JUVENILE RADIO-TAG STUDY:

LOWER GRANITE DAM,

1985-86

Final Report

by

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ABSTRACT

In 1985 and 1986, research was conducted at Lower Granite Dam to assess the feasibility of using a miniaturized radio tag for estimating spill effectiveness, fish guidance efficiency (FGE), collection efficiency (CE), and survival at the dam. The results indicate that the tag can provide acceptable estimates of powerhouse and spillway passage, that FGE and CE estimates may be affected by the chinook salmon smolts inability to compensate for the tags weight, and that survival estimates could be frustrated by an inability to completely separate dead fish bearing live tags from live tagged fish moving downstream. The passage model developed for Lower Granite Dam is applicable to other dams that have similar smolt passage configurations, and it can be adapted to situations with more passage routes.

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INTRODUCTION

Using group releases of radio-tagged smolts represents a new and potentially powerful research tool that could be effectively applied to juvenile salmonid passage problems at dams on the Columbia and Snake Rivers. A system of strategically located radio monitors could automatically detect and record individually tagged juvenile salmonids as they pass through the spillway, powerhouse, bypass system, or tailrace. Estimation of spill effectiveness, fish guiding efficiency (FGE), collection efficiency (CE), spillway survival, powerhouse survival, and bypass survival may be possible without handling large numbers of unmarked fish. Because nearly all tagged fish arriving at the dam can potentially be sampled, the numbers of marked fish required for individual experiments could be reduced to a small fraction of those required with conventional marking techniques.

A prototype juvenile radio-tag system was developed and tested by the National Marine Fisheries Service (NMFS) and Bonneville Power Administration (BPA) at John Day Dam in 1984 (Giorgi and Stuehrenberg 1984). Results indicated that the system could provide acceptable estimates of powerhouse and spillway passage.

Research at Lower Granite Dam in 1985 (Stuehrenberg et al. 1986) indicated that measures of spillway effectiveness were probably attainable, but acceptable measures of FGE and estimates of survival may be difficult to achieve.

Research in 1986 continued testing of the tag system to further define its application and limitations. Field work included 1) releases in the forebay and tailrace under a no-spill environment and 2) testing of new systems to improve tag detection. Laboratory tests included 1) the response of the tag in hostile environmental conditions (spillway passage) and 2) the effects of the radio tag on fish buoyancy compensation. This report provides results of the work along with a summarization of the combined 1985-86 field and assumption testing.

PART I: 1986 FIELD TESTS

The objective of the 1986 field studies was to continue assessment of the juvenile radio-tag system's ability to measure spillway and powerhouse passage; FGE; CE; and survival through spillways, bypasses, and turbines.

To achieve this objective we 1) released tagged fish in the forebay and tailrace and monitored their passage through the dam under a no-spill environment, 2) tested the effectiveness of underwater antenna systems and a recently designed microprocessor-based tag monitor, and 3) determined whether criteria could be established which would enable us to distinguish tagged live fish from tagged dead fish.

Methods and Materials

Study Area

Lower Granite Dam is located at Snake River Kilometer 173. It is the fourth dam upstream from the confluence of the Snake and Columbia rivers. The dam has six turbines and eight spill gates. The turbines are on the south end of the dam, the spillway is on the north end of the powerhouse, and the navigation lock and earthen fill portion of the dam are north of the spillway (Fig. 1). Smolts passing through the powerhouse may pass through the turbines or the juvenile bypass system. If they enter the bypass system, they can exit back through the turbines, fall out of the overflow on the north end of the bypass gallery into the spillway tailrace, or travel through the bypass pipe

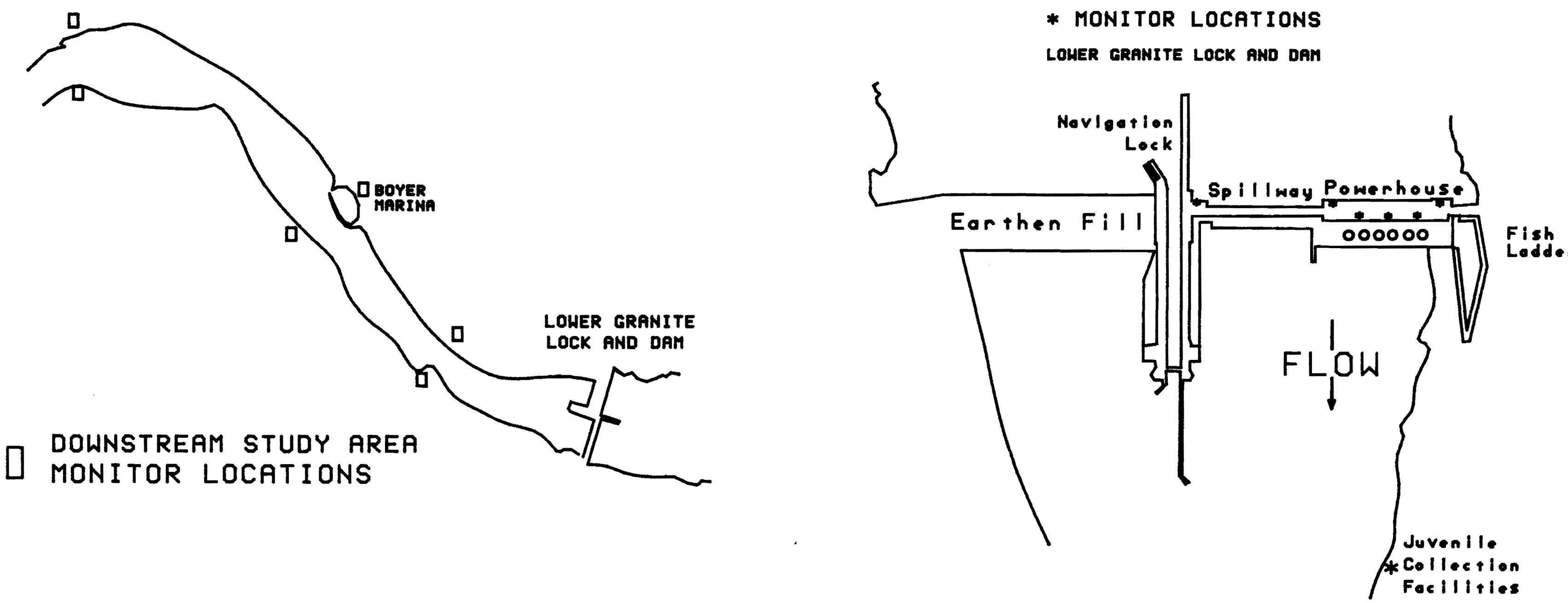

Figure 1.--Radio telemetry monitor locations at and downstream from Lower Granite Dam, 1985-86.

to the separator and into the collection facility downstream from the dam. Other passage routes at the dam are the spillway where smolts may pass under the spill gates (when there is spill), through the navigation lock, or down the fish ladder.

Equipment

The juvenile radio tag was developed by NMFS electronics personnel to monitor movements of individual salmonid smolts. The tags are battery powered transmitters that operate on a carrier frequency of approximately 30 megahertz (MHz). The transmitter and batteries are coated with Humiseal[1/] and a mixture of paraffin and beeswax to form a flattened cylinder 26x9x6 mm which weighs approximately 2.9 g in air (Fig. 2). A 127-mm flexible whip antenna is attached to one end of the tag. Each tag transmits pulses of information on one of nine frequencies spaced 10 kilohertz (kHz) apart (30.17 to 30.25). The pulse rate was set at two per second to provide a minimum tag life of 4 days. The width characters of each pulse provide individual identification (codes) for each tag. Detection range of the tag varied from 12 to 1,000 meters depending primarily on the depth of the fish and the type of antenna used on the monitor. Underwater antennas have the shortest detection range.

The juvenile radio-tag system utilizes a series of strategically located signal monitors. Each monitor is made up of a broadband radio receiver, a

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

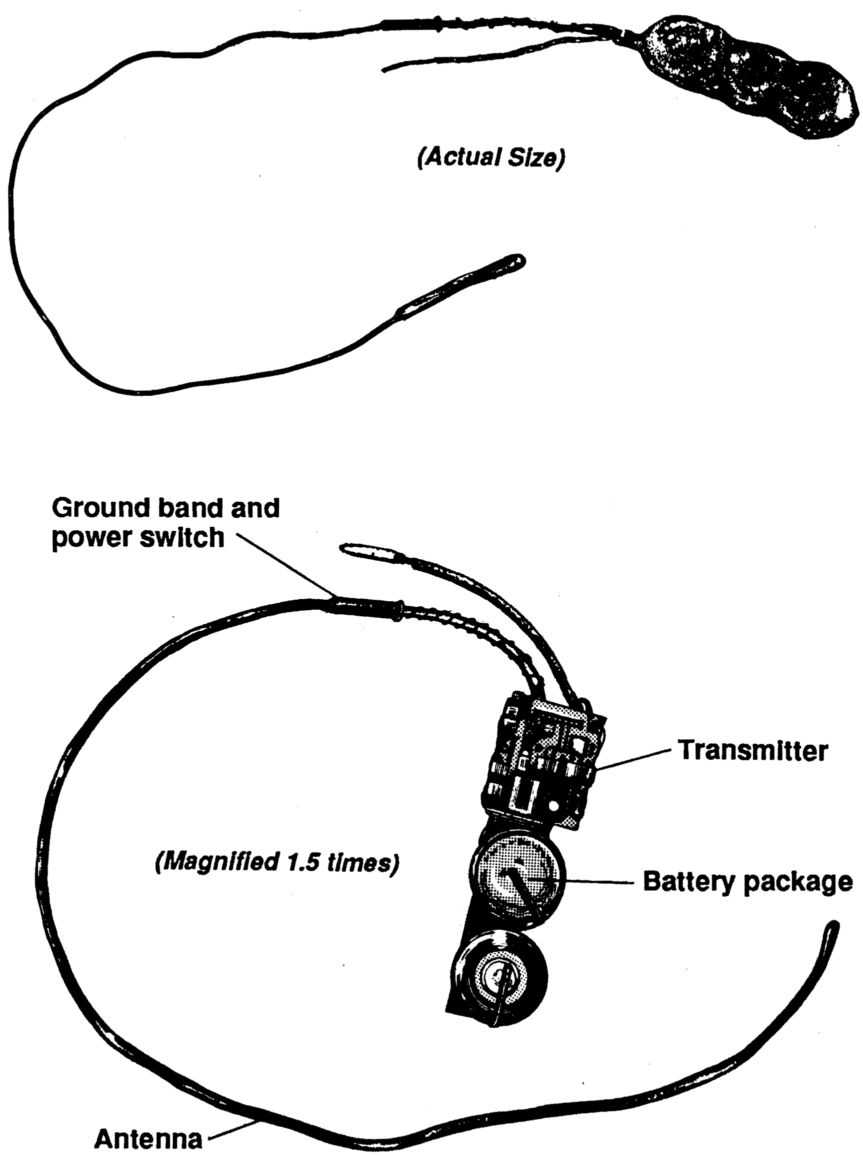

Figure 2.--NMFS, juvenile radio tag used at Lower Granite Dam, 1985-86.

pulse decoder, a digital printer, and a cassette tape recorder. Monitors operate on 12-volt DC current.

The location of the monitors was essentially the same as in 1985 (Fig. 1). Monitors were arranged so that it was possible to isolate various passage locations including the powerhouse, spillway, gatewells, and separator. Additionally, three sets of monitors were located 1.4, 3.2, and 6.1 km downstream from the dam. These three transect sites were the primary recovery sites for the radio-tagged fish. Two auxilliary sets of monitors were also tested in 1986 -- one near the powerhouse and one near the Central Ferry Bridge, 22 km downstream from the dam.

Two types of antennas were used. Underwater antennas were suspended in all gatewells, along the face of the dam in front of the powerhouse, in each spill opening, and in the juvenile separator. Three-element beam antennas were used at the downstream transect sites and the powerhouse tailrace. The powerhouse and spillway antenna systems were ganged together with line amplifiers. Each amplifier boosted the signal to a level equal to the signal lost in the line between underwater antennas. This effectively produced equal tag signals at the monitor for radio tagged smolts at both ends of the powerhouse and spillway. All of the monitors were operated with single antenna input with the exception of the gatewell monitors. Each of the inputs (2) for the gatewell monitors was capable of monitoring three gatewells and thus gatewell activity was definable to a given turbine unit.

Test fish were collected from the bypass population at Lower Granite and McNary dams. Fish from McNary Dam were used to augment the limited number of large chinook salmon available at Lower Granite Dam. Yearling chinook salmon smolts (>150 mm FL) with minimal descaling were separated from the sample and held for radio tagging. Fish were collected 1 or 2 d prior to tagging and held in 1.3-m diameter (open system) tanks at Lower Granite Dam. Smolts collected at McNary Dam were transported to Lower Granite Dam and held at least 1 d prior to tagging. Fish were identified as to source at the time of tagging (Table 1).

Fish were tagged in accordance with procedures described by Stuehrenberg et al. (1986). The tagged smolts recovered in the circular tanks for at least 10 h prior to release. Tags were decoded just prior to release, and fish were then placed on two boats and transported to the release site 5 km upstream from the dam. Half of the fish were simultaneously released on each side of the river about 100 m from shore. Following the upstream release, separate groups of live and dead fish were released into the tailrace frontroll of the turbine boil near the center of the powerhouse. Sample sizes for forebay and tailrace releases are detailed in Tables 2.

In addition to the forebay and tailrace releases, another release was made in 1986. The additional release utilized a few of the Dworshak Hatchery spring chinook salmon which were dedicated to a spill/turbine survival study conducted at Lower Granite Dam. The purpose of this trial was to examine the feasibility of utilizing the radio tag in a survival study of this nature. On 30 March 1986 at 1930 h, two groups of radio-tagged smolts (spillway and tailrace) were included with the branded fish released for the survival study. Thirty-three and twenty-nine fish each were released via a 10.25-cm diameter hose into the spillbay and at the barge loading dock into the tailrace, respectively. Tag recoveries were monitored at the downstream transects including the one at Central Ferry.

In 1985, approximately 15% of the radio-tagged fish entering the powerhouse were not detected at the face of the dam. In 1986, we attempted to

Table 1. Source of yearling chinook salmon smolts radio tagged at Lower Granite Dam, 1986

Release date	Fish source: McNary	Fish source: Lower Granite	Total tagged	Released
9 April	61	50	111	104
18 April	84	47	131	124
26 April	70	71	141	139

held for radio tagging. Fish were collected 1 or 2 d prior to tagging and held in 1.3-m diameter (open system) tanks at Lower Granite Dam. Smolts collected at McNary Dam were transported to Lower Granite Dam and held at least 1 d prior to tagging. Fish were identified as to source at the time of tagging (Table 1).

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Table 2. Release data for radio tagged yearling chinook salmon smolts, Lower Granite Dam, 1986.

Release date	Release time (h)	Release location	Release number
9 April	0920	5 km upstream	68
	0949	Tailrace	Live 20
			Dead 16
			Total 104
18 April	1318	5 km upstream	86
	1350	Tailrace	Live 23
			Dead 15
			Total 124
26 April	1730	5 km upstream	99
	1803	Tailrace	Live 25
			Dead 15
			Total 139

improve this recovery rate of tags at the dam by employing a new antenna/radio receiver system. On 9, 18, and 26 April 1986, a total of 68, 86, and 99 radio-tagged yearling chinook salmon, respectively, were released 5 km upstream from Lower Granite Dam, and their passage was monitored at the dam in an effort to evaluate the antenna/receiver systems.

Prior to the first forebay release, a system of underwater antennas was developed for both the powerhouse and spillway forebay monitors. Using a juvenile radio tag suspended on a downrigger at various depths and towed across the upstream face of the dam, we were able to define the detection zone at the turbine intake (Fig. 3a).

Two monitors were placed on the powerhouse, each covered half of the powerhouse. Underwater antennas, 30 m long, were suspended from the deck into the trashrack (three antennas per turbine intake). A monitor was also placed on the spillway at the start of the first test, but it was moved to the powerhouse tailrace when flow projections indicated that water would not be available for spill (Fig. 3a). Before the second release, we changed the configuration of the underwater antenna system (Fig. 3b) to increase the detection range for the fish that sound near the face of the dam upon entering the turbine intakes (the area of shortest exposure, Fig. 3a). In addition to the 30-m long antennas that were left in place, another set of short antennas were suspended down to the top of the trashrack. The resultant detection zone is depicted in Figure 3b. Prior to the third release, changes were again made to the underwater antenna systems in an effort to increase the tag detection zone (Fig. 3c). The monitor with antennas suspended to the top of the trashracks was not changed, but the antennas for the deep system were moved upstream from the metal trashracks. To support the antennas, a rope was

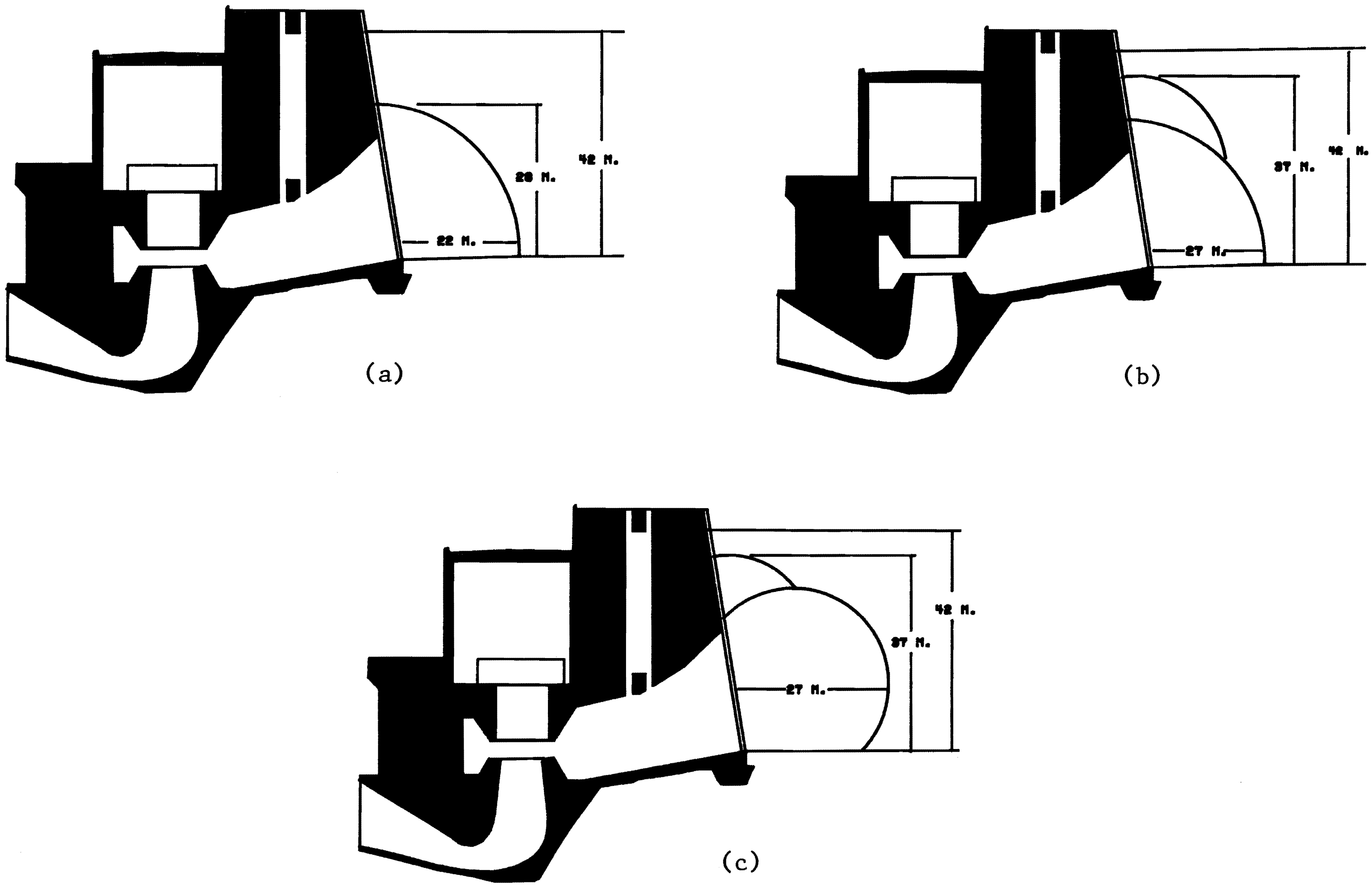

Figure 3.--Areas bounded by curved lines indicate detection zones for miniaturized radio tag. Three antenna configurations: (a) coaxial antenna cable suspended into trashrack, (b) an additional cable is suspended to the top of the trashrack, (c) original cable (a) is suspended in front of trashrack avoiding contact with metal framework.

stretched across the powerhouse roughly 10 m upstream from the face of the dam. Inner tubes were tied to the rope, and the underwater antennas were run from the intake deck through the inner tubes and down to a depth of 24 m.

Prior to the field studies the monitors and cassette tape recorders were changed from integrated circuitry to microprocessor based circuitry. This change reduced the time required to detect and record (less than 1 second) the coded juvenile radio tags. For tagged smolts passing through the powerhouse, tag exposure was about 6 seconds. The operation of the monitors in the field was observed continuously. Prior to the third forebay release, we tuned all receivers to maximize detection sensitivity throughout the total band width of our nine channels and incorporated a design change to stabilize individual channel frequency windows for the forebay monitors. The design change was developed before the field season, but due to lack of parts could not be installed in time for the first two releases. The late arriving parts were installed following the second release.

Results

1986 Passage and FGE Evaluation

Migration routes observed for radio-tagged chinook salmon smolts released at Lower Granite Dam in 1986 are summarized in Figure 4. There was no spill, so all passage was through the powerhouse. Results indicated that approximately 66% (range 62-75%) passed through the turbines and 34% (range 25-38%) were intercepted by the submersible traveling screen and/or diverted into the collection system. Fish identified as turbine passage were 1) tags last heard in the forebay that were not detected by the gatewell and separator monitors plus 2) those tags not heard in the forebay but detected by the

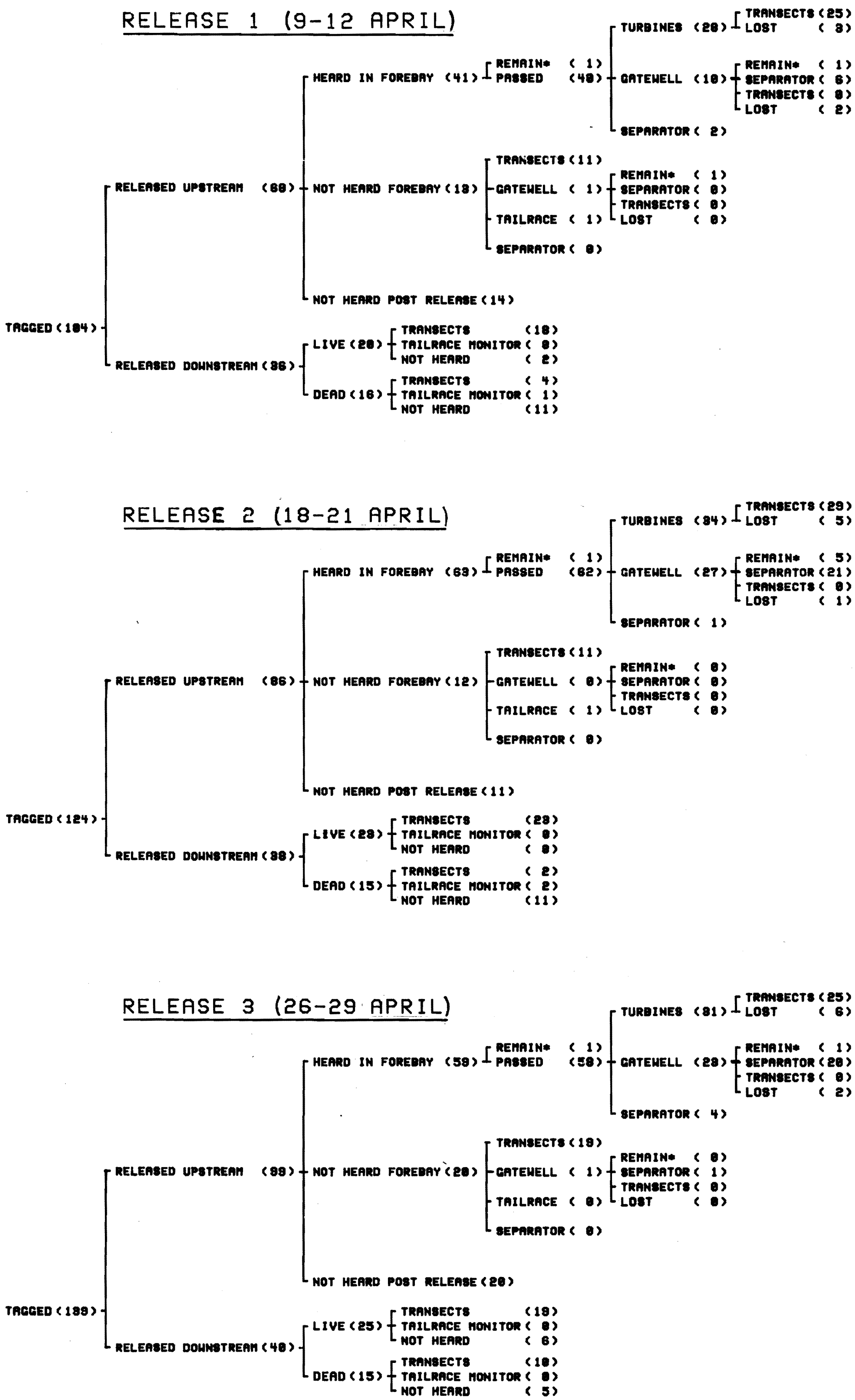

Figure 4.--Migration routes observed for radio-tagged chinook salmon smolts released at Lower Granite Dam, 1986.

* Indicates tags remaining in the study area at the end of the test period.

tailrace and/or downstream monitors. Measures of absolute FGE could not be made because of tags unheard in the forebay and the tag's impairment of swim bladder gas exchange which could affect the fish's vertical distribution in the water column (an assumption based on prior testing).

Forebay Monitor Evaluation

Forebay releases were made on 9, 18, and 26 April 1986 to evaluate the effectiveness of the forebay monitor system. From the first upstream release, 24% (13 of 54) of the detected tagged fish were missed at the face of the dam (Fig. 4). Results from the second forebay release indicated that detection improved; only 16% of the total detected population passing the dam were undetected at the turbine intake (Fig. 4). Data from the third release indicated that 25% (20 of 79) were not detected before passage (Fig. 4). These rates may be considered minimum figures as fish not detected while they passed through the study area are not included in the rates presented.

The failure to improve detection from 1985 to 1986 was not attributable to the antenna system alone but also to detector sensitivity and to lack of stabilization of the individual tag channel frequencies. The failure to improve detection in the third release was caused by an error in tuning the channel frequencies (below the frequency band transmitted by the tags). The error was not discovered until most of the fish from the third release had passed the dam.

Receiver tests conducted at the electronics shop following the field season indicated that the mistuned receivers probably caused the lower detection rate observed in the third and final release. Changes made in tuning the channel windows stabilized the receiver within the ranges of temperature and humidity experienced on the Columbia River system.

Further post field season testing was conducted by the electronics shop to establish the proper channel window width. Most of the tags tested transmitted on a frequency 1 kHz above the channel center frequency. Several were 2 kHz above center frequency, one was 4 kHz above, and one was 2 kHz below. With the 1985-86 receivers, the tag 4 kHz above center frequency would never have been recorded and those 2 kHz from center frequency would only rarely be recorded. In situations with long time exposure to the antenna, sufficient records would be obtained from tags 2 kHz off frequency to substantiate a tag's presence, but in short time exposure situations detection would be unlikely. Because of the limited amount of electronic components that can be placed on the juvenile tag substrate, the loading of the radio antenna can change the output of the tag. The loading of the antenna is affected by the relationship of the antenna to the fish's body and can change somewhat as the fish moves. Based on this information, the monitor channel windows will be set to plus and minus 5 kHz for future research.

In summary, for fish arriving at the dam, a detection rate of 85% is achievable assuming equipment problems that occurred in 1986 are eliminated. Detection rates of 85% were more than adequate to generate the estimates of powerhouse and spill passage proportions presented in Stuehrenberg et al. 1985, where the 95% C.I. around the spill passage estimates for 20 and 40% spill were 28.7 to 49.0% and 50.5 to 71.1%, respectively.

Tailrace Release

Recoveries of tagged fish at the downstream transects indicated that live fish could not always be discriminated from dead fish. Generally, we expected that live fish would always move downstream at a faster rate than dead fish.

This was not the case. Inspection of Figure 5 shows there is some overlap in the travel times of live and dead fish at every transect. Furthermore, nine live fish (13% of all released) were never detected anywhere following release. We assume these fish failed to migrate through the detection zone during the battery life of the tag, or that the tags or the fish died (both low probability based on laboratory tests). It is unlikely that any tagged fish could traverse all three transects without being detected.

These data would indicate that dead radio-tagged fish cannot be consistently differentiated from live ones in the tailrace. Therefore, it would appear that accurate measures of passage survival of chinook salmon will not be possible with the juvenile radio-tag system on the main-stem Snake and Columbia River dams.

Spillway Release

The fish released into the spillway on 30 March 1986 during a special test spill condition (Park 1987) were recovered at a higher rate than those released in the tailrace. Of all spillway fish, 82% (n=27) were detected on at least one transect station following release, compared with 59% (n=17) for the tailrace release. The net result is survival rate of 139%--clearly an unreasonable estimate.

Two factors are believed to have greatly affected this test. First, the test was run before the normal spring chinook salmon outmigration. With fish not willing to move in the river, differences between the flows that the radio-tagged smolts were released into could significantly affect movement to the transects closer to the dam and vulnerability to predation. None of the smolts reached the monitor at Central Ferry. Secondly, smaller fish were used

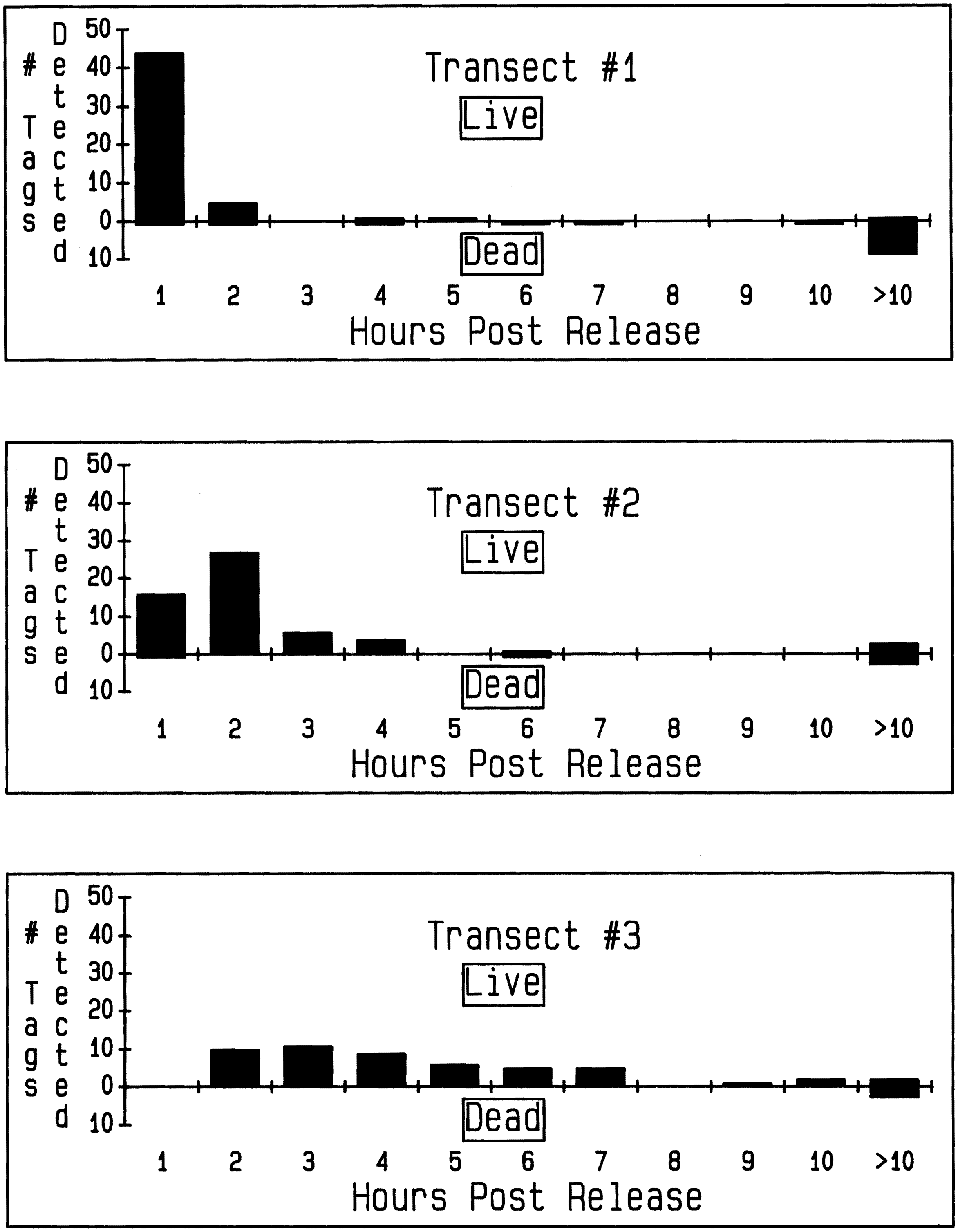

Figure 5.--Number of tagged fish which were detected following their release in the tailrace. The time scale indicates elapsed time (h) from release to passage through each transect's detection zone. Data for both live and dead fish bearing active radio tags appear in the upper and lower portion of each histogram, respectively.

in this test than in later releases. Small fish size increases tagging mortality, decreases buoyancy equilibration rates, and decreases tag reliability.

PART II: ASSUMPTION TESTS

In 1985, we conducted a variety of tests to address tag regurgitation, delayed mortality, tag effects on buoyancy and swimming performance, duration of tag life, and response of the tag to hostile environmental conditions. Of those items we examined in 1985, two required further scrutiny in 1986.

In 1985, we assessed the effects turbulence/impact on tag operation by discharging 51 subyearling chinook salmon through a water cannon at our field station at Pasco, Washington. The cannon nozzle is directed toward the pond surface at a 45 degree angle with the tip approximately 1.5 m above the surface. Fish exit the nozzle at approximately 17 ft/s. These conditions were intended to approximate the conditions a tag-bearing fish encounters when passing through the spillway. In our test, 16% of the tags failed. However, the fish were quite small (<140 mm fork length), and considerable effort was required to push the tag into the esophagus. We suspect that this difficulty may have caused tag failure by cracking the water-tight wax seal during insertion. Consequently, we repeated this test in 1986 employing yearling chinook salmon of the larger size used in field studies.

Also in 1985, we observed that the radio tag impaired a fish's ability to regulate its buoyancy. Yearling chinook salmon displayed responses that indicated that the tag was interfering with swim bladder inflation by either occluding the duct leading from the esophagus to the bladder or occupying so much space that the bladder could not expand sufficiently. There was enough concern regarding this effect that we felt it necessary to continue this line of investigation in 1986.

Methods and Materials

On 5 May 1986, yearling chinook salmon were acquired from the collection facility at McNary Dam and transported to NMFS' Pasco Field Station. Fifty-four fish (>155 mm) were anesthetized and tagged according to the procedures detailed in Stuehrenberg et al. (1986). Tag function and fish condition were checked at 12 h post-tagging and just prior to testing at 24 h. Radio-tagged fish were then discharged through the water cannon, recaptured in accordance with the procedures in Stuehrenberg et al. (1986), and tag operation assessed.

Buoyancy compensation tests were carried out on 6 and 7 May with 67 yearling chinook salmon collected at McNary Dam and transported to the Pasco facility. Fish were anesthetized and individually placed in the chamber described by Stuehrenberg et al. (1986). A partial vacuum was applied, and the pressure was reduced until the fish just rose off the bottom. The pressure of neutral buoyancy (P_{nb}) was determined by subtracting the reduction in pressure necessary to float the fish (Pr) from the atmospheric pressure (Pa). The P_{nb} approaches atmospheric pressure as buoyancy nears neutrality and is thus an indirect measure of bladder volume (Saunders 1965). After initial measurements of P_{nb} were made, the control fish were returned to holding tanks for 24 h to recover. Test fish were similarly anesthetized and decompressed, but were tagged prior to being returned to their holding area. A second buoyancy measurment was made 24 h later on all control and test fish. Post-treatment P_{nb} values were expressed as a percent of pre-treatment values as follows:

$$\text{Percent recovery of } P_{nb} = \left(\frac{P_{nb} \text{ final}}{P_{nb} \text{ initial}}\right) \times (100)$$

(Fried et al. 1976). Percent recovery values for controls should fluctuate around 100%. Tagged fish should approach 100% as the bladder is inflated as compensation for the weight of the tag and initial buoyancy is regained.

Results

Impact/Turbulence Effects on Radio Tag

The impact tests indicated that such conditions can cause tags to malfunction but at a very low rate. Of the 54 fish initially tagged, 46 were actually tested and evaluated in a 24-h post test observation period. The remainder either died during the holding period, were consumed by predators, suffered tag failure immediately following insertion, or were entrained in the water cannon. Only 1 of the 46 (2.2%) test fish exhibited tag failure following the test. The failure resulted from a broken switch mechanism which we attributed to the impact the fish experienced.

Buoyancy Compensation

The P_{nb} values could not be measured for 22 of the 67 yearling chinook salmon tested (33 control and 34 tagged). During decompression, 13 fish (11 controls and 2 tagged) never rose off the bottom of the test chamber but emitted gas through their mouth. The remaining nine fish (all tagged) floated at the surface at ambient pressure (Tables 3 and 4). Thus 26% of all tagged fish (9 of 34) exhibited a response never observed for any control fish. This indicates that the tag does affect buoyancy.

There is further evidence that the radio tag affects buoyancy. The percent recovery to initial P_{nb} was measured for 45 fish (23 controls and 22 tagged fish) which did not exhibit gas emission or floating. The mean percent

Table 3. Buoyancy compensation data for radio-tagged yearling chinook salmon (N=33), 1986.

Length (mm)	Weight (g)	% recovery of initial P_{nb}	Comments
173	51.7	187	
164	41.7	121	
202	83.7	129	
190	67.7	138	
198	78.7	117	
183	57.7	144	Floating fish
180	51.7	139	
170	48.7	<74	Gas emitted
171	54.7	36	
177	49.7	129	
178	53.7	152	
194	69.7	108	
180	59.7	198	
175	49.7	>114	Floating fish
192	66.7	>116	Floating fish
192	71.7	126	
170	50.7	>120	Floating fish
175	50.7	>131	Floating fish
182	56.7	85	Gas emitted
160	39.7	156	
185	61.7	118	
187	65.7	95	
185	63.7	>112	Floating fish
194	74.7	118	
191	68.7	86	
185	59.7	>122	Floating fish
195	77.7	>144	Floating fish
182	55.7	>159	Floating fish
179	53.7	130	
182	60.7	106	
188	59.7	281	
170	49.7	106	
170	45.7	65	

Table 4. Buoyancy compensation data for control yearling chinook salmon (N=34), 1986.

Length (mm)	Weight (g)	% recovery of initial P_{nb}	Comments (Pr = in Hg)
225	108.0	101	Gas emitted Pr>15.0
193	77.5	118	
177	53.5	84	
187	66.5	82	
192	67.5	<96	Gas emitted Pr>7.0
195	72.5	106	Gas emitted Pr>3.0
177	52.5	<92	Gas emitted Pr>4.0
174	52.5	75	
170	45.5	100	
172	49.5	92	
170	46.5	90	
178	55.5	84	
190	67.5	100	
216	97.5	109	
188	65.5	<97	Gas emitted Pr>4.0
196	77.5	122	Gas emitted Pr>10.0
177	51.5	61	
189	61.5	<100	Gas emitted Pr>8.0
174	48.5	<103	Gas emitted Pr>8.5
196	69.5	96	
186	63.5	131	Gas emitted Pr>7.0
185	55.5	112	
193	62.5	100	
213	92.5	154	Gas emitted Pr>14.0
170	43.5	118	
198	74.5	100	
163	42.5	108	
203	87.5	113	
177	48.5	115	
180	63.5	93	
196	75.5	90	Gas emitted Pr 0.0
181	57.5	118	
156	37.5	130	
173	48.5	110	

recovery values were 100.0% for controls and 123.5% for tagged fish. Data are detailed in Tables 3 and 4. Using a Mann-Whitney U test, we found the percent recovery of the two groups significantly different (U statistic = 121, P = 0.003).

These results are considerably different from those observed in 1985 (Table 5). In 1985, 35% of the tagged fish exhibited either gas emission or flotation at ambient pressure, but only 2% of the controls exhibited such responses. Furthermore, in 1985, tagged fish had difficulty entraining a sufficient volume of air to regain their pretagging P_{nb} values, and the mean percent recovery was 85.4% (Stuehrenberg et al. 1986). In contrast, tagged fish in 1986 entrained excess air in their gas bladders and apparently had difficulty discharging it; the mean percent recovery for tagged fish was 123.5% (Table 5). The reason for these interannual differences in percent recovery is not certain. Even so, in evaluating both years of data, it appears that the tag impairs swim bladder gas exchange which could affect the vertical distribution of tagged fish in the water column.

PART III: SPILL EFFECTIVENESS PROBABILITY MODEL

Spill effectiveness estimates were calculated for data collected in 1985 at two spill levels, 20 and 40%. For details of the estimation procedure, see Appendix A. The levels of discharge were maintained for a 48-h period, during which the radio-tagged fish were passing the dam. For both spill conditions, yearling chinook salmon passed over the spillway at a rate in excess of the proportion of the total flow discharged through the spillway. During the time 20% of the river flow was discharged through the spillway, an estimated 40.5% ±11.8 (95% C.I. = 28.7 to 52.3%) of the tagged chinook salmon passed the spillway. At 40% spill, spillway passage was 60.6% ±13.8 (95% C. I. = 46.8 to

Table 5. Comparison of buoyancy data from 1985 and 1986 tests of radio tag effects on yearling chinook salmon.

	1985	1986
Average length (mm)	176.0	182.0
Tagged	37	33
Gas emitted (n)	11	2
Floating (n)	1	9
% recovery ($\bar{x}$)	85.4	123.5
Control	39	34
Gas emitted (n)	1	11
Floating (n)	0	0
% recovery ($\bar{x}$)	107.8	100.0

74.4%). We then tested the null hypothesis that the observed spill effectiveness was equal to the prevailing spill level, using standard normal deviates (Sokal and Rohlf 1987, p. 105)

The test statistics were calculated at 3.41 and 2.80 for the 20 and 40% spill conditions, respectively. For both cases, we rejected the null hypothesis ($P<0.01$).

Spill effectiveness estimates are plotted in Figure 6, and a straight line is extrapolated through the origin. These data suggest that for yearling chinook salmon at Lower Granite Dam, the relationship between spill passage and the percentage of water spilled may be a curvilinear function rather than a straight line relationship.

Based on the relationship between migration routes of radio-tagged smolts and purse seine catches in the John Day forebay (Giorgi 1984), migration routes of large radio-tagged chinook salmon smolts accurately reflect those of the untagged population. The direct effect of fish buoyancy on the spill effectiveness estimates is reduced by the fact that spill water is taken from the same depth as the entrance of the turbine intakes.

The previously mentioned effect of tagging on fish buoyancy leads to a question in using our model to estimate spill effectiveness. If tagged and untagged fish differed in buoyancy and vertical distribution during the 1985 field experiments, they would have been guided into the bypass system in different proportions. As a result, spill effectiveness estimates made using tagged fish might not apply to all migrating fish. The simulation exercise in Appendix A shows that under a wide range of vertical distribution bias conditions, our spill effectiveness estimates apply to untagged as well as tagged fish. We therefore believe that our estimates accurately represent the chinook salmon smolts migrating during the time period of our experiments.

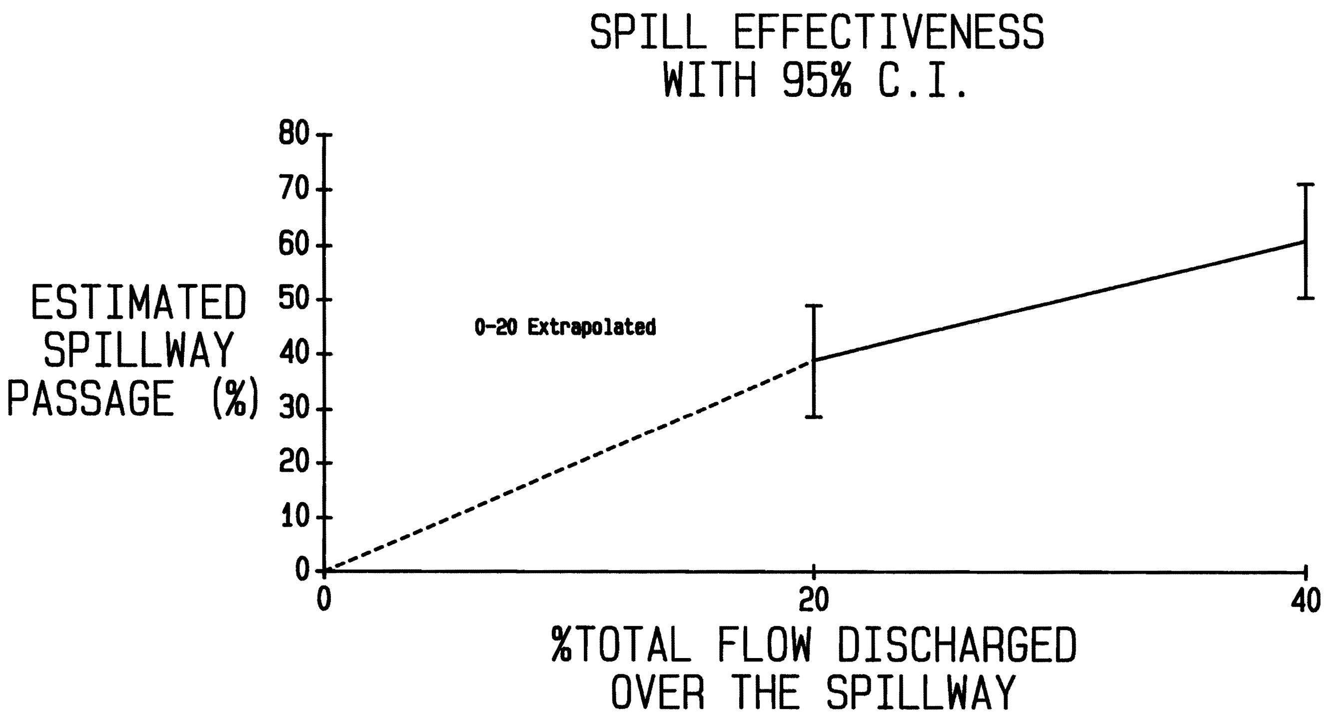

Figure 6.--Estimated spill effectiveness at Lower Granite Dam based on the passage of radio-tagged chinook salmon smolts through the spillway at spill levels of 20 and 40% of the total river flow (1985).

SUMMARY 1985-86 TESTS

Miniaturized radio tags which are inserted into the stomachs of yearling chinook salmon may cause unacceptable rates of mortality in host fish or may impair their swimming performance. Effective tag loss can result from regurgitation of the tag or operational failure of the device. Furthermore, the requirement of tagging smolts large enough to accommodate the tag may provide data unrepresentative of the general population. All of these factors are important considerations when evaluating the feasibility of using the radio tag to estimate FGE, survival, or spill efficiency. In 1985 (Stuehrenberg et al. 1986) and 1986, we conducted investigations to address these concerns (Table 6).

These tests indicated that the effects of radio tags on yearling chinook salmon were minimal and acceptable. Tagged fish did not incur higher mortality than untagged individuals. Whether tagged or not, fish exposed to pressure changes simulating those experienced during turbine passage died at the same rate (0.7 to 1.6% mortality) (Stuehrenberg et al. 1986). Tagged fish appear to be representative of the general population with respect to survival.

Tag regurgitation was minimal, ranging from 0 to 2.7%. Regardless of the treatment (simulated turbine passage, simulated spill passage, or ambient conditions), regurgitation rates were about the same (Stuehrenberg et al. 1986) (Table 6). Thus we would expect no differential tag loss due to regurgitation resulting from passage through a particular conduit (e.g., spillway or powerhouse).

In our field studies, we selected the largest fish available since they could better accommodate the tag. There was some concern that these fish were

Table 6: Summarization of tests to evaluate the various effects of the radio tags on yearling chinook salmon and the effects of passage conditions on the radio tag. Tests were conducted over 2 years, 1985 (Stuehrenberg et al. 1986) and 1986.

Test/objective	Results	Conclusions
1) Compare survival of tagged vs. control fish exposed to pressure changes simulating turbine passage. a/	H_o accepted	When exposed to conditions, tagged fish exhibit the same survival as untagged fish.
2) Determine tag regurgitation rate under three conditions: ambient and simulated spill and turbine passage. a/	1) Under ambient holding conditions, all volitional regurgitation occurs within 4 h post tagging. 2) Turbine condition = 0.8 - 1.4% tag regurgitation. 3) Spill condition = 0% tag regurgitation.	Tag regurgitation associated with either turbine or spill passage is negligible.
3) Determine if large (taggable) smolts exhibit passage behavior different from the general population, using fish guidance as the response. a/	Accept H_o: μ guided = μ unguided	Large (taggable smolts are representative of the general population with respect to guidance behavior.
4) Compare tag failure rate under three conditions: ambient and simulated spill and turbine passage. a/ b/	Accept H_o: μ turbine = μ ambient	Pressure changes associated with turbine passage and spill-like impact does not affect tag performance.
5) Determine if the tag interferes with the regulation of air bladder volume. a/ b/	The tag impaired the hosts ability to entrain and discharge air from the gas bladder.	Impaired gas exchange may affect vertical distribution. Therefore, recommend against using radio tag for FGE work.
6) Determine if the tag impairs swimming performance, using swimming stamina as the response. a/	Accept H_o: μ tagged = μ controls	Radio tags do not decrease swimming performance.

a/ Tests were conducted in 1985. Details regarding tests can be found in Stuehrenberg et al. (1986).
b/ Tests were conducted in 1986. Details regarding tests can be found in this document.

not representative of the general population, especially with respect to their guidability by submersible traveling screens (STS). However, when examined, the size composition of guided and unguided fish were the same, indicating that the screens were not size selective (Stuehrenberg et al. 1986).

Overall, radio-tag performance was acceptable. Most failures observed within the 72-h test period for field studies occurred within 10 h following activation and insertion, and we recommend this as a minimum holding time prior to release. During the potential detection, or tag recovery, period (10 to 72 h) for field studies, the tag decay or failure rate was only 4.3%. When active tags were subjected to simulated turbine pressure conditions (Stuehrenberg et al. 1986) and spill-like impact, they exhibited the same failure rate as control tags held under ambient conditions. Thus, passage route should not affect the rate of tag failure.

Radio tags apparently interfered with some fish's ability to adjust swim bladder volume. Impaired fish were unable either to entrain or discharge the amount of air necessary to attain pretagging buoyancy levels. It is possible that this condition may to some extent perturb their normal vertical distribution in the water column which in turn may affect FGE.

Radio tags did not reduce swimming capability of yearling chinook salmon in tests conducted in 1985 (Stuehrenberg et al. 1986). Fish fitted with radio tags exhibited levels of swimming stamina which were slightly lower than those observed for control fish, with mean Ucrit values of 4.04 and 4.43 BL/S, respectively. However, the means were not statistically different. On this basis, we conclude that the radio tag does not significantly impact the swimming performance of yearling chinook salmon and that tagged fishes migrational behavior is representative of the general population in that respect.

Based on results from this 2-year study, we do not recommend that the miniaturized radio tag be employed in estimating absolute FGE. Since the tag does impair swim bladder gas exchange, this could affect the vertical distribution of tagged fish in the water column and potentially, the fish's susceptibility to guidance by STS. However, the tag system could provide relative week to week or year to year differences in FGE. This could be useful to verify the net and hydroacoustic data at dams such as Lower Granite Dam where there is considerable variability in FGE.

In this program we also evaluated the feasibility of using the radio tag in survival studies. We found that it was not possible to definitively discriminate between live and dead fish bearing active tags. Some dead fish were observed to drift to the downstream monitor transects at the same rate as live fish. In a river situation where high velocities prevail, it is unlikely that an absolute criteria for identifying live fish can be developed. Consequently, we recommend against using the current radio tag for survival studies in river situations of this nature. However, in smaller tributaries, these criteria may not be so hard to define. Stier and Kynard (1986) successfully employed a miniaturized radio tag to estimate survival of Altantic salmon, Salmo salar, smolts passing through a turbine at Holyoke Dam on the Connecticut River. In that study, investigators were able to readily distinguish dead from live fish based on rate of downstream movement. Considering their success in a relatively small river system, we could expect that the NMFS radio tag may be successfully employed in survival studies at smaller rivers within the Columbia-Snake River Basin.

The most promising use for the radio tag in passage research in the Columbia and Snake rivers is for estimating the proportion of the yearling chinook salmon population which passes a dam via either the spillway or powerhouse. Research conducted at John Day Dam demonstrated that radio-tagged fish approaching the dam exhibited the same migration patterns as the general population (Giorgi et al. 1985). In that study, radio-tagged yearling chinook salmon were tracked through the same areas in the forebay where purse seine sampling indicated fish were concentrated. Also, the diel passage patterns witnessed for radio-tagged fish were consistent with observations made for the general population (Giorgi et al. 1985).

In 1985, Kuehl (1986) also estimated spill effectiveness at Lower Granite Dam using hydroacoustic techniques. She found that 11, 19, and 35% of the fish population passed over the spillway when 4, 20, and 40% of the river flow was discharged through the spill way, respectively. These estimates are considerably different from our measures of 41% at 20% spill and 61% passage at 40% spill. There may be several reasons for this, Kuehl's (1986) estimates are not species specific whereas ours pertain only to yearling chinook salmon. Also Kuehl generated her estimates at different times. In one case, the estimate was based on only 4 h of sampling. We suggest that in the future, hydroacoustic and radio tag studies be complementary and that independent estimates be generated simultaneously, on the same population, and under the same flow conditions. Such an approach would permit us to evaluate the merits and deficiencies of both techniques in an efficient manner.

CONCLUSIONS AND RECOMMENDATIONS

1. The miniaturized radio tag system is an effective tool for estimating the proportions of yearling chinook salmon populations passing a dam via either the spillway or powerhouse and for estimating spill effectiveness (proportions passing over the spill at varying levels of spill).

2. With respect to migration routes and passage location, there is no evidence to indicate that radio-tagged smolts exhibit passage behavior different from untagged fish.

3. We recommend that concurrent radio-tag and hydroacoustic spill effectiveness studies be conducted. This direct comparison would permit the merits and deficiencies of both techniques to be efficiently evaluated.

4. We do not recommend that the radio tag be used to estimate mortality associated with dam passage in large, swift rivers such as the Snake or Columbia. However, based on radio-tag survival studies conducted in a smaller river (Stier and Kynard 1986), its use in tributaries within the Columbia Basin warrants investigation.

5. We do not recommend that the juvenile radio-tag system be employed to estimate absolute FGE for chinook salmon. Host fish exhibited difficulty adjusting swim bladder volume which could potentially perturb their normal vertical distribution and guidance.

ACKNOWLEDGMENTS

Support for this research came from the region's electrical ratepayers through the Bonneville Power Administration.

We thank the National Marine Fisheries Service personnel who provided support and assistance crucial to the execution of this project, especially

Dave Brastow, Cheryl Buck, and Jay Wilson for programming, data analysis, and statistical analysis. Chuck Barlett, John Govig, and Mark Kaminski provided the design, construction, and maintenance of all electronic equipment employed during this study.

We gratefully acknowledge the assistance of the U.S. Army Corps of Engineers and Fish Passage Center personnel for obtaining the flow conditions necessary for this study and the project personnel at Lower Granite Dam for their assistance during a very busy period at the dam.

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APPENDIX A

MODELING AND ESTIMATION

Using data recovered from the radio receiver monitors, each released fish was assigned to one of eight categories referred to below as detection fates:

1) Detected passing via spillway and again downstream.
2) Detected passing via spillway but not downstream.
3) Detected passing via turbine and again downstream.
4) Detected passing via turbine but not downstream.
5) Detected passing both into powerhouse and in bypass system.
6) Detected only in bypass system.
7) Detected downstream but not at the dam.
8) Not detected after release

Each fish released during the experiment underwent exactly one of these detection fates. We assumed that the probability of experiencing a particular fate was the same for each fish released and that each fish's fate was independent of all others.

If $N_1, N_2, \ldots, N_8$ are the numbers of fish observed in each category and $\pi_1, \pi_2, \ldots, \pi_8$ are the probabilities of the fates, then the N_i are multinomially distributed with

$$P(N_1, N_2, \ldots, N_8 \mid N_R, \pi_1, \pi_2, \ldots, \pi_8)$$

$$= \frac{N_R!}{N_1!\, N_2! \ldots, N_8!} \prod_{i=1}^{8} \pi_i^{N_i}$$

where $N_R = \sum_{i=1}^{8} N_i$ is the number of fish released.

The probabilities π_i were reexpressed in terms of the following parameters:

P_d = probability that a fish migrated to the dam with a functional tag.

P_s = probability that a fish reaching the dam passed via the spillway.

P_g = probability that a fish entering the powerhouse was guided into the bypass system.

P_{fs} = probability that a fish passing via the spillway was detected by spillway intake monitors.

P_{ft} = probability that a fish passing via the powerhouse was detected by powerhouse intake monitors.

P_{ls} = probability that a fish was lost to downstream detection after passing via the spillway.

P_{lt} = probability that a fish was lost to downstream detection after passing via the turbines.

For the purpose of estimation, spill effectiveness was considered equivalent to P_s and FGE equivalent to P_g.

An example illustrates the process of reexpression. If a fish underwent the first detection fate, it reached the dam with a functional tag, passed through the spillway, was detected by the spillway intake monitors, and reached the downstream monitors with a functional tag. If each of the events in this series was independent of the others, then the probability of undergoing the first fate was the product of the probabilities of these events:

$$\pi_1 = P_d \, P_s \, P_{fs} \, (1 - P_{ls})$$

The remaining π_i were reexpressed in a similar manner. Appendix Figures A1 to A4 present schematically the series of events corresponding to each of the detection fates and may be used in verifying the reexpressions of $\pi_2 - \pi_8$.

The reexpressed π_i are as follows:

$$\pi_1 = P_d \, P_s \, P_{fs} \, (1 - P_{1s})$$

$$\pi_2 = P_d \, P_s \, P_{fs} \, P_{1s}$$

$$\pi_3 = P_d \, (1 - P_s) \, (1 - P_g) \, P_{ft} \, (1 - P_{1t})$$

$$\pi_4 = P_d \, (1 - P_s) \, (1 - P_g) \, P_{ft} \, P_{1t}$$

$$\pi_5 = P_d \, (1 - P_s) \, P_g \, P_{ft}$$

$$\pi_6 = P_d \, (1 - P_s) \, P_g \, (1 - P_{ft})$$

$$\pi_7 = P_d \, [P_s \, (1 - P_{fs}) \, (1 - P_{1s}) + (1 - P_s) \, (1 - P_g) \, (1 - P_{ft}) \, (1 - P_{1t})]$$

$$\pi_8 = 1 - P_d \, [1 - P_s \, P_{1s} \, (1 - P_{fs}) - (1 - P_s) \, (1 - P_g) \, P_{1t} \, (1 - P_{ft})]$$

The maximum likelihood estimator (MLE) for $\underline{p} = (P_d, P_s, \ldots, P_{1t})'$ was obtained using the invariance property of maximum likelihood estimation (Mood et al. 1974). The MLEs for the parameters are:

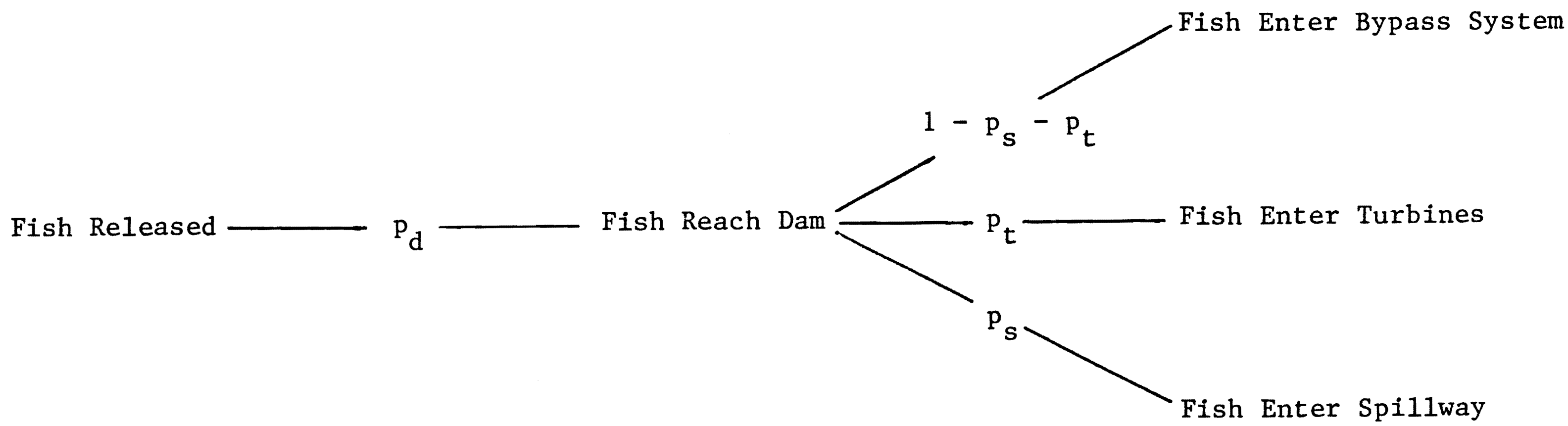
$$P_d = \frac{C + D}{N_1 \, N_5 \, N_R}$$

$$P_s = \frac{C}{C + D}$$

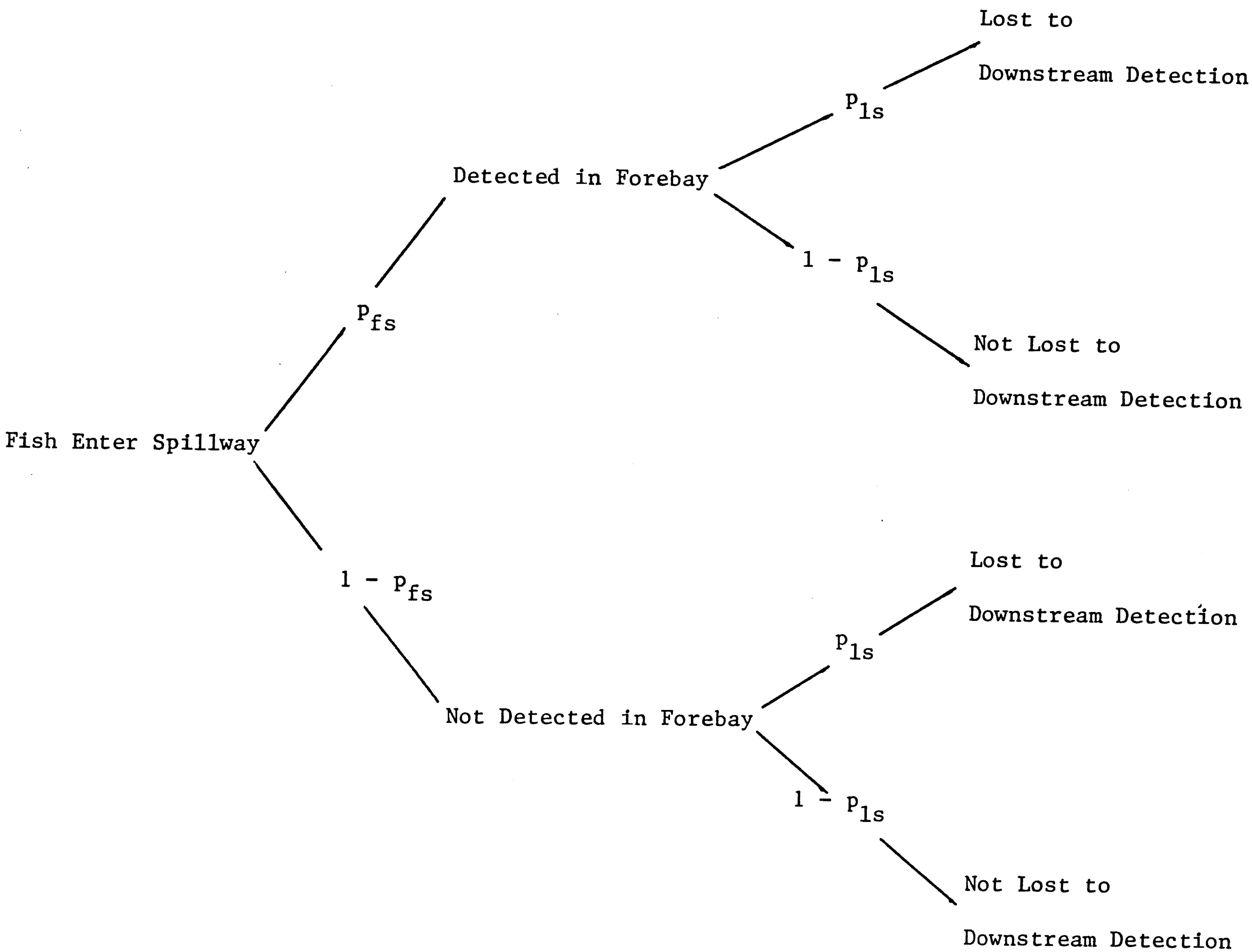
$$P_g = \frac{N_5}{N_3 + N_4 + N_5}$$

$$P_{fs} = \frac{N_1 \, N_5}{N_1 \, N_5 + N_5 \, N_7 - N_3 \, N_6}$$

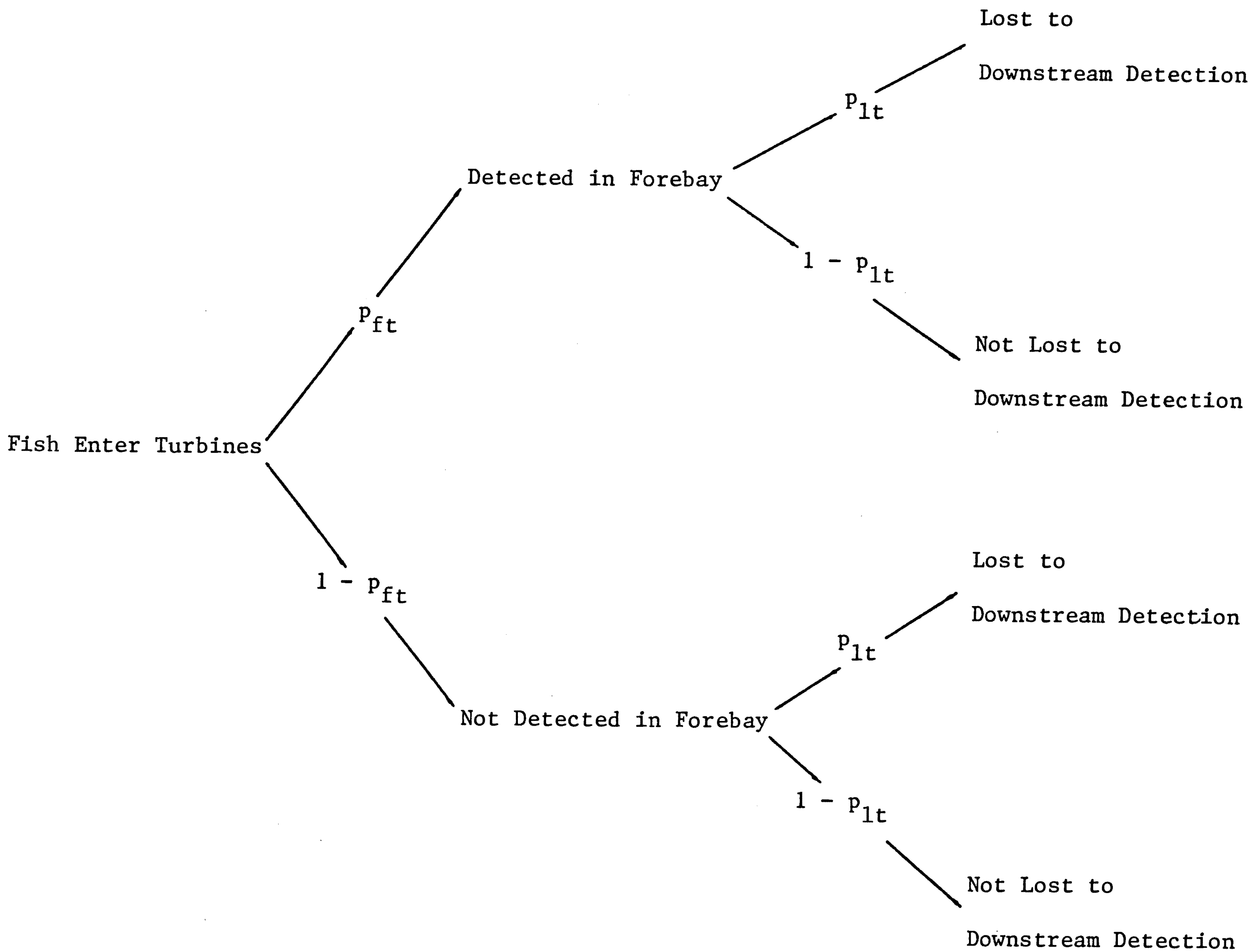
$$P_{ft} = \frac{N_5}{N_5 + N_6}$$



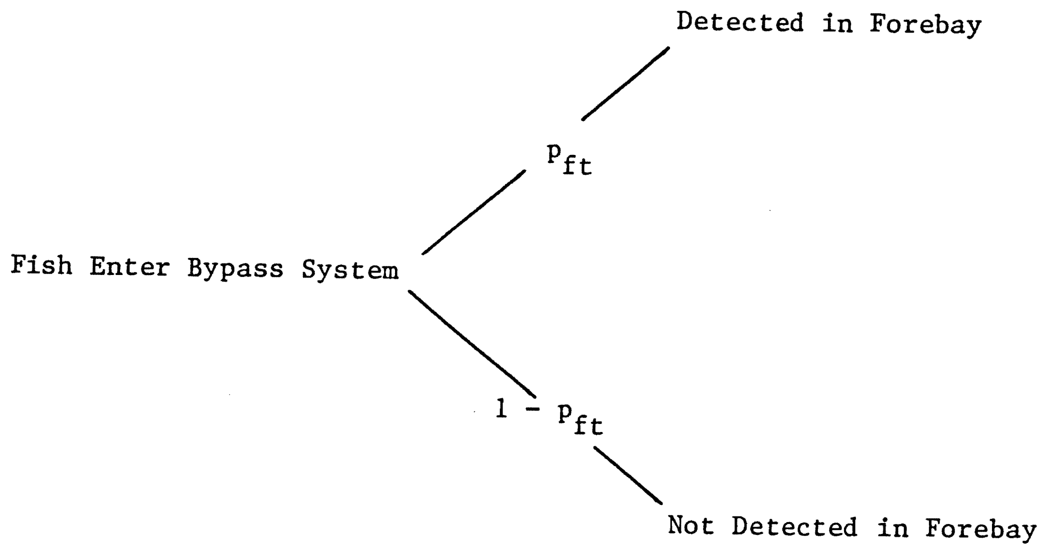
Appendix Figure A1.--Possible dam passage routes of radio tagged fish following release. p_d, p_t, and p_s are as defined in the text.



Appendix Figure A2.--Possible detection fates of fish entering the spillway. p_{ft} and p_{ls} are as defined in the text.



Appendix Figure A3.--Possible detection fates of fish entering the turbines. p_{ft} and p_{lt} are defined in the text.



Appendix Figure A4.--Possible detection fates of fish entering the bypass system. p_{ft} is as defined in the text.

$$P_{1s} = \frac{N_2}{N_1 + N_2}$$

$$P_{1t} = \frac{N_4}{N_3 + N_4}$$

where $C = (N_1 + N_2)(N_1 N_5 + N_5 N_7 - N_3 N_6)$ and $D = N_1 (N_3 + N_4 + N_5)(N_5 + N_6)$.

Sampling variances were estimated numerically for each parameter using the delta method (Brownie et al. 1985, p. 214). For further details on MLE derivation and sampling variance estimation, see Wilson (1987).

The afore mentioned effect of tagging on fish buoyancy leads to a question in using the modeling and parameter estimation process proposed herein. If tagged and untagged fish differed in buoyancy and vertical distribution during the 1985 field experiements, they were guided into the bypass system in different proportions. As a result, those parameter estimates depending on $N_3 \ldots N_7$ (the observed quantities directly affected by vertical distribution and fish guidance) were biased relative to untagged fish. Using the Monte Carlo experiment outlined below, the following question was addressed: Does FGE bias alter parameter estimates sufficiently to be of practical importance in making management decisions?

Experimental releases of radio-tagged fish were simulated under various combinations of spill effectiveness and FGE. Each release was considered a sample from a multinomial population with parameters $N_R = 100$, $\pi_1, \pi_2, \ldots, \pi_8$. The π_i are functions of $\underline{P}$. For simulation purposes, π_i was calculated specifying the following values for the P (.):

1) P_s was 0.4 or 0.6, similar to the estimates obtained in the field experiments.

2) P_g was 0.25, 0.50, or 0.75, representing low, medium, and high FGE levels.

3) P_d, P_{fs}, P_{ft}, P_{1s}, and P_{1t} were assigned the values estimated during the field experiments. For example, P_d was 0.788 when P_s was 0.4 and 0.754 when P_s was 0.5 (Appendix Table A1).

The simulation of these populations was conducted under the six combinations of spill effectiveness and FGE presented in Appendix Table A2. For each combination, 1,000 releases were simulated, assigning 100 "released" fish to the N_i using pseudorandom number generation based on the P_i obtained as above. For each release, $\underline{P}$ was estimated, $\bar{\underline{P}}$, the mean $\underline{P}$ estimate over 1,000 releases was then calculated. For each parameter, I calculated $\bar{P}(.)$ - $P(.)$, the deviation of the mean estimate from the value used in the simulation. The larger the magnitude of the deviation, the greater the effect FGE had on the parameter estimates of spill effectiveness and the other parameters.

The deviations of the mean estimates from the simulation values are presented in Appendix Table A1. The mean parameter estimates showed negligible deviations from the true value when FGE ranged from 0.25 to 0.75. The deviation of mean spill effectivenes (P_s) estimates from the parameter value was less than or equal to 0.01 for all simulation conditions. We therefore believe that it is unlikely that FGE bias would seriously affect spill effectiveness estimates in radio-tagging experiments. P_d, P_{ft}, and P_{1s}, P_{fs}, and P_{ft} showed no discernible bias over a range of FGE values.

Appendix Table A1: Results of 1985 field experiment.

a) Numbers of fish released and observed for Detection Fates 1-7.

	N							
		Fate[a/]						
Spill level (%)	Released	1	2	3	4	5	6	7
20	101	21	5	18	8	19	1	6
40	100	31	7	12	7	7	1	8

b) Maximum likelihood estimates and standard deviations (SD) of model parameters.

	20% spill		40% spill	
Parameter	MLE	SD	MLE	SD
P_s	0.405	0.0601	0.606	0.0702
P_g	0.422	0.0736	0.269	0.0870
P_d	0.788	0.0399	0.754	0.0417
P_t	0.344	0.0580	0.288	0.0673
P_{fs}	0.806	0.0887	0.831	0.0800
P_{ft}	0.950	0.0487	0.875	0.1169
P_{1s}	0.192	0.0773	0.184	0.0629
P_{1t}	0.308	0.0905	0.368	0.1107

a/ Fates are defined on the first page of Appendix A.

Appendix Table A2: Sensitivity of various probability estimates (P_s, P_d, P_{ft}, P_{ls}, P_{fs}, P_g, and P_{lt}) at specified values of FGE and spill effectiveness. The values are the mean MLE - true parameter value, for the specified parameter estimate and FGE level.

Paramenter estimate	Actual FGE	Actual spill effectiveness	
		0.4	0.6
P_d	0.25	0.001	0.002
	0.50	-0.001	0.000
	0.75	0.003	0.000
P_{ft}	0.25	0.002	0.001
	0.50	0.001	-0.003
	0.75	0.001	-0.002
P_{ls}	0.25	0.001	-0.001
	0.50	-0.003	-0.001
	0.75	-0.002	-0.001
P_{fs}	0.25	0.007	-0.001
	0.50	0.004	0.008
	0.75	0.002	0.003
P_{lt}	0.25	-0.004	-0.003
	0.50	0.000	-0.007
	0.75	0.002	-0.004
P_s	0.25	0.000	-0.006
	0.50	0.001	-0.003
	0.75	-0.002	0.000

APPENDIX B

Budgetary Summary

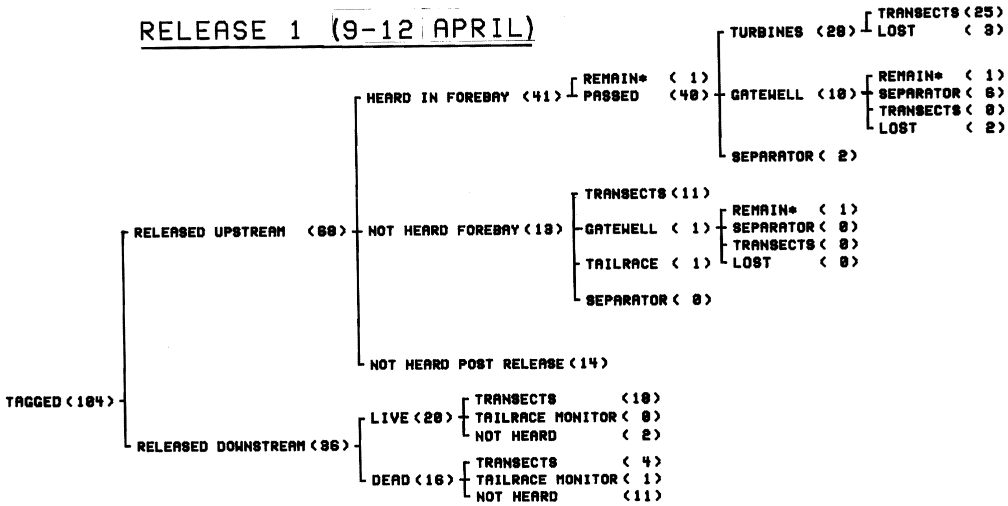
A. Summary of expenditures

1) Labor		$321,938
2) Travel persons		14,620
3) Transportation of things		18,591
4) Rent, communication, and utilities		7,907
5) Printing and reproduction		67
6) Contract services		2,501
7) Supplies, materials, and equipment		227,104
8) SLUC		6,808
9) NOAA and DOC overhead		123,208
	TOTAL	722,744

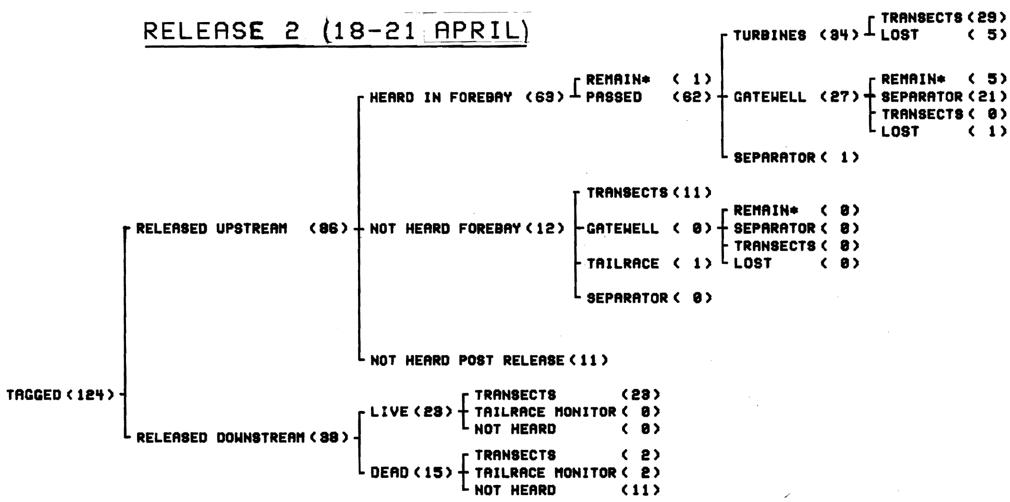
B. Major property items

1) Graphics plotter	$2,613
2) Microcomputer Compaq Deskpro	3,175
3) Printer, Epson FX-286	515

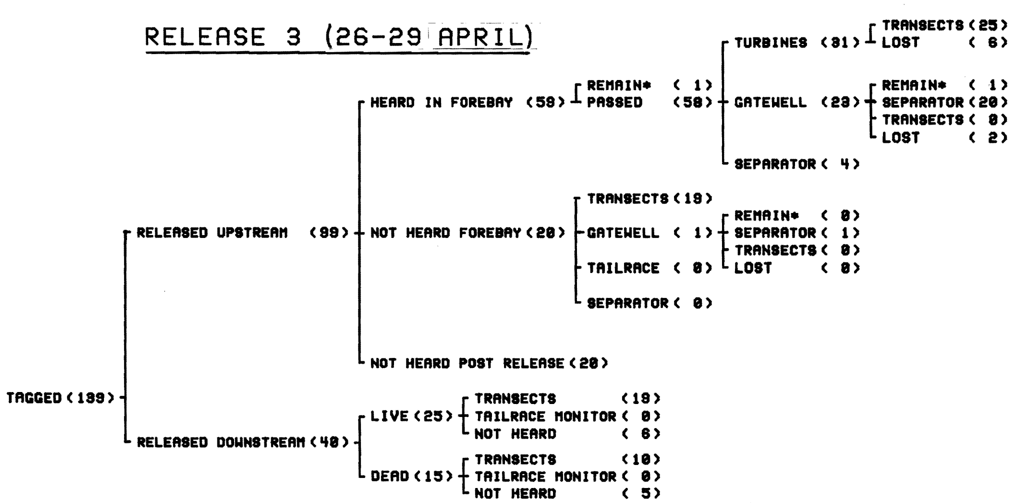
RELEASE 1 (9-12 APRIL)

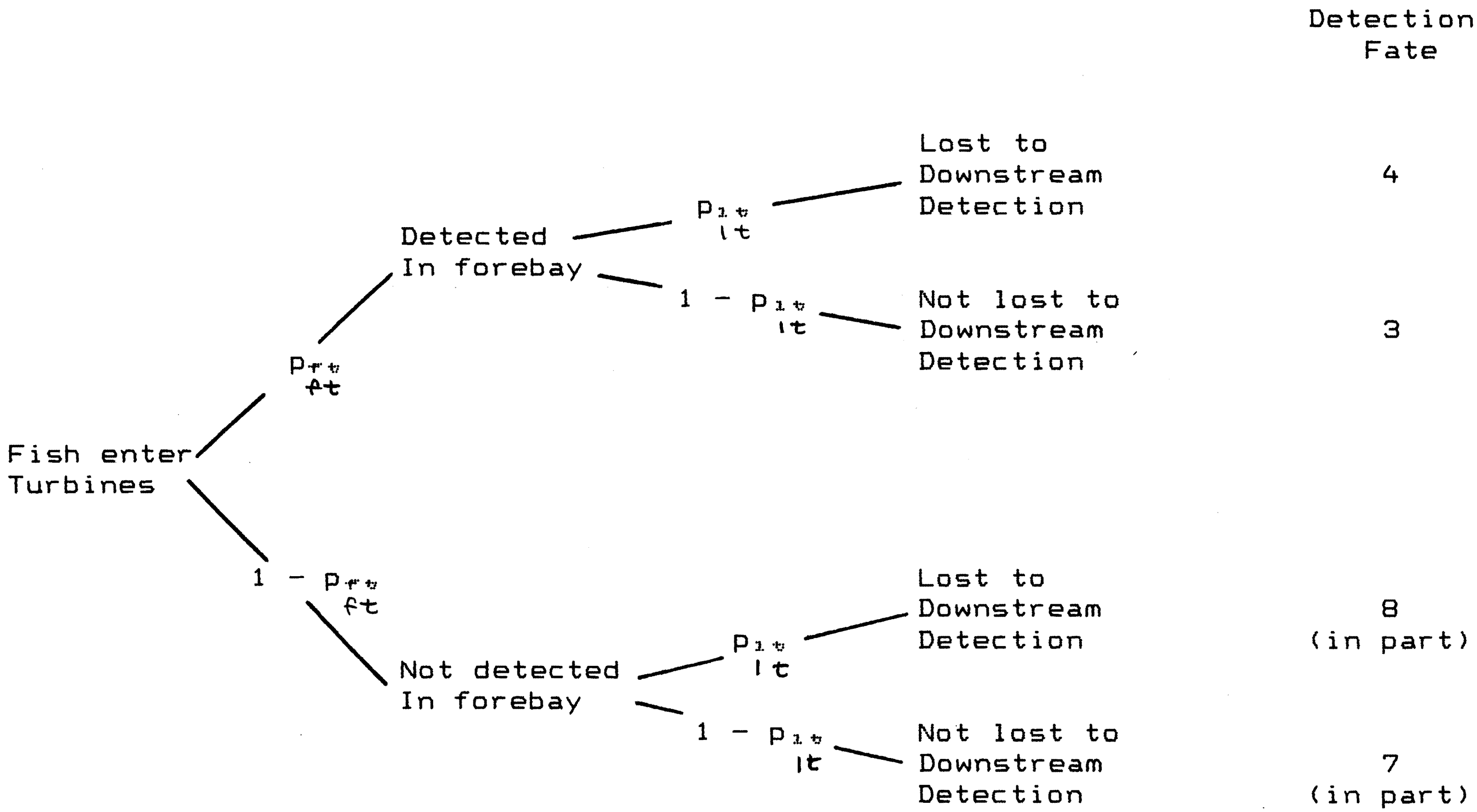


RELEASE 2 (18-21 APRIL)

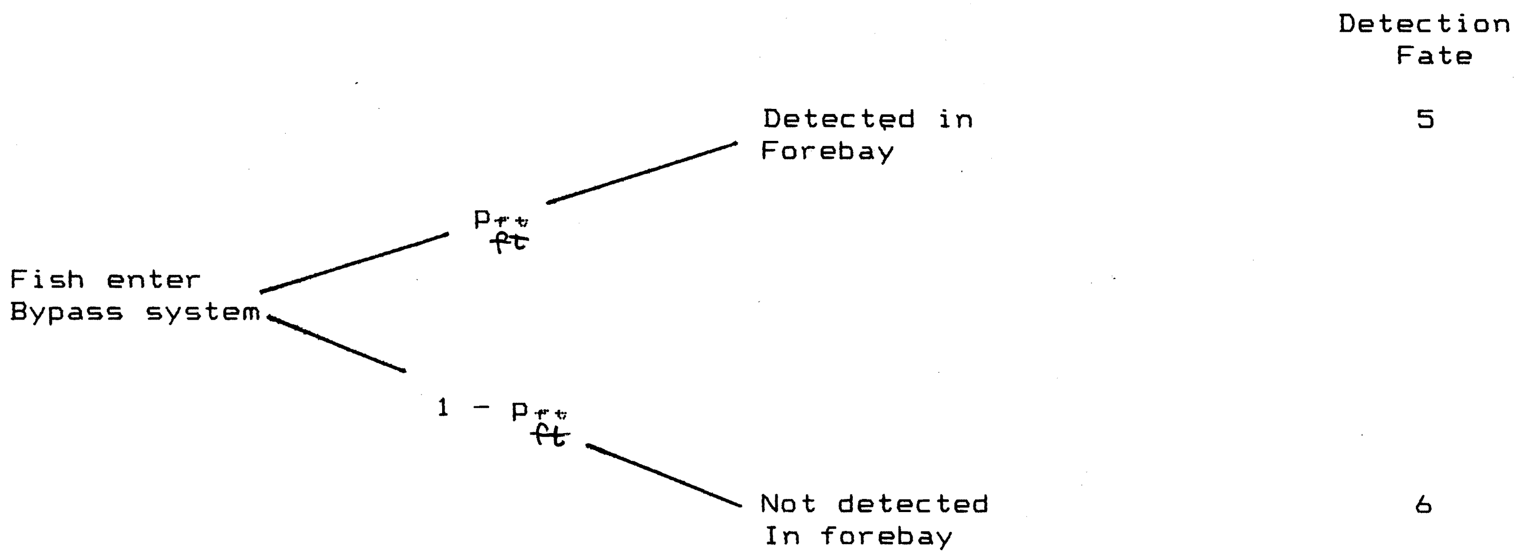


RELEASE 3 (26-29 APRIL)

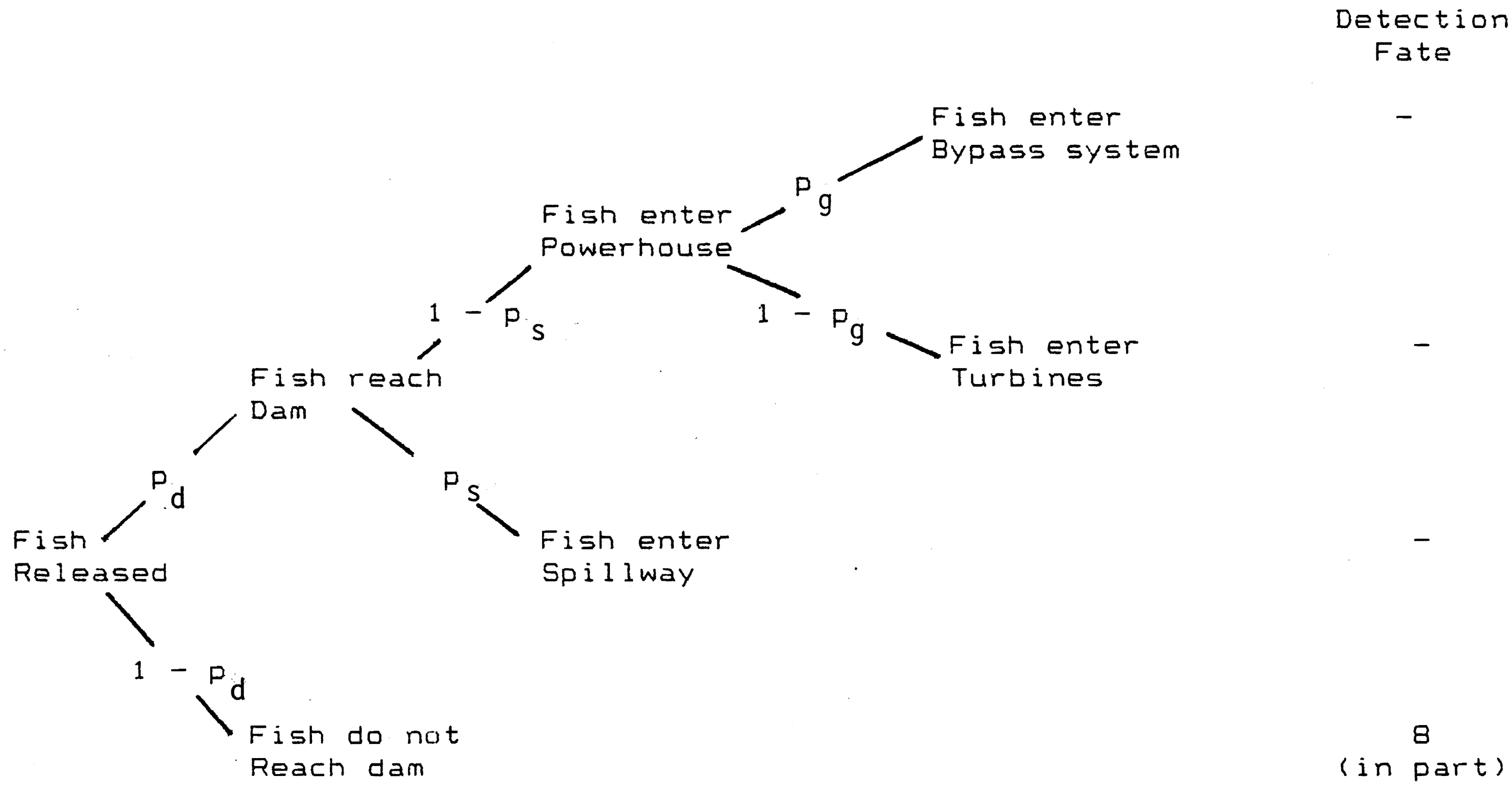




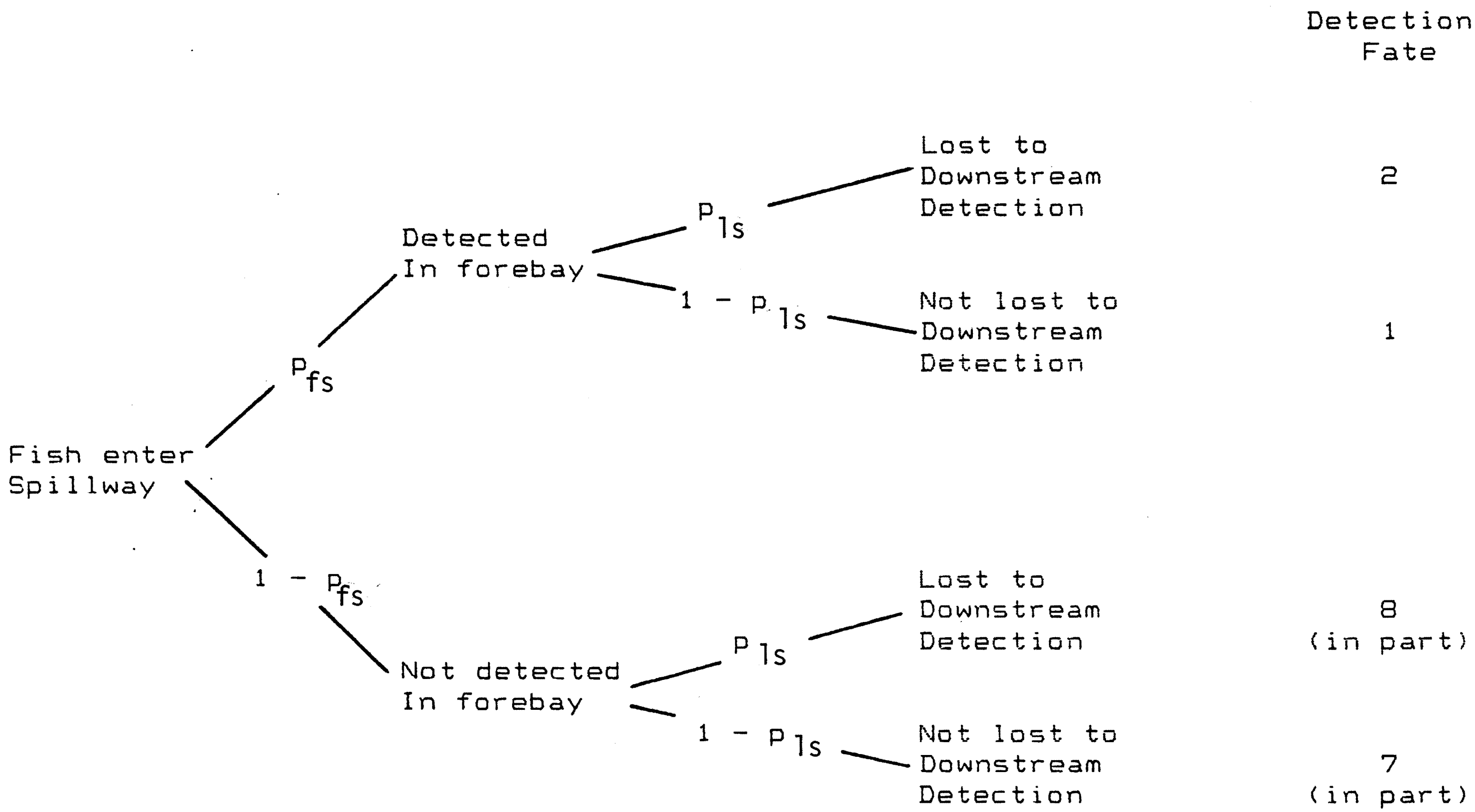
Appendix Figure A3. Possible events and detection fates of fish that enter the turbines. p_{ft} and p_{lt} are defined in the text.



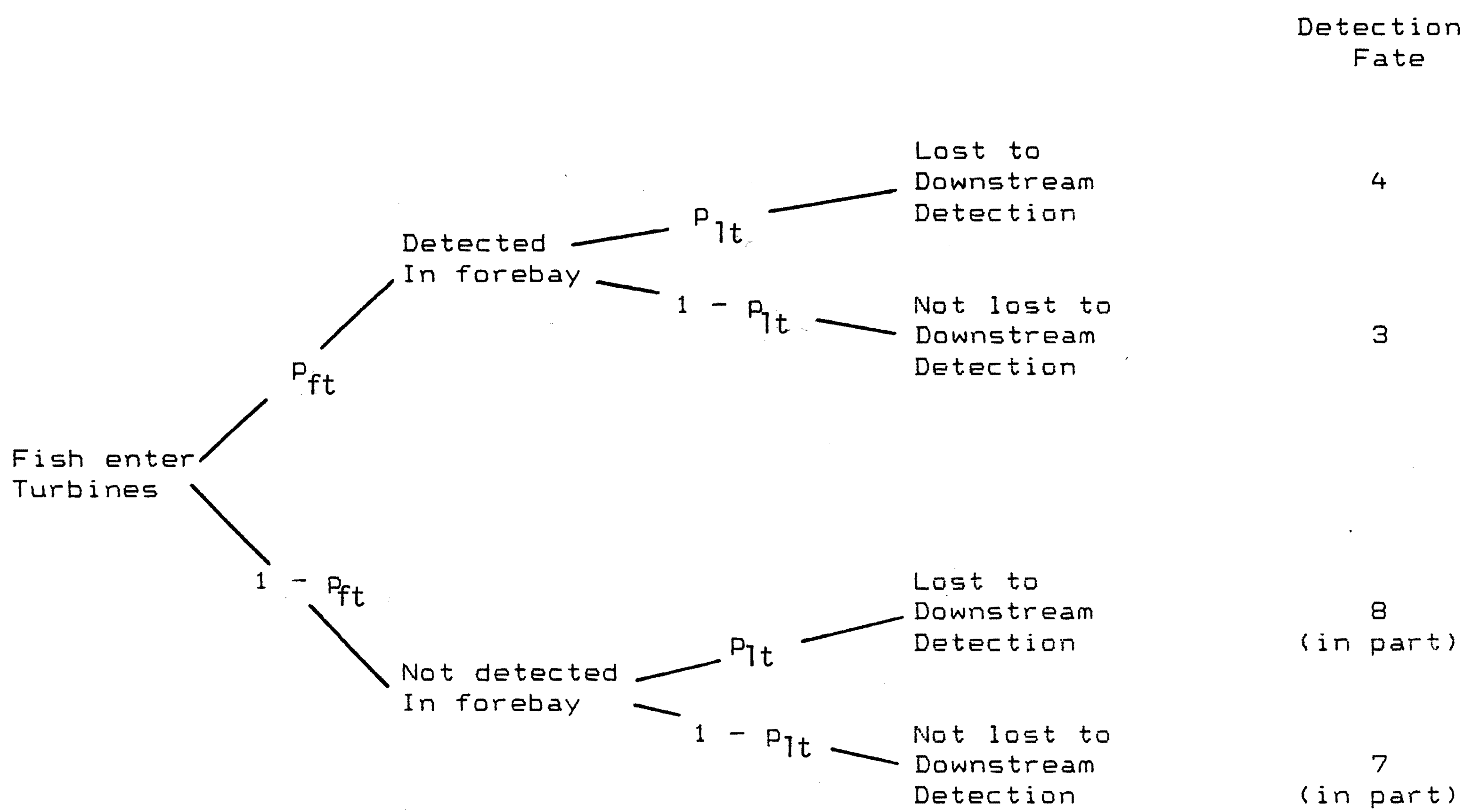
Appendix Figure A4. Possible events and fates of fish that enter the bypass system. p_{ft} is defined in the text.



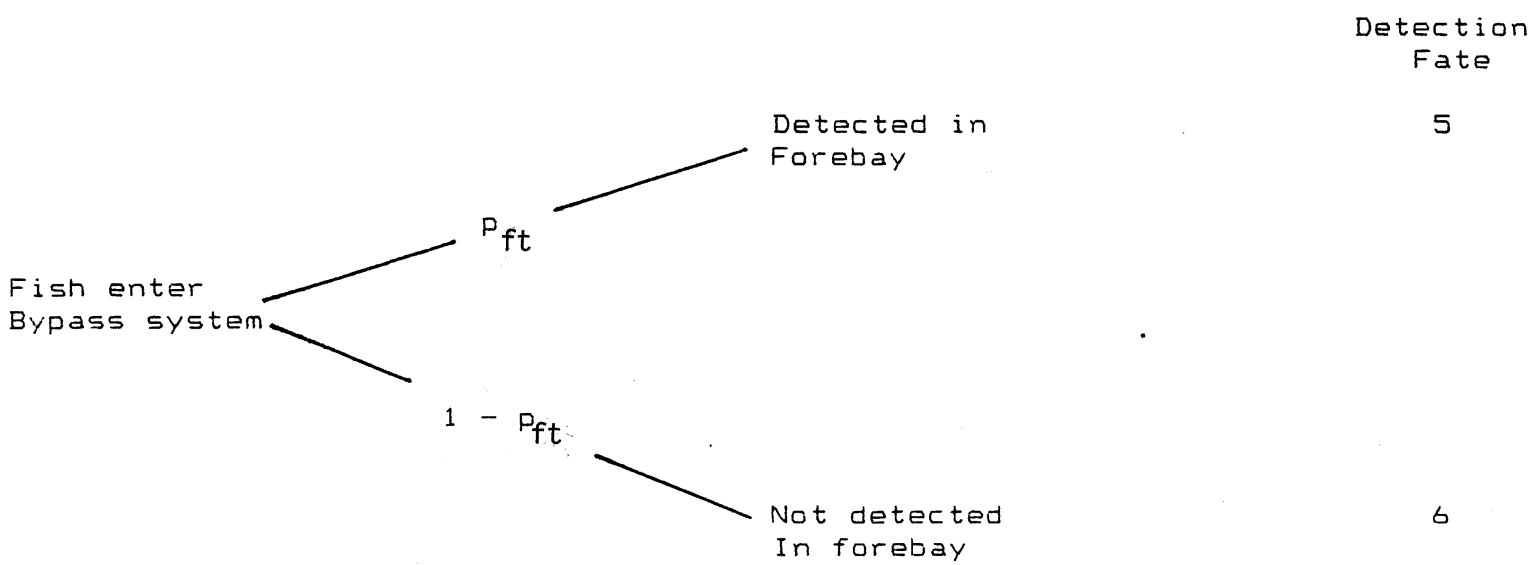
Appendix Figure A1. Possible events and detection fate experienced by a fish between its release and its choice of dam passage route. p_d, p_g, and p_s are defined in the text.



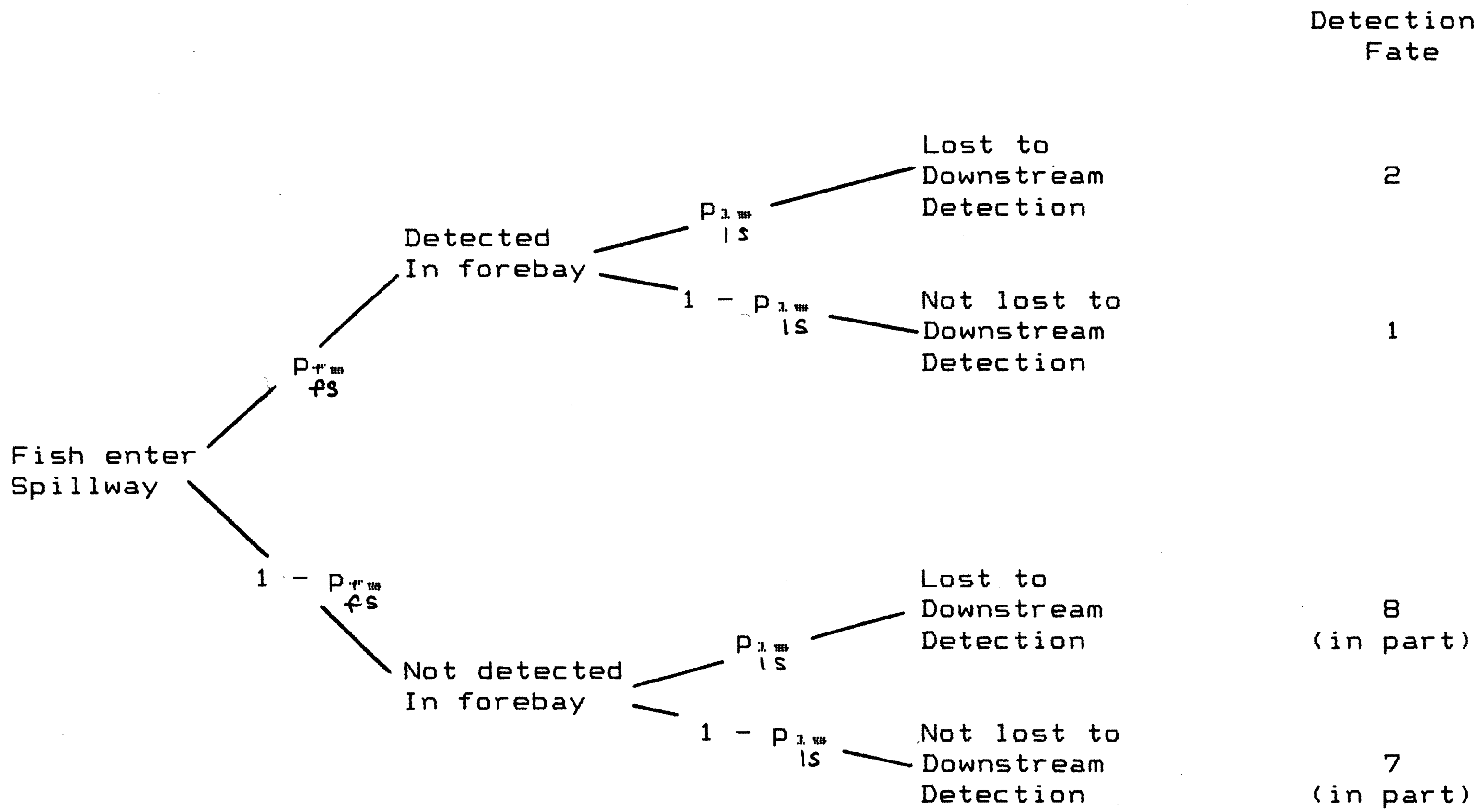
Appendix Figure A2. Possible events and detection fates of fish that enter the spillway. p_{fs} and p_{ls} are defined in the text.



Appendix Figure A3. Possible events and detection fates of fish that enter the turbines. p_{ft} and p_{lt} are defined in the text.



Appendix Figure A4. Possible events and fates of fish that enter the bypass system. p_{ft} is defined in the text.



Appendix Figure A2. Possible events and detection fates of fish that enter the spillway. p_{fs} and p_{ls} are defined in the text.

Appendix Table A1: Results of 1985 field experiment.

a) Numbers of fish released and observed for detection fates 1-7.

		N						
		Fate						
Spill Level	Released	1	2	3	4	5	6	7
20%	101	21	5	18	8	19	1	6
40%	100	31	7	12	7	7	1	8

b) Maximum likelihood estimates and standard deviations (S.D.) of model parameters.

	20%		40%	
Parameter	MLE	S.D.	MLE	S.D.
P_s	.405	.0601	.606	.0702
P_a	.422	.0736	.269	.0870
P_d	.788	.0399	.754	.0417
P_t	.344	.0580	.288	.0673
P_{fs}	.806	.0887	.831	.0800
P_{ft}	.950	.0487	.875	.1169
P_{1s}	.192	.0773	.184	.0629
P_{1t}	.308	.0905	.368	.1107

did you decide to put these in FCE estimates?