	0.000
06/28	2	0.000	0.000
06/29	0		
06/30	0		
07/01	1	0.000	0.000
07/02	0		
07/03	0		
07/04	1	0.000	0.000
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	0		
07/10	0		
07/11	0		
07/12	0		
07/13	0		
07/14	0		
07/15	0		
07/16	0		
07/17	0		
07/18	0		
07/19	0		
07/20	0		
07/21	0		
07/22	0		
07/23	0		
07/24	0		
07/25	0		
07/26	0		
07/27	0		
07/28	1	0.000	0.000
07/29	0		
07/30	0		
07/31	0		
08/01	0		
08/02	0		
08/03	0		

Table 3. --Continued.

Date	MONITOR SYSTEM - A MAIN Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
08/04	0		
08/05	0		
08/06	0		
08/07	0		
08/08	0		
08/09	0		
08/10	0		
08/11	0		
08/12	0		
08/13	0		
08/14	0		
08/15	0		
08/16	0		
08/17	0		
08/18	0		
08/19	0		
08/20	0		
08/21	0		
08/22	0		
08/23	0		
08/24	0		
08/25	0		
08/26	0		
08/27	0		
08/28	0		
08/29	0		
08/30	0		
08/31	0		
09/01	0		
09/02	0		
09/03	0		
09/04	0		
09/05	0		
09/06	0		
09/07	0		
09/08	0		
09/09	0		
09/10	0		
09/11	0		
09/12	0		
09/13	0		
09/14	0		
09/15	0		
09/16	0		
09/17	0		

Table 3.--Continued.

Date	MONITOR SYSTEM - A MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
09/18	0		
09/19	0		
09/19	0		
09/20	0		
	MONITOR SYSTEM - A SUBSAMPLE		
03/24	1		
03/25	0		
03/26	0		
03/27	0		
03/28	0		
03/29	0		
03/30	0		
03/31	0		
04/01	0		
04/02	0		
04/03	0		
04/05	0		
04/06	0		
04/07	0		
04/08	0		
04/09	0		
04/10	0		
04/11	0		
04/12	0		
04/13	0		
04/14	0		
04/15	0		
04/16	0	–	
04/17	0		
04/18	1	0.000	0.000
04/19	0		
04/20	0		
04/21	1	0.000	0.000
04/22	2	0.000	0.000
04/23	0		
04/24	1	0.000	0.000
04/25	0		
04/26	3	0.000	0.000
04/27	7	0.777	1.806
04/28	8	0.000	0.000
04/29	5	0.000	0.000
04/30	23	0.006	0.018

Table 3.--Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
05/01	17	0.037	0.095
05/02	22	0.011	0.028
05/03	14	0.000	0.000
05/04	13	0.185	0.451
05/05	17	0.086	0.184
05/06	10	0.000	0.000
05/07	26	0.000	0.000
05/08	5	0.000	0.000
05/09	25	0.001	0.003
05/10	9	0.000	0.000
05/11	44	0.012	0.021
05/13	45	0.006	0.011
05/14	23	0.000	0.000
05/15	52	0.014	0.023
05/16	68	0.004	0.006
05/17	47	0.025	0.044
05/18	13	0.037	0.111
05/19	14	0.000	0.000
05/20	18	0.034	0.092
05/21	13	0.000	0.000
05/22	8	0.000	0.000
05/24	22	0.000	0.000
05/25	13	0.000	0.000
05/26	14	1.282	2.909
05/27	18	6.250	7.502
05/28	18	0.617	1.426
05/29	6	0.000	0.000
05/30	6	0.000	0.000
05/31	1	0.000	0.000
06/01	2	0.000	0.000
06/02	5	5.000	11.174
06/03	0		
06/04	1	0.000	0.000
06/05	1	0.000	0.000
06/06	0		
06/07	2	0.000	0.000
06/08	0		
06/09	2	0.000	0.000
06/10	1	0.000	0.000
06/11	1	0.000	0.000
06/12	0		
06/13	0		
06/13	0		
06/14	15	0.000	0.000
06/15	0		

Table 3.--Continued.

Date	MONITOR SYSTEM – A SUBSAMPLE		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
06/16	2	0.000	0.000
06/17	1	0.000	0.000
06/18	0		
06/19	1	0.000	0.000
06/20	0		
06/21	0		
06/22	1		
06/23	0		
06/24	0		
06/25	0		
06/26	0		
06/27	0		
06/28	0		
06/29	0		
06/30	0		
07/01	0		
07/02	0		
07/03	0		
07/04	0		
07/05	0		
07/06	0		
07/07	0	–	
07/08	0		
07/09	0		
07/10	0		
07/11	0		
07/12	0		
07/13	0		
07/14	0		
07/15	0	–	
07/16	0		
07/17	0		
07/18	0		
07/19	0		
07/20	0		
07/21	0		
07/22	0		
07/23	0		
07/24	0		
07/25	0		
07/26	0		
07/27	0		
07/28	0		
07/29	0		
07/30	0		

Table 3.--Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
07/31	0		
08/01	0		
08/02	0		
08/03	0		
08/04	0		
08/05	0		
08/06	0		
08/07	0		
08/08	0		
08/09	0		
08/10	0		
08/11	0		
08/12	0		
08/13	0		
08/14	0		
08/15	0		
08/16	0		
08/17	0		
08/18	0		
08/19	0		
08/20	0		
08/21	0		
08/22	0		
08/23	0	-	
08/24	0		
08/25	0		
08/26	0		
08/27	0		
08/28	0		
08/29	0		
08/30	0		
08/31	0		
09/01	0		
09/02	0		
09/03	0		
09/04	0		
09/05	0		
09/06	0		
09/07	0		
09/08	0		
09/09	0		
09/10	0		
09/11	0		
09/12	0		
09/13	0		

Table 3.--Continued.

Date	MONITOR SYSTEM - A SUBSAMPLE		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
09/14	0		
09/15	0		
09/16	0		
09/17	0		
09/18	0		
09/19	0		
09/19	0		
09/20	0		
	MONITOR SYSTEM - B MAIN		
03/24	0	-	-
03/25	0	-	-
03/26	0	-	-
03/27	0	-	-
03/28	0	-	-
03/29	0	-	-
03/30	0	-	-
03/31	0	-	-
04/01	0	-	-
04/02	0	-	-
04/03	0	-	-
04/05	0	-	-
04/06	0	-	-
04/07	0	-	-
04/08	0	-	-
04/09	0	-	-
04/10	0	-	-
04/11	0	-	-
04/12	0	-	-
04/13	0	-	-
04/14	2	0.000	0.000
04/15	0	-	-
04/16	2	0.000	0.000
04/17	2	0.000	0.000
04/18	5	0.000	0.000
04/19	4	0.000	0.000
04/20	3	0.000	0.000
04/21	8	0.000	0.000
04/22	18	0.858	1.308
04/23	15	2.051	2.898
04/24	16	2.734	3.305
04/25	28	1.902	1.948
04/26	32	1.086	1.138

Table 3. --Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
04/27	31	4.281	3.510
04/28	36	2.691	2.265
04/29	46	3.015	2.162
04/30	43	3.792	2.671
05/01	66	2.662	1.601
05/02	68	4.518	2.424
05/03	31	3.094	2.668
05/04	64	3.630	2.111
05/05	89	1.851	1.056
05/06	68	1.110	0.779
05/07	249	1.900	0.631
05/08	53	2.702	1.878
05/09	150	3.665	1.417
05/10	57	2.406	1.604
05/11	108	1.395	0.755
05/12	131	0.631	0.382
05/13	88	1.360	0.903
05/14	77	1.881	1.246
05/15	116	2.171	1.089
05/16	141	0.719	0.398
05/17	242	0.475	0.208
05/18	98	0.666	0.425
05/19	155	0.282	0.165
05/20	548	0.647	0.179
05/21	711	0.545	0.139
05/22	261	0.638	0.262
05/24	804	0.752	0.167
05/25	375	0.495	0.170
05/26	329	0.692	0.244
05/27	294	0.576	0.218
05/28	399	0.494	0.165
05/29	244	0.446	0.192
05/30	90	0.752	0.514
05/31	61	0.815	0.684
06/01	36	1.546	1.448
06/02	23	0.791	1.190
06/03	9	0.000	0.000
06/04	7	13.333	19.381
06/05	5	3.200	7.421
06/06	10	10.714	14.832
06/07	11	12.121	13.326
06/08	5	1.800	4.755
06/09	5	2.400	5.729
06/10	2	0.000	0.000
06/11	4	0.000	0.000

Table 3. --Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Prdbability of missing a, PIT tag (%)	Standard deviation
06/12	3	0.000	0.000
06/13	3	0.000	0.000
06/13	3	0.000	0.000
06/14	44	2.153	1.671
06/15	4	0.000	0.000
06/16	4	0.000	0.000
06/17	0		
06/18	0		
06/19	1	0.000	0.000
06/20	1	0.000	0.000
06/21	1	0.000	0.000
06/22	7	8.163	12.709
06/23	2	0.000	0.000
06/24	0		
06/25	1		
06/26	0		
06/27	1		
06/28	1	0.000	0.000
06/29	0		
06/30	0		
07/01	1		
07/02	1	0.000	0.000
07/03	0		
07/04	0		
07/05	0		
07/06	0		
07/07	0		
07/08	0		
07/09	1	0.000	0.000
07/10	0		
07/11	0		
07/12	0		
07/13	0		
07/14	1	0.000	0.000
07/15	0		
07/16	0		
07/17	0		
07/18	0		
07/19	0		
07/20	0		
07/21	0		
07/22	0		
07/23	0		
07/24	0		
07/25	0		

Table 3.--Continued.

Date	MONITOR SYSTEM - B MAIN		
	Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
07/26	0		
07/27	0		
07/28	0		
07/29	0		
07/30	0		
07/31	0		
08/01	0		
08/02	0		
08/03	0		
08/04	0		
08/05	0		
08/06	0		
08/07	0		
08/08	0		
08/09	2		
08/10	0		
08/11	0		
08/12	0		
08/13	0		
08/14	0		
08/15	0		
08/16	0		
08/17	0		
08/18	0		
08/19	0		
08/20	0		
08/21	0		
08/22	0		
08/23	0		
08/24	0		
08/25	0		
08/26	0		
08/27	0		
08/28	0		
08/29	0		
08/30	0		
08/31	0		
09/01	0		
09/02	0		
09/03	0		
09/04	0		
09/05	0		
09/06	0		
09/07	0		
09/08	0		

Table 3.--Continued.

Date	MONITOR SYSTEM - B MAIN Number of PIT tags detected	Probability of missing a PIT tag (%)	Standard deviation
09/09	0		
09/10	0		
09/11	0		
09/12	0		
09/13	0		
09/14	0		
09/15	0		
09/16	0		
09/17	0		
09/18	0		
09/19	0		
09/19	0		
09/20	0		