Drone and Fish Tests Conducted to Set up the Corner-Collector PIT-tag Detection System at Bonneville Dam

Sandra L. Downing and Earl F. Prentice

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

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U.S. Department of Energy
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BACKGROUND

In 2004, the U.S. Army Corps of Engineers completed a surface-flow bypass system that passes juvenile salmonids at the Second Powerhouse at Bonneville Dam. Fish enter a modified ice and trash sluiceway: an ogee was added near the entrance to the passageway, and the sluiceway flume was extended one-half mile below the dam (Figure 1). Over the past 2 years, this corner-collector bypass system has been attracting large numbers of the migrating salmonids (especially steelhead).

Without PIT-tag detection for this pathway, reach survival estimates, smolt-to-adult return ratios, and other methods used to determine the effectiveness of current management policies and restoration strategies that rely on PIT-tag data have been weakened. Consequently, to provide the PIT-tag data required for these research, monitoring, and evaluation efforts, the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers have been working to develop a PIT-tag detection system for the corner-collector flume.

Figure 1. Aerial photo of Bonneville Dam taken by the U.S. Army Corps of Engineers. The arrow points to the straight section of the exit flume for the new corner-collector bypass system where the PIT-tag antenna was installed (the photo was taken before it was installed).

Based on the data requirements of the survival models used by fish managers, statisticians determined that an overall detection rate of 60% was needed for the corner-collector PIT-tag system in order to replace the numbers of detections that were available at Bonneville Dam before operation of the corner collector began. Starting in 2003, BPA contracted with Digital Angel Corporation (formerly Destron-Fearing), to develop a detection system that would meet the 60% detection goal. In order to produce a system that would work with a 17- by 17-ft antenna, Digital Angel had to redesign all of the components that make up a PIT-tag detection system (i.e., they developed a new antenna, new transceiver, and new tag).

By June 2005, Digital Angel appeared to have successfully pushed the PIT-tag technologies to new limits with this system, but they had difficulty finding a company to manufacture the antenna housing until the end of November. Therefore, it was not until the system had been completely installed in April 2006 that the whole system could be tested for the first time. This approach was acceptable given that each PIT-tag installation typically requires its own site-specific solutions because each site has unique features (e.g., electromagnetic noise parameters vary significantly from site to site and electrical grounding can be problematic).

After all the components of the PIT-tag detection system had been installed, Digital Angel conducted a number of electronic tests under both "dry" and wet flume conditions to set up the system for fish detection. They were then ready to have tagged drones and fish pass through the system in order to determine how well the system was performing and what improvements were needed to meet the 60% tag-reading goal.

BPA contracted National Marine Fisheries Service (NMFS) to assist Digital Angel in setting up their equipment by conducting drone and fish tests. Both the BPA and its contractors anticipated that the new system would undergo adjustments during 2006. Thus, evaluations to determine tag-reading efficiencies for different salmonid populations traversing the PIT-tag system were scheduled to be conducted in 2007, after the operation and maintenance of this system is better understood. To help design this evaluation, NMFS released tagged fish in 2006 from three locations in front of the entrance to the corner collector to determine if this variable would affect tag detection by the corner-collector PIT-tag system. This report covers the work conducted by NMFS during April and May 2006 as related to these tests.

DRONE TESTS

Normally, short wooden sticks with tags glued into them are used to evaluate the performance of PIT-tag systems. NMFS did not think that these tags would work well for this evaluation because Digital Angel wanted to know how well the system was reading tags at different vertical and horizontal locations within the huge antenna. Therefore NMFS designed floating drones specifically for this project; the drones held tags at three water depths (~1 ft from the bottom, mid-depth (~7 ft), and ~1 ft below the surface) (Figure 2).

Figure 2. Photo of floating drones designed and released by NMFS. The tags were inserted into wooden blocks fastened onto plastic vanes, which were connected to floats with three lengths of rope (the one shown yielded a tag passing through the antenna near the bottom of the flume). A 12-oz ball weight was attached at the bottom to help maintain orientation.

On 24 and 25 April 2006, NMFS assisted Digital Angel by releasing the floating drones from three horizontal locations across the flume (toward shore, at center, and toward the river; Table 1). Furthermore, NMFS inserted two different tag models into the drones: the current ST tag, which will be in most tagged salmonids passing through the corner collector during 2006, and the new SST tag, which was developed by Digital Angel specifically for corner-collector project. The SST will become the standard tag within the Columbia River Basin in 2007.

On 24 and 25 April 2006, NMFS released 102 ST-tagged drones and 99 SST-tagged drones from the upstream end of the fishing platform located near the antenna (Table 1). For these tests, the G2 transceiver designed for the corner-collector PIT-tag system was set up to save a time-stamped record every time the system read a tag. Consequently, a single tag could have multiple records. Setting up the transceiver this way allowed us to compare the number of reads per tag for the two tag types. Except for a few of the drones that were released near the shore edge of the flume, the movement of the surface water pushed most of the floating drones toward the middle of the flume (therefore, we then just released the rest from the center).

Table 1. The table provides the locations and numbers of ST-tagged and SST-tagged drones released to help set up the detection system at the corner collector (BCC).

Drone Information			
Tag location	Release location	ST tags	SST tags
Top		57	54
Middle		21	21
Bottom		24	24
	Center	77	74
	Shore	13	13
	River	12	12
	All	102	99

The results did not suggest any pattern in detection of the tags at different depths and so all of the results were lumped together.

The PIT-tag system detected 53 of the ST-tagged drones (52.0%) and 70 of the SST-tagged drones (70.7%). With these drone-release numbers and reading efficiencies, the confidence intervals are ±7.5-10% for these results. The median number of reads per tag was 3 for ST tags and 5 for SST tags. A *t*-test indicated that the number of reads per tag between the two tag types was significantly different ($P = 0.002$). The frequency distribution graphs illustrate the improved detection of SST-tagged drones compared to the ST-tagged drones, as more SST tags were detected in the higher detection categories (number of reads per tag) and fewer in the lower categories, especially in the 0 or undetected category (Figure 3). By combining some of the detection categories, the difference between the tags is easier to visualize (Figure 3, lower panel). The pattern for the ST-tagged drones showed an inverse relationship between the number of reads per tag and the percentage of tags detected, while the SST-tagged drones had similar percentages in all four detection categories.

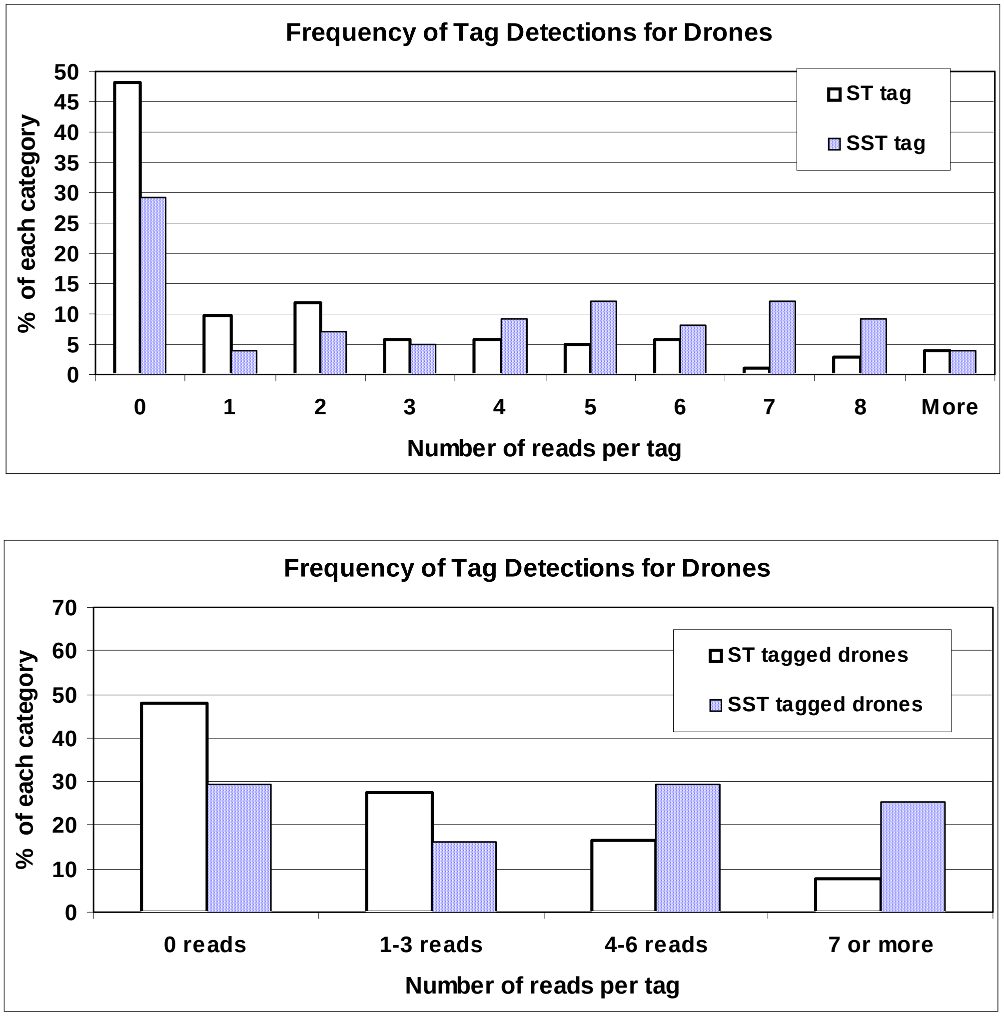


Figure 3. Frequency distributions for ST-tagged and SST-tagged drones. The upper graph (a) includes all read-per-tag categories, while the lower graph (b) combines read-per-tag categories with similar values. Since we knew how many drones were released, the undetected or 0-reads category was included.

An oscilloscope was connected to the transceiver during drone tests so that we could observe the modulation of the tags as they passed through the antenna and any RF noise not filtered by the transceiver. After being released, it took approximately 8 sec for each tagged drone to reach the antenna's electromagnetic field. Observations of the oscilloscope screen suggested that SST-tagged drones went undetected because of poor tag orientation and ambient noise. Ambient noise varied in intensity and frequency and seemed to occur randomly (e.g., sometimes there was no noise for 5 min and then noise would occur for 1 sec, a few seconds, or several minutes). Water does not pass through the antenna in a laminar flow; the surface water oscillates from side to side, and a few standing waves are prevalent (Figure 4).

Since it was unknown whether orientation of the drones was the same as for tagged fish, we compared reads per tag data for the ST-tagged drones to that of tagged river-run juvenile migrants (n = 105) that were detected between 20-26 April. We included only fish with ST tags.

A *t*-test indicated that reads per tag for ST-tagged fish and for drones were not significantly different ($P = 0.831$). Both groups had median values of 3 reads per tag, and their detection frequency distributions were similar (Figure 5).

Figure 4. Photo of the water moving down the corner-collector flume near the PIT-tag antenna.

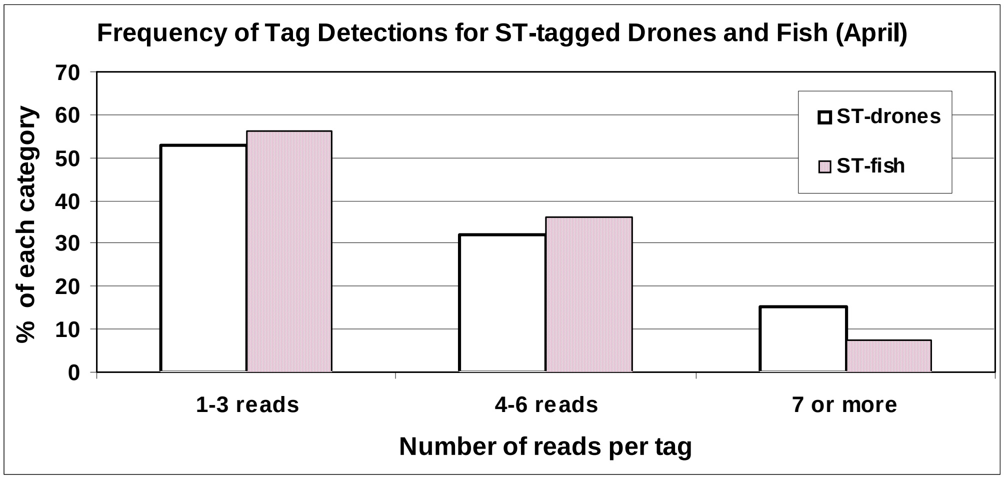


Figure 5. The frequency distribution graphs for the ST-tagged drones and fish (only those detected 20-26 April). To show the patterns better, read-per-tag categories with similar values were combined. Since we did not know how many fish had transited the flume without being detected, the 0-reads category was excluded.

FISH TESTS

Preliminary Evaluations

On 4 May, NMFS released 191 river-run hatchery yearling Chinook salmon to help Digital Angel set up their equipment and determine how to best set up the release hose we would be using to release test fish in front of the entrance to the corner collector (Figure 6). In this preliminary test, all fish were released from the middle of the entrance. As with the drone test, half of the fish were tagged with ST tags (n = 99) and half with SST tags (n = 92). Generally, the ambient noise during these tests was lower and less frequent than what had been observed during the drone tests (see Appendix for a discussion on noise, which includes graphs for all of the dates that tests were conducted). Oscilloscope observations again suggested that tagged fish were missed because of noise and poor orientation and not because of code collision (i.e., 2 or more tags going through the electromagnetic field simultaneously).

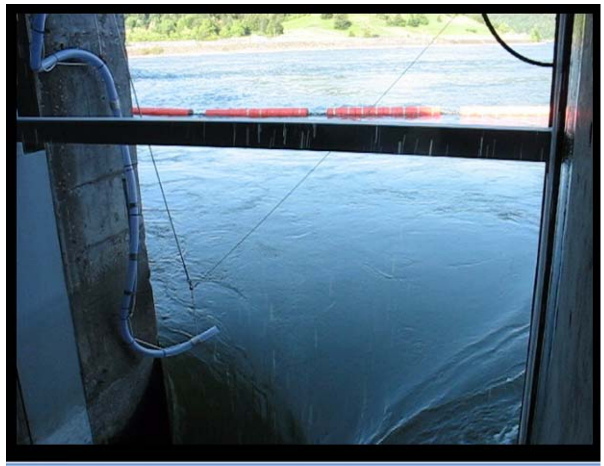


Figure 6. Photos of the setup used to suspend the 4-inch hose in front of the entrance to the corner collector. By adjusting the guide lines attached to this hose, we could position the hose to different locations for releasing fish in front of the entrance. These photos show the middle and north release locations.

Reading efficiencies were similar to those recorded during drone tests for the two tag models: 75.0% for SST-tagged and 40.4% for ST-tagged fish. Again, because of low tag numbers and reading efficiencies, the confidence intervals were wide (±7.5-10%); therefore, these results provided only ballpark estimates. However, the main purpose of these tests was to help Digital Angel in setting up its equipment and not to determine tag-reading efficiencies for the corner-collector PIT-tag system.

To examine whether detection was any different between fish we released and those going through the corner collector of their own volition, we compared detection results on 4 May for ST-tagged fish that we released (n = 40) vs. those for ST-tagged juvenile migrant river-run fish (n = 218). Detection frequency distributions of test fish and river-run fish were similar (Figure 7). Both showed the pattern of an inverse relationship between the number of reads per tag and the percentage of tags detected. The median number of reads per tag was 3 for detected test fish and 2 for river-run fish; both values were in the lowest number category (1-3) of reads per tag.

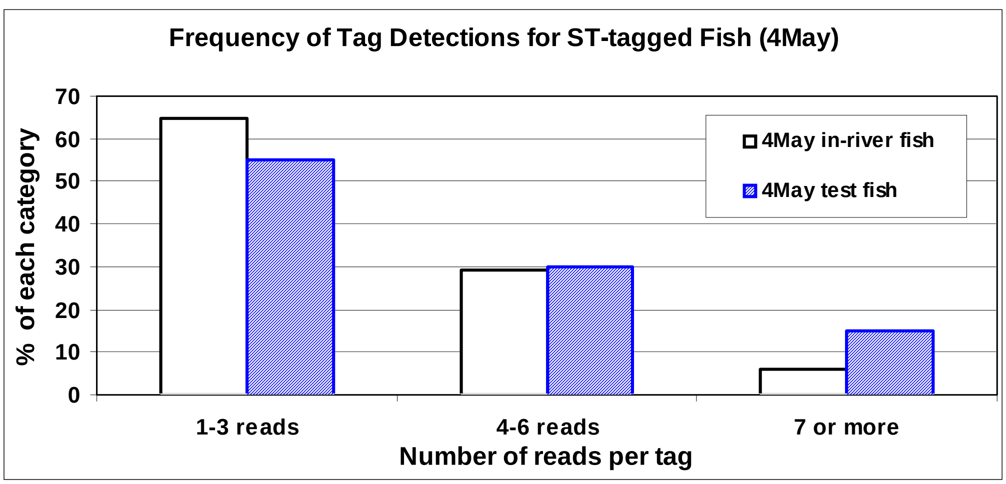


Figure 7. Detection frequency distributions for ST-tagged test fish (n = 40) and ST-tagged river-run fish (n = 218) detected on 4 May 2006. To show the patterns better, read-per-tag categories with similar values were combined into separate categories. Since we did not know how many river-run fish had transited the flume, the 0-reads category was excluded.

Comparison of results for preliminary fish tests with those for drone tests showed that results were similar (Figures 8 and 9). Detection frequency distributions showed similar patterns: an inverse relationship for ST-tagged fish or drones and an equal distribution for SST-tagged fish or drones. Furthermore, the median number of reads per tag for tagged fish released on 4 May was 3 for ST tags and 5 for SST tags. Therefore, it appeared that the drones worked well for estimates of how well yearling Chinook salmon would be detected. We still need to determine how well other salmonid populations, which behave differently from yearling Chinook, are detected by the system.

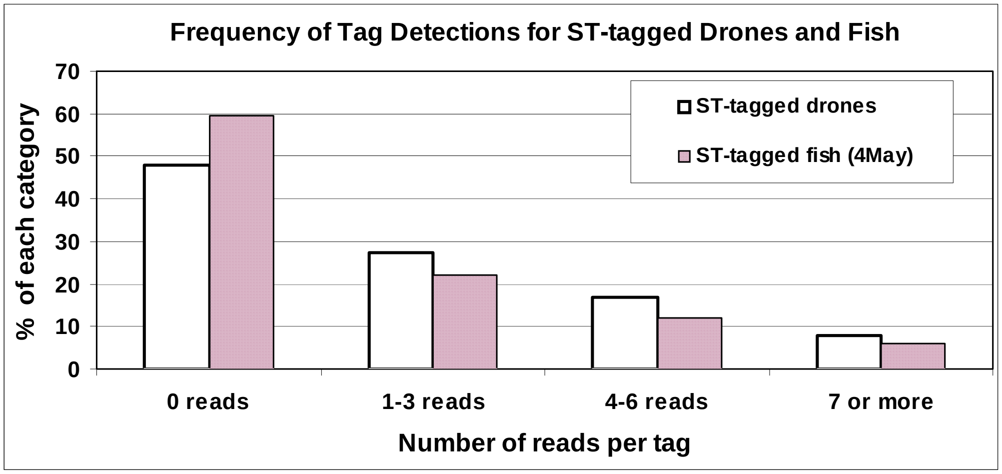


Figure 8. Frequency distribution graphs for the ST-tagged drones released in April and test fish released on 4 May 2006. Since we did know how many fish had transited the flume, the 0-reads category was included.

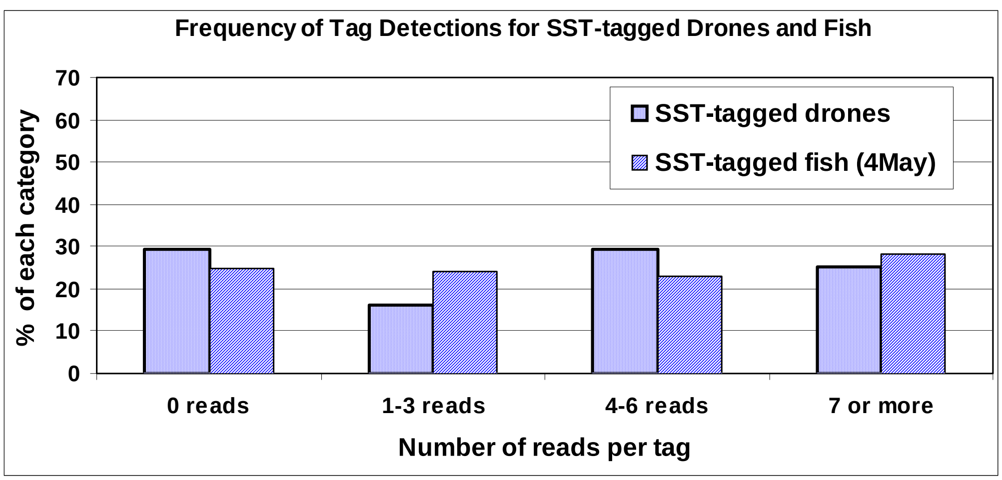


Figure 9. Frequency distribution graphs for the SST-tagged drones released in April and test fish released on 4 May 2006. Since we did know how many fish had transited the flume, the 0-reads category was included.

Multiple Release Locations

To evaluate whether tag detection rates were affected by release location, NMFS released fish from three different surface locations in front of the corner-collector entrance. These were the north side of the entrance, the middle of the entrance, and the south side of the entrance (see Figure 6). We planned to conduct this evaluation using both Chinook salmon and steelhead. However, given that we were collecting test fish from the juvenile fish facility, and that the corner-collector bypass system attracted a higher percentage of steelhead than the juvenile fish facility, we were unable to obtain sufficient numbers of steelhead for this evaluation. Therefore, we were able to conduct these tests only with Chinook salmon (Table 2).

Table 2. Numbers of tagged Chinook salmon and steelhead detected by either the detection system at the corner collector (BCC) or at the juvenile fish facility (B2J) between 24 April and 12 June 2006. The ratios of the BCC site to B2J site for the two salmonid populations are also presented. Although not shown in the table, it is important to note that the PIT-tag detection system at B2J detected more than 99% of the tagged fish passing, while the corner-collector PIT-tag system detected less than 50%. Therefore, the steelhead ratio given here is under-represented.

	All Chinook salmon	All steelhead
BCC site	14,557	5,905
B2J site	30,719	2,378
BCC:B2J ratio	0.5	2.5

Around 1,250 river-run hatchery yearling Chinook salmon were tagged with SST tags on 15-17 May using standard tagging procedures. They were then released approximately 24 h after tagging from one of the three locations within the capture velocity zone of the corner collector. Releasing larger numbers of fish compared to the earlier release numbers improved our statistical power, with standard errors of ±5% for results at each of the three locations.

Since we could not predict noise levels during these tests, we released from all three locations on each day. It turned out that noise levels were fairly low during the tests (see Appendix for graphs showing details on noise levels during these tests).

As expected, we saw some variation among the results for releases from each location, but this variation was not significant (Table 3). A two-variable ANOVA was not significant for release ($P = 0.830$) or location ($P = 0.986$). Therefore, the results for all of the releases were combined, yielding a detection rate of 68.6% for the SST-tagged yearling Chinook salmon (Table 3). Furthermore, based on these results, it will be possible to use a single release location in the 2007 evaluation of the corner-collector PIT-tag system.

With 1,236 fish, the precision level for the reading efficiency of 68.6% was ±3%; therefore, it appears that the corner-collector detection system will be able to meet the 60% detection goal for SST-tagged yearling Chinook salmon. Further evaluation will be needed to confirm that the PIT-tag system still meets this goal for yearling Chinook salmon in 2007. The 2007 evaluations are also needed to determine if the system can detect tagged steelhead and subyearling Chinook salmon at the 60% detection level.

Table 3. Fish numbers and reading efficiencies of SST-tagged Chinook salmon released from three locations in front of the entrance to the corner collector. Since there were no significant differences among reading efficiencies at these locations, reading efficiencies for the combined groups are also provided.

		SST-tagged Chinook Salmon		
	Release location	Number Detected	Number Released	Reading Efficiency
Release 1	N side	93	147	63.3
Release 1	middle	91	152	59.9
Release 1	S side	117	146	80.1
Release 2	S side	78	137	56.9
Release 2	middle	103	136	75.7
Release 2	N side	86	128	67.2
Release 3	N side	102	136	75.0
Release 3	middle	81	118	68.6
Release 3	S side	97	136	71.3
All	N side	281	411	68.4
All	middle	275	406	67.7
All	S side	292	419	69.7
	Locations combined	848	1236	68.6

Steelhead

It has been documented that steelhead behave differently than spring Chinook salmon in all other PIT-tag systems. Thus, to help Digital Angel learn whether the difference in detections between the two salmonid species was critical for the corner-collector system, we released SST-tagged and ST-tagged steelhead. On 18 May, we released one group of SST-tagged steelhead from the middle location (n = 417). We also released a small group of ST-tagged Chinook salmon on 18 May (n = 106) and a small group of ST-tagged steelhead on 19 May (n = 159).

Reading efficiency for SST-tagged steelhead (68.8%) was similar to that of SST-tagged yearling Chinook salmon (68.6%), but reading-efficiency for ST-tagged steelhead was much higher (57.2%) than for ST-tagged Chinook (44.3%; Table 4). With the small release numbers of ST-tagged fish, confidence intervals did overlap slightly; however, these results do make one wonder whether fish behavior is affecting detection. When higher numbers of fish are released in 2007, we will be able to determine reading efficiencies more accurately. However, these results did show that further adjustments by Digital Angel were not required in 2006 to obtain the reading efficiencies needed for steelhead.

Table 4. Reading efficiencies are presented for the different groups of tagged Chinook salmon and steelhead. All of these test fish were released from the middle location.

Reading Efficiencies for Steelhead and Chinook Salmon			
Group	Number Detected	Number Released	Reading Efficiency
SST-tagged Steelhead	287	417	68.8
SST-tagged Chinook	848	1236	68.6
ST-tagged Steelhead	91	159	57.2
ST-tagged Chinook	47	106	44.3

The detection-frequency distributions for steelhead showed similar patterns for the two different tag models: an inverse relationship with the ST-tagged fish and an equal distribution for the SST-tagged fish (Figure 10). The median number of reads per tag for tagged steelhead was 4 for the ST tags and 5 for the SST tags.

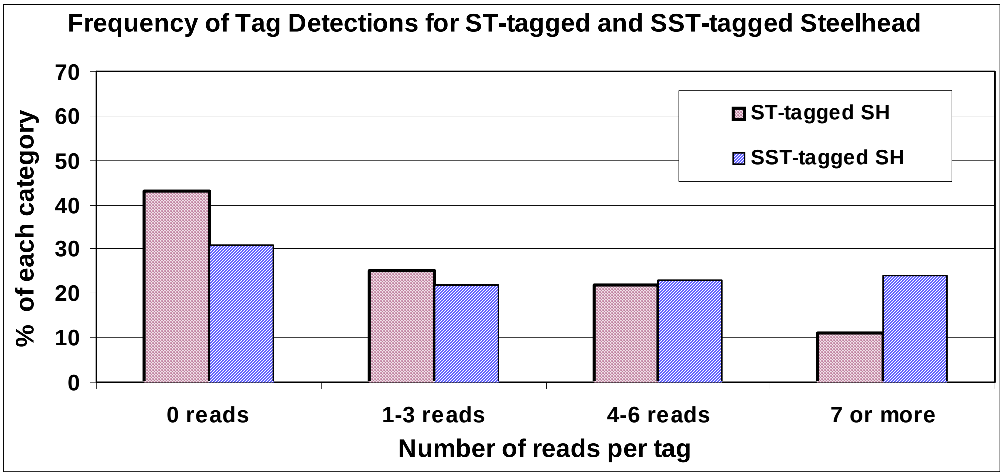


Figure 10. Detection frequency distributions for SST-tagged and ST-tagged steelhead released on 18-19 May 2006. Since we did know how many fish had transited the flume, the 0-reads category was included.

Because the median number of reads per tag for ST-tagged test steelhead (4) was higher than what had been observed for spring Chinook salmon, we examined whether detection was different between the steelhead we released and those passing through the corner collector of their own volition. The median read-per-tag value for the 70 river-run steelhead that passed the corner collector on 19 May was only 2 for the ST tag. Furthermore, the detection frequency distributions of ST-tagged river-run steelhead had a more extreme inverse relationship between the number of reads per tag and the percentage of tags than had been observed with other ST-tagged groups (Figure 11).

Comparing the detection frequency distributions for ST-tagged river-run steelhead over the 4 days of testing (Figure 12), one notes that the 19 May results seem more extreme than results on other days (though all of them had fewer fish in the 7 reads or more category than the test fish). Nevertheless, it would not be prudent to draw any definite conclusion based on only 159 test fish released on one day; therefore, we will need to wait until 2007 when higher numbers of steelhead will be released.

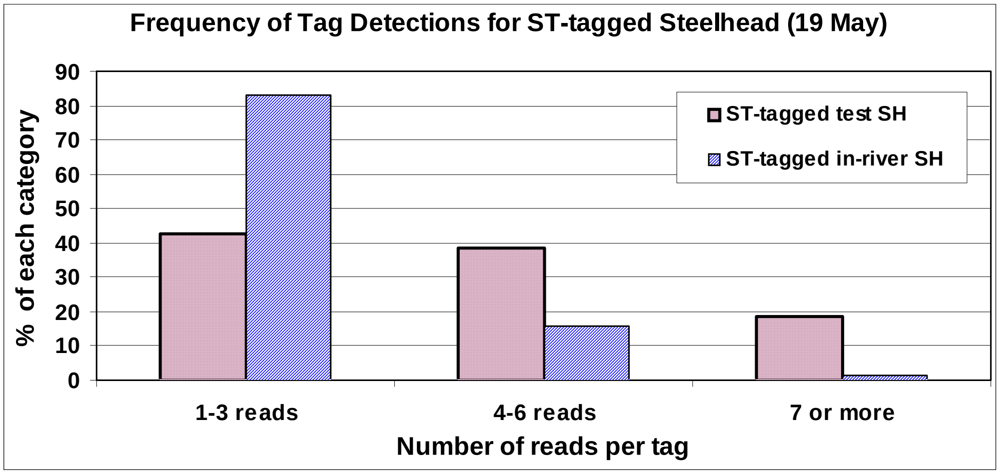


Figure 11. Frequency distributions for ST-tagged test steelhead (n = 40) and river-run steelhead (n = 218) detected on 19 May 2006. To show the patterns better, read-per-tag categories with similar values were combined. Since we did not know how many river-run fish had transited the flume, the 0-reads category was excluded.

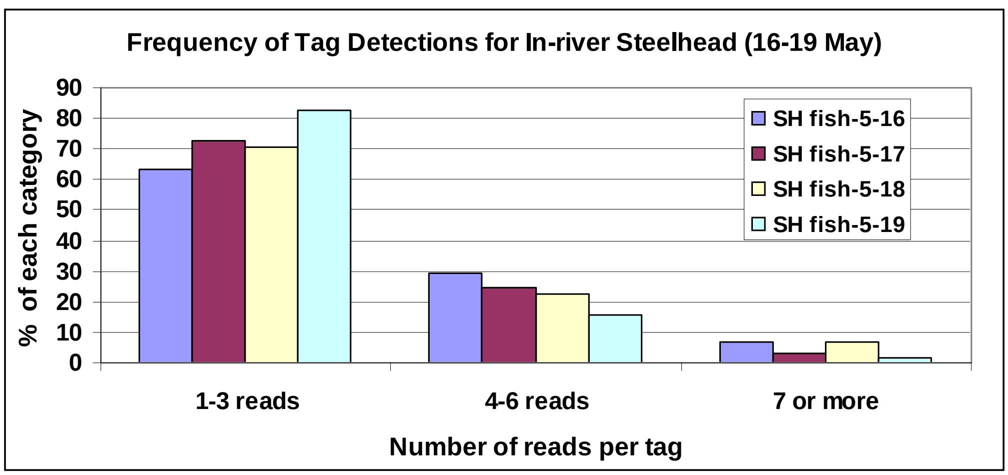


Figure 12. Frequency distributions for ST-tagged river-run steelhead detected on 16-19 May 2006 (numbers of fish detected ranged from 70 to 172). To show the patterns better, read-per-tag categories with similar values were combined. Since we did not know how many river-run fish had transited the flume, the 0-reads category was excluded.

FUTURE EVALUATION

The full-scale evaluation scheduled for 2007 is important because fish detected at the corner collector will provide critical data points for the statistical models upon which the fisheries community depends. Therefore, we will need to know how well the PIT-tag system is performing after it has been operating for a year. From the work summarized in this report, we observed several aspects of testing that will be important to designing the full-scale evaluation. These observations are discussed below. Using the information from these observations will allow testing for the 2007 evaluations to be completed faster than originally estimated.

Fish Collection and Tagging

The Smolt Monitoring Program was able to sort fish for us, and this process went quickly as long as the targeted salmonid population was available. During the first few days of our test week, unexpectedly low numbers of steelhead were available. Otherwise, tagging went quickly. Fish were held in 44-gallon containers to 6-ft-diameter fiberglass tanks after they were tagged. It was important to hold tagged steelhead for only 24 h because these fish displayed strong migratory behavior (i.e., bumping into the tank sides and nets covering the tanks). This behavior would have caused injury and increased stress to the fish if it had continued for several days (i.e., fish would have been in poor condition if they had been held for more than a few days). Regardless of where the tagged fish were held after tagging, they were transferred to the powerhouse deck in 44-gallon transport cans (~75 fish/can).

Release Methods and Locations

The ability to release fish from a single location at the entrance to the corner collector will greatly speed up releases of fish, as it will eliminate the need to reposition the release hose, which requires additional time. Based on the ~69% reading-efficiency results for the SST-tagged fish, it will be necessary to release 1,000 tagged fish to yield results with a 3% precision rate or 2,100 to yield results with a 2% precision rate. Since the fisheries community will primarily be using SST tags in 2007, it will not be necessary to test multiple tag types, as was originally discussed for this evaluation.

We tested two ways of releasing the fish: first, we dipped fish out of the transport containers with small nets and transferred them into small containers of water; second, we dipped fish out of transport containers and released them directly from the small nets (Figure 13). By far, the latter method was easier and faster. Keeping the tagged fish in the net, each fish was then placed near the antenna of a portable PIT-tag transceiver (FS2001) to scan its tag before it was released into the hopper. The fish quickly exited the hose. Using this method, it should be possible to release 1,000 fish in one day.

Figure 13. Powerhouse deck above the entrance to the corner collector where fish were released. Flush water was added to the 4-inch hose to keep fish moving through the hose.

Because noise levels are not predictable, and can change quickly, we recommend that if possible, different groups should be released together during any future evaluations (i.e., alternate transport containers containing the different salmonid populations). This was not possible during our evaluation because of the initial low numbers of steelhead.

ACKNOWLEDGEMENTS

We wish to thank the following individuals for helping us with collecting, tagging, and releasing the test fish: Lila Charlton, Laura Leighton, Dean Ballinger, and Bruce Mills from the Pacific States Marine Fisheries Commission; and Ben Sandford and Todd Bennett from National Marine Fisheries Service. We also express our gratitude and appreciation to Lyle Gilbreath of National Marine Fisheries Service for his leading role in setting up the release equipment. In addition, we wish to thank the following individuals for helping us with the drone testing: Jeff Moser and Galen Wolf of National Marine Fisheries Service, Roger Anderson and Brad Peterson of Digital Angel, and Scott Livingston and Darren Chase of Pacific States Marine Fisheries Commission. We also thank the U.S. Army Corps of Engineers for helping to coordinate this research at Bonneville Dam.

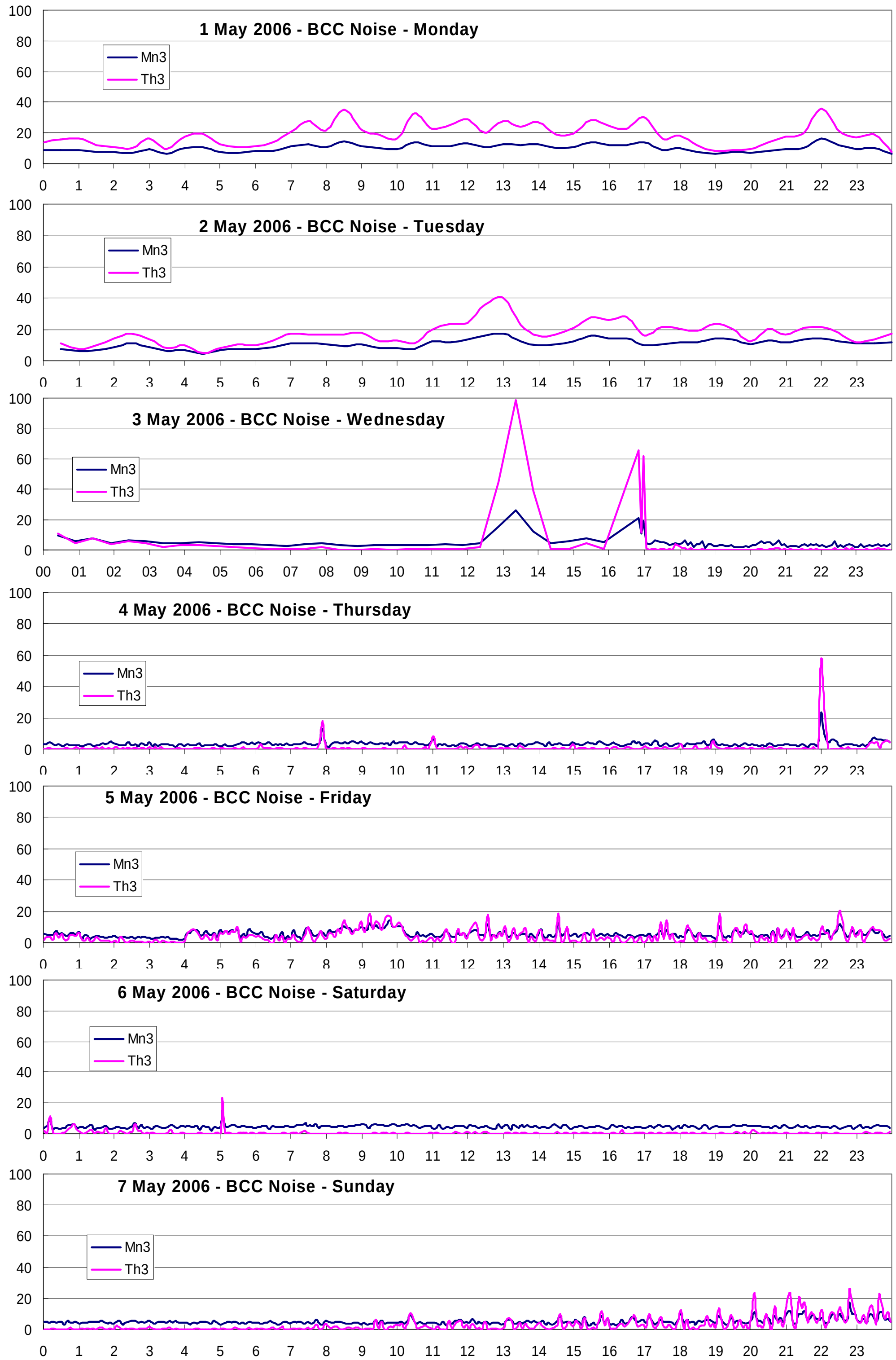
APPENDIX: Electromagnetic Noise Evaluations of the Corner-Collector System

Digital Angel Evaluations

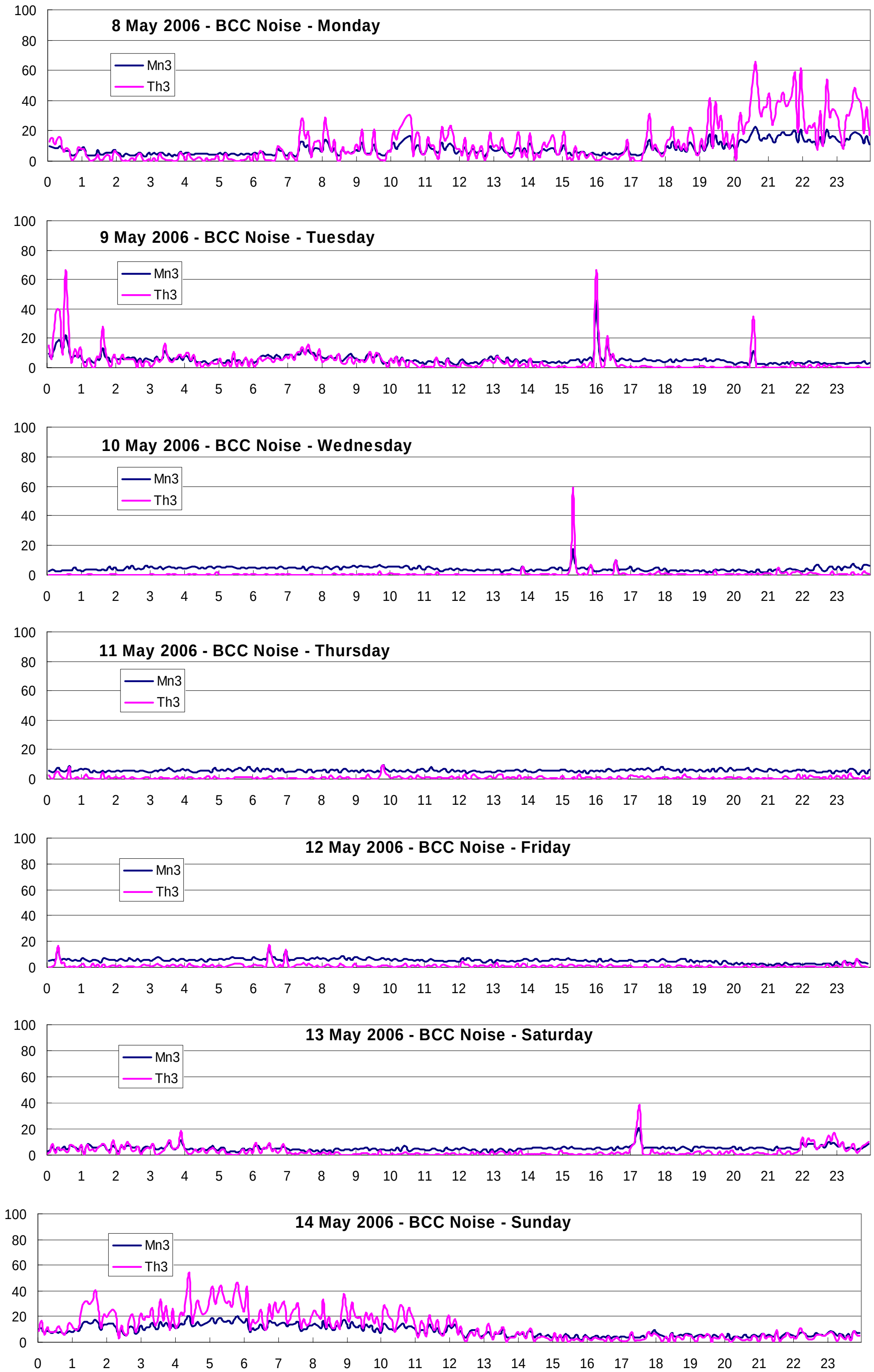
Based on the oscilloscope observations during drone tests, which indicated that ambient noise was sometimes causing tags to be missed, Digital Angel began monitoring and analyzing the noise levels. Right after the preliminary fish test on 4 May 2006, they installed a new version of firmware that allowed them to monitor the noise on a finer time scale (<1 sec). Originally, they had surmised that the ambient noise being recorded was due to mechanical movement of the shield as the water rushed by because ambient noise levels had been quite low before the flume was watered up. However, the noise was too random to attribute all of it to mechanical movement of the shield. In fact, it was sometimes quiet for whole days (Appendix Figure 1).

Therefore, Digital Angel began working with the U.S. Army Corps of Engineers to identify what might be operating when the noise levels are high. At the same time, Digital Angel began having its engineers investigate whether they could modify anything within the transceiver to improve the performance. This type of detective and engineering work takes time. It is also the type of work that Digital Angel anticipated would need to occur as they learned how their equipment operated at the corner-collector site. As we all have been told, it will take some time for them to optimize the equipment. Unfortunately, funding for this work was requested only through the month of May, so these optimizations were restricted to what could be accomplished during a single month.

Appendix Figure 1 shows daily graphs of noise data processed by the PIT-tag transceiver at BCC during May 2006. Laboratory tests have indicated that there is a noise level which represents a threshold above which tags are sometimes missed. In these graphs, this level was set to 20, which is a signal level of around 400mV. Noise data were processed every 5 min; each data point is made up of 3,000 noise samples.



Appendix Figure 1. Hourly noise levels by day in the corner collector PIT-tag detection system (BCC) at Bonneville Dam measured by 1) medians of root mean square signal strength, as measured by DSP (Mn3) and 2) percentages of samples that exceeded threshold noise for tag-reading interference (Th3).



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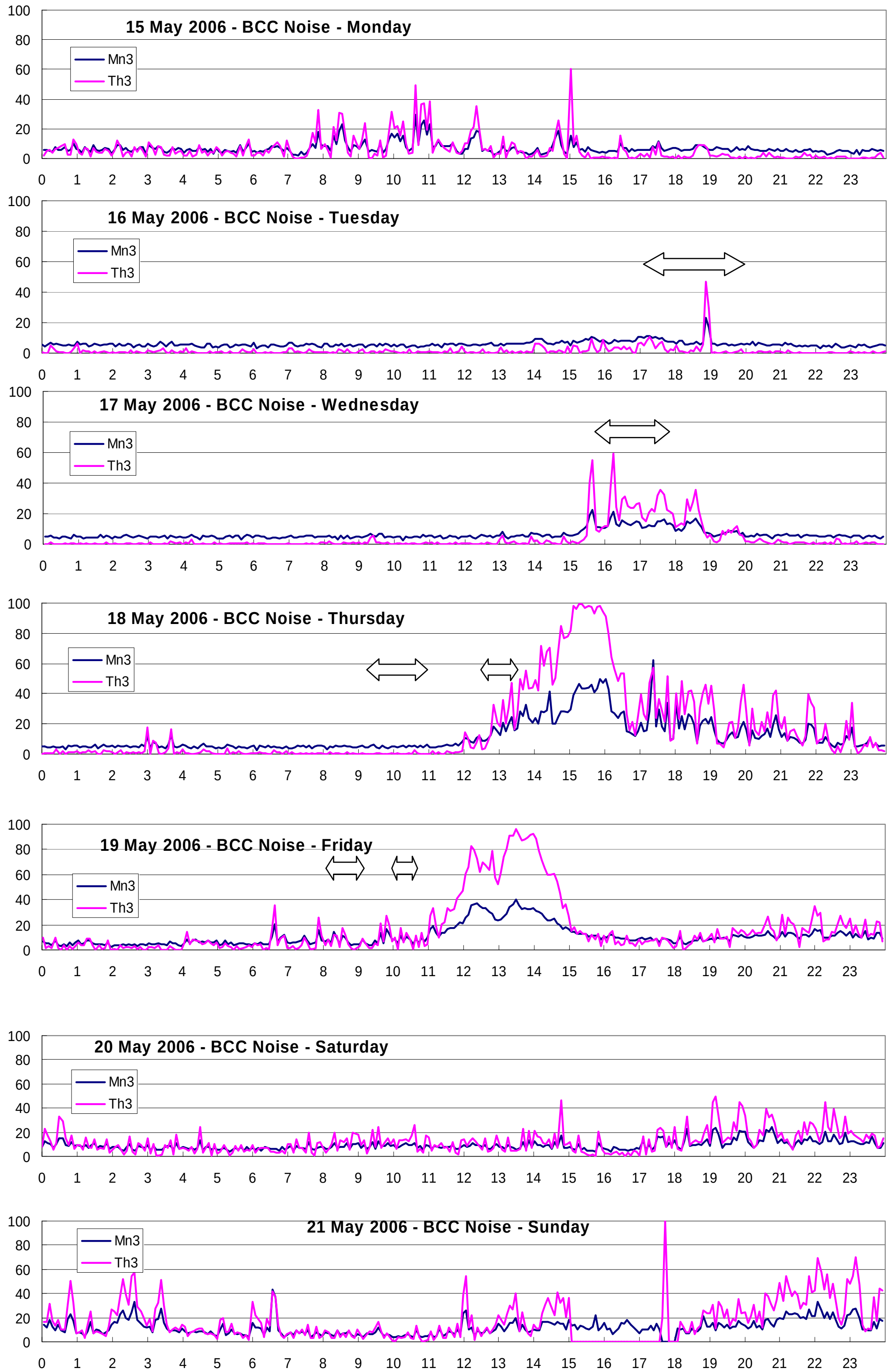

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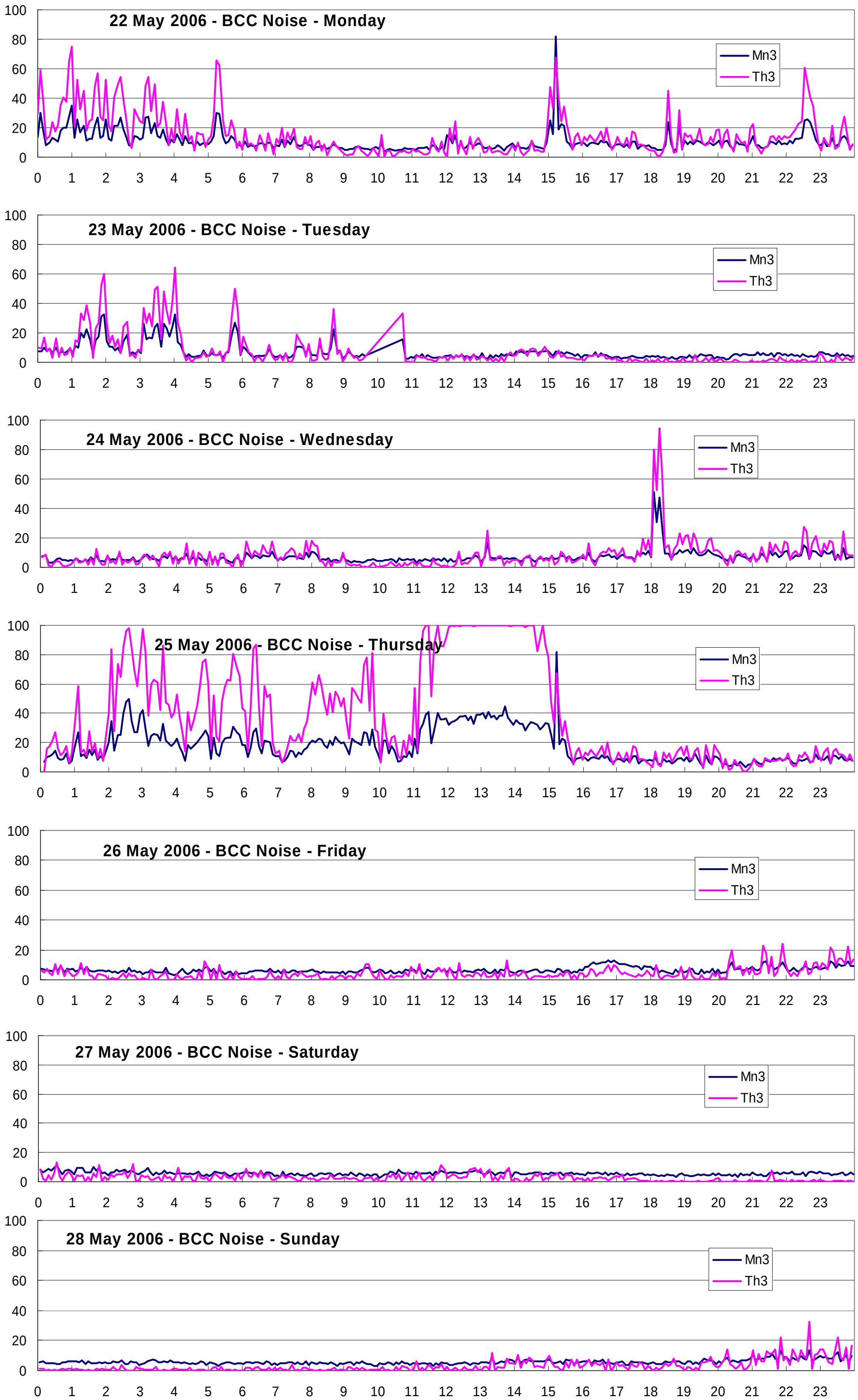

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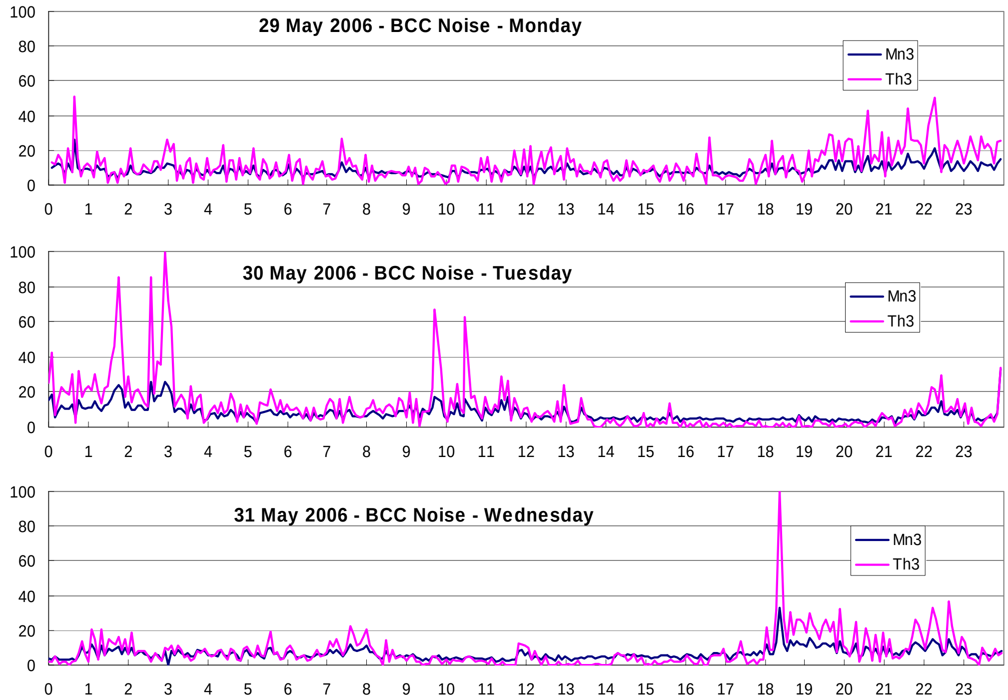

Appendix Figure 1. Continued.

Following their monitoring of the noise situation in May, Digital Angel reported that:

- There did *not* appear to be any repeatable daily occurrence of noise levels.
- There did *not* appear to be a correlation between temperature or wind and noise.
- There did appear to be a correlation between the channel water level and noise. However, there were inconsistencies, suggesting that there was more to the noise than just water level. This could also have been coincidental: the noise could have been changing due to the magnitude and frequency of systems that came online to deal with changes in the water level of the channel and the forebay.
- The noise appears to be from a number of different sources or possibly from the same source but in different operational modes. The noise measured at the test point in the transceiver after the signal has been processed by the DSP varied in appearance as follows: 1) a consistent and repetitive waveform; 2) a wave form that is consistent, but with random frequency or occurrence; and 3) a wave form that indicates high levels of noise, but with no consistency or repetition. This suggests multiple noise sources.
- Some tags do get detected during times of high noise, which indicates that the Digital-Signal-Processing (DSP) algorithms are capable of overcoming certain types and/or levels of noise.

- Possible noise caused by movement of the shield has not been ruled out, but this type of noise would not generate a consistent repetitive waveform.
- Much of the noise is impulsive in nature and could possibly be reduced with modifications to the receiver circuitry.
- Long periods of observed low noise levels indicate high noise levels are not inherent to the system, but are being produced by external means. Past experience with PIT-tag systems suggests many if not all of the noise sources could be identified and eliminated or reduced using proven techniques.

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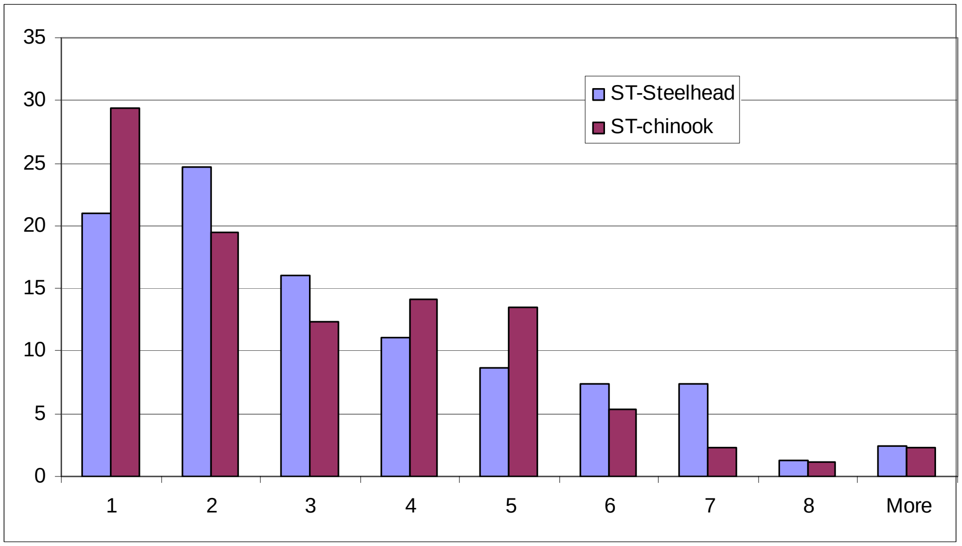
Since it was obvious during drone testing that ambient noise did cause some of the tags to be missed (it was also obvious that some tagged drones were missed because of poor orientation; in these cases, there would be no peaks observed on the screen from either noise or a tag). Sometimes the noise was sufficiently strong and lasted long enough that we could not see any sign of the tag going through the antenna. Other times, one could see a peak caused by the tag going through, but because of the presence of other noise, the transceiver was unable to decode the modulation. To determine whether the noise was a significant factor in the PIT-tag system missing tagged fish, NMFS calculated the number-of-reads per tagged fish during periods of quiet and high noise. This analysis has been effective in the past to show when noise has been a problem.

We limited our investigation to ST-tagged fish because most fish transiting the corner collector in 2006 were tagged with this tag type. Therefore, we excluded all data for fish tagged with either SGL tags or SST tags (the SGL tag was the first FDX-B tag manufactured by Digital Angel for work in the corner collector; however, less than one million of these tags were produced before Digital Angel replaced them with the SST tag). We analyzed the results for Chinook salmon (n = 170) and steelhead (n = 81) on 10 May and found no statistical difference ($P = 0.371$) between their numbers-of-reads per tagged fish (each had a median of 3; Appendix Figure 2). Therefore, in analyses under different noise conditions, we did not separate the different species.

We defined periods of high noise as times when the mean noise value was consistently ≥20% and periods of quiet noise as times when the mean noise was <10%. Since noise was below 10% during most of the month of May (see Appendix Figure 1), we chose some quiet periods for comparison that were near the noisy periods. For this report, the noisy periods of time that we analyzed were a) 18 May from 1330 to 1800 PDT, b) 19 May from 1200 to 1500, c) 25 May from 0230 to 1000, and d) 25 May from 1130 to 1500 (Appendix Table 1).



Appendix Figure 2. Percentages of two salmonid species (Chinook salmon and steelhead) for different number-of-reads categories for ST-tagged fish detected on 10 May 2006 by the PIT-tag system in the corner collector.

Appendix Table 1. Start and end times and median values for mean and peak noise measurements taken during examples of high and low noise conditions.

	Time		Median values for noise measurements	
	Start	End	Mean	Peak
High noise examples				
18-May	13:33:21	18:58:29	26	103
19-May	12:03:00	14:59:00	30	76
May 25A	02:31:17	09:56:55	20	47
May 25B	11:32:03	14:58:18	35	100
Low noise examples				
18-May	04:00:00	09:01:00	5	21
20-May	12:01:00	17:01:00	7	31
24-May	11:29:58	15:30:19	6	4
26-May	02:31:23	10:30:05	5	2

Quiet times analyzed for comparison were a) 18 May from 0400 to 0900, b) 20 May from 1200 to 1700, c) 24 May from 1130 to 1530, and d) 26 May from 0230 to 1000. With the non-DSP transceivers installed at the juvenile fish facilities and in the fish ladders, median noise measurements of ≥20% would basically prevent tag detection.

Unfortunately, because the PIT-tag system only has one antenna, and we were using river-run fish, we had no idea how many fish were missed entirely by the detection system. Results from analyzing the noisy and quiet times showed some consistent, though not large, differences. Although the median number of reads per fish did not show a consistent difference between noisy and quiet examples, averages for quiet examples were closer to 3 and those for noisy examples closer to 2 (Appendix Table 2). Furthermore, there were lower percentages of fish that were detected by only a single read during the quiet times (Appendix Table 3).

Appendix Table 2. The median values for the mean and peak noise measurements are presented along with the median and average values for the number of reads per fish for the different examples. In addition, the number of ST-tagged fish detected during each example is given.

	Median values for noise measurements			Fish	Reads per fish	
	Mean	Peak		count	Median	Average
High noise examples						
18-May	26	103		320	2	2.33
19-May	30	76		159	2	2.28
May 25A	20	47		145	2	2.17
May 25B	35	100		51	2	2.14
Low noise examples						
18-May	5	21		61	3	3.05
20-May	7	31		272	2	2.68
24-May	6	4		49	2	2.73
26-May	5	2		97	3	3.41

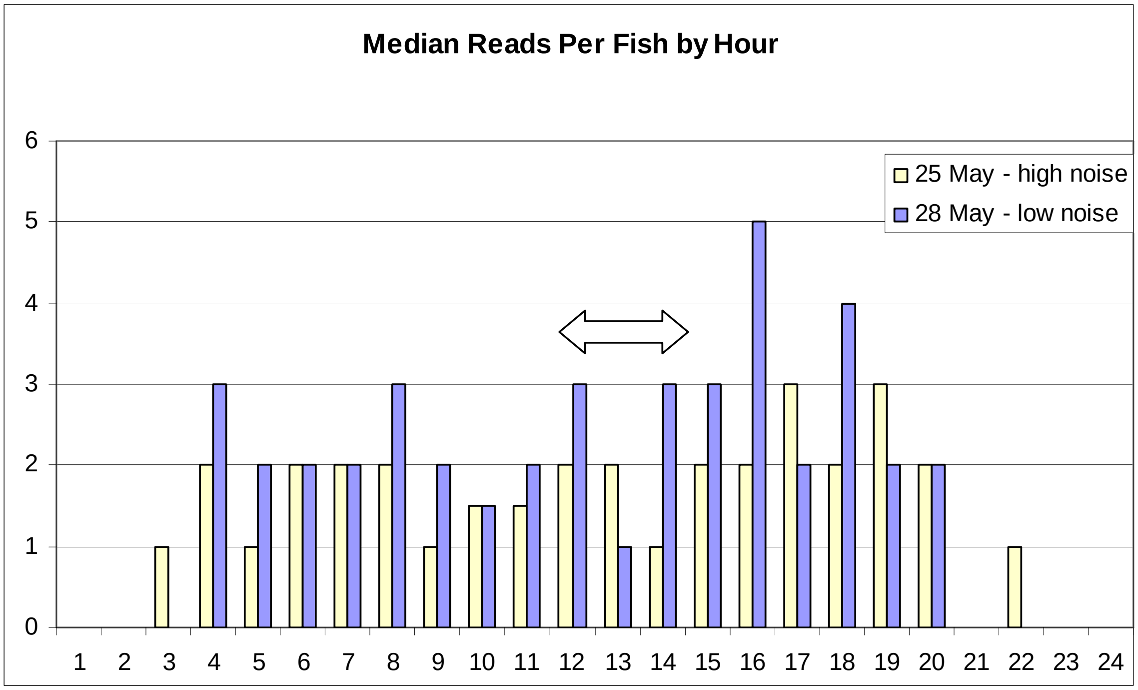
Appendix Table 3. Median values for mean and peak noise measurements are presented along with the percentages for different reads-per-fish categories for each noisy and quiet example.

	Median values for noise measurements			Percentages of different reads-per-fish categories				
	Mean	Peak		1 read		1-3 reads	4-6 reads	7 or more reads
High noise examples								
18-May	26	103		41		80	17	3
19-May	30	76		43		81	17	2
May 25A	20	47		44		88	10	3
May 25B	35	100		39		86	12	2
Low noise examples								
18-May	5	21		29		65	28	7
20-May	7	31		35		75	19	6
24-May	6	4		36		71	24	5
26-May	5	2		25		60	30	10

The differences in percentages of fish in different categories (Appendix Table 3) suggest that during noisy periods, we may be missing minimally an additional 10% and maybe as high as 15% of the ST-tagged fish. Since noise was quite high in these examples, it appears that the DSP software is doing a good job. Fortunately, the times when the mean noise measurements were ≥20% were rare during May 2006.

In the above analyses, we took distinct time periods for comparing the performances under noisy and quiet conditions, but in reality, the noise conditions can change at any time. A comparison of performance for the overall noisiest day (25 May) and one of the quiet days (28 May) demonstrated how median values for number of reads per fish varied widely over both days (Appendix Figure 3).

Except for two extreme hours, the numbers of ST-tagged fish used to calculate median values for each hour ranged from 10 to 44. For both days, the median value for the whole day was 2 reads per fish. Furthermore, results for the noisiest period of time on 25 May (denoted by the double-headed arrow) were not really distinguishable from results for the rest of that day.



Appendix Figure 3. Median values of reads per ST-tagged fish on an hourly basis are presented for the noisiest day (25 May) and a typical low-noise day (28 May). The double-headed arrow denotes hours with the highest noise levels on 25 May.

Given that the PIT-tag system already misses over 50% of the ST-tagged fish under quiet noise conditions, we may learn more about differences in performance under diverse noise conditions when more SST-tagged fish are passing through the corner collector in 2007. Since SST tags have median number of reads per fish of around 5, it may be easier to differentiate differences under diverse noise conditions by using them for the analyses. In the interim, it would be beneficial if Digital Angel could reduce some of the observed noise levels with modifications to the receiver circuitry.