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Influence of a low intensity electric sea lion deterrence system on the migratory behavior of fishes in the upstream migrant tunnel (UMT) at Bonneville Dam

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Introduction

Predation by pinnipeds, such as California sea lions (*Zalophus californianus*), Pacific harbor seals (*Phoca vitulina*), and Stellar sea lions (*Eumetopias jubatus*) on returning adult Pacific salmon (*Oncorhynchus* spp.) in the Columbia River basin has become an increasing concern for fishery managers trying to conserve and restore threatened and endangered runs of salmonids. As a result, Smith-Root Incorporated (SRI; Vancouver, Washington) proposed a demonstration project to evaluate the potential of an electrical array to deter marine mammals (SRI 2007). The objective of their work was to develop, deploy, and evaluate a passive, integrated electric and sonar array that selectively inhibits upstream marine mammal movements and predation, without injuring pinnipeds or affecting anadromous fish migrations. However, before such a device could be placed in the field, concerns by regional fishery managers about the potential effects of such a device on the migratory behavior of or injury to Pacific salmon, steelhead (*O. mykiss*), Pacific lampreys *(Entoshpenus tridentata)*, and white sturgeon (*Acipenser transmontanus*) needed to be addressed.

Recently, we completed hatchery and laboratory evaluations of small-scale versions of an array on the behavior and potential for injury to adult steelhead and Pacific lampreys (Mesa and Copeland 2009). We found that steelhead successfully passed over a small array in a hatchery raceway when it was energized to minimal levels known to deter sea lions in laboratory tests (i.e., a surface voltage gradient of 0.6 V/cm, a pulse width [PW] of 0.4 ms, and a pulse frequency [PF] of 2 Hz). However, when surface voltage gradients were increased to a range of 0.8 – 1.1 V/cm, the passage of steelhead over the array was reduced by 13 – 33%. Finally, exposing steelhead to a surface voltage gradient of 1.9 V/cm, 0.4 ms PW, and 2 Hz resulted in no significant injuries. Similar work by Ostrand et al. (2009) showed that large white sturgeon may

experience altered behavior and mortality if exposed to the array under continuous operation and that these effects would be reduced if the array were operated intermittently. They concluded that the location of a field-based array should be thoroughly studied and aspects of intermittent operation of the array be refined.

Although the results described above provide some initial insight into the behavioral responses of fish that may encounter a low intensity electric array in the field, more work is needed. Questions remain, for example, about extending results from the laboratory experiments of Mesa and Copeland (2009) to conditions in the field, including their use of hatchery fish, scaled-down, prototype arrays, and the relevance of the electrical conditions they tested. Although electric field modeling done recently by SRI indicates that the electrical conditions tested by Mesa and Copeland (2009) would be similar to those in a field-based array, there is still concern about the large size of the array proposed for installation below Bonneville Dam on the Columbia River and its true electrical characteristics. Although Mesa and Copeland (2009) stated that a complete understanding of fish behavior in response to the array may be tenable only after careful *in-situ* testing of a full-scale apparatus, it seemed prudent to conduct some tests at a scale in between laboratory and full field deployment. Thus, the research described here tested the effects of a somewhat larger array placed within a section of a fish ladder at Bonneville Dam (the upstream migratory tunnel, or UMT) on the migratory behavior of adult salmonids. These tests were much different and provided more ecological realism than previous studies because: (1) the array was longer, so fish had to swim a greater distance (ca. 6 m) through an energized volume of flowing water; (2) the test fish used were free-swimming, motivated adult fishes that have already ascended the Cascades Island fish ladder and most of the UMT; (3) water velocities in the UMT were similar to those in many areas of the river; and (4) no

manipulation, holding, or handling of test fish were required. Conducting tests of a moderately-sized electrical array in the UMT was a logical "next step" towards the possible installation of a field-based array in the Columbia River. Specifically, our objective was to assess the effects of a low intensity electrical array on the rate of movement and behavior of upstream migrating adult salmonids in the UMT.

Methods

Study site.—Experiments were conducted in a small section of the UMT, which connects the Cascades Island fish ladder to the Washington Shore fish ladder near Powerhouse 2 at Bonneville Dam (Figure 1), the first hydroelectric dam upstream from the mouth of the Columbia River. The UMT is a 300-m-long, 2-m-wide straight, concrete channel located on the forebay side of Powerhouse 2. Migrating adult salmonids exit the Cascades Island fish ladder, enter and swim up the UMT, and then enter the final, upstream section of the Washington shore fish ladder before continuing their upstream journey.

Experimental apparatus.—The electric array, designed by SRI, was positioned in the very upstream end of the UMT, just downstream of the junction with the Washington shore ladder. The array was 12-m-long and consisted of a fiberglass-reinforced plastic frame with flooring and walls constructed from ultra high molecular weight sheets to prevent any electrical conductance to the concrete walls of the UMT. When turned on, the array energized a volume of water about 6 m long from the surface to the bottom and across the width of the UMT. The two energized electrodes were metal plates positioned perpendicular to river flow and located 3.13 m and 9.25 m from the downstream end of the array (Figure 2). Un-energized parasitic electrodes served to keep the electrical field within the 6 m boundary.

Four customized pulsators, which converted incoming alternating current to pulsed direct current, served as the power supply for the electric array. The output of the pulsators was controlled and monitored with a computer, custom software, and external relays. Heavy gauge insulated wire was used to connect the pulsators to the electrode arrays. All electrical equipment was housed in a mobile trailer near the UMT. After the array was installed, point values of the electric field intensity (i.e., voltage gradient in V/cm) were mapped with a calibrated oscilloscope by personnel from SRI. Voltage gradients were measured at 10, 92 (mid-column), and 168 cm (near the surface) from the bottom of the array. For complete details on the electric array, see SRI (2010). Water depth in the UMT was maintained at about 2 m.

Fish movement and behavior—Fish movement and behavior through the array were captured using a dual-frequency identification sonar (DIDSON) acoustic camera, which provides near video-quality images by simultaneously transmitting and receiving acoustic beams. In high frequency mode, images were constructed from 96 beams oriented 0.3° apart in the horizontal dimension and 14° wide in the vertical dimension. At this frequency and in turbulent water, images could be formed within a range of about 4.5 m (Figure 3). The DIDSON camera was attached to an adjustable mount designed and built by SRI so we could pan the camera in any direction. We positioned the camera about 4 m downstream of the array (looking upstream) and a meter below the water surface tilted down at an angle of about 10 degrees (Figure 4). Data from the DIDSON were sent via a cable to routing hardware, where images were recorded to a laptop computer.

To determine the influence of the array on fish passage, we compared the rate of passage and behavior of fish approaching the array when it was on and off. Rates of passage were calculated as percentages and a fish was categorized as passing through the array if it hesitated at

the entrance for several seconds, then swam into the array upstream out of the field of view (FOV) of the DIDSON or simply swam through without hesitation. Fish were categorized as not passing through the array if they hesitated at the entrance and dropped back downstream out of the FOV of the DIDSON or swam into the entrance then drifted or turned around and swam downstream. On 23 April, at 0800 hrs, we recorded fish approaching and passing through the array for 2 h when it was off. After this control period, we energized the array and continued recording for another 2 h. For this, we exposed fish to 0.6 V/cm at a PW of 0.4 ms and a PF of 2 Hz as they moved through the UMT. These were the minimal levels known to deter sea lions in laboratory tests and were typical values measured near the water surface between the energized electrodes (Figure 5). After this first test was complete (i.e., a 2-h control period followed by a 2-h treatment period), we waited 1 h before starting another. On 27 April, we conducted three more tests evaluating 0.6, 0.32, and 0.14 V/cm (PW of 0.4 ms, PF of 2 Hz), except that each test was comprised of a 0.5 h control and a 0.5 h treatment period, totaling three 1 h blocks of time. During our study, most of the fish in the UMT were probably spring Chinook salmon *O. tshawytscha*, but there could have been steelhead and other fishes present.

After the tests were complete, we reviewed the DIDSON files for each block of time and recorded the number of fish that approached and entered the array and the number of fish that drifted or moved downstream and recorded the behavior of each fish as they approached or swam through the array, including whether they hesitated, entered the array and promptly moved downstream, or showed signs of confusion or being affected by the electricity. From these numbers, we estimated the number and percentage of fish that passed through the array for each block. For control and treatment groups, we pooled the data from replicate blocks and calculated a mean number and percentage of fish that moved past the array. We did not replicate two of our

later tests because regional fishery managers stopped our work based on results from our first two days. We used z-tests to determine whether the mean passage rates of fish when the array was energized were significantly ($P < 0.05$) lower than those of control fish.

Results

In total, we observed 1,340 fish in the video data we reviewed, with 509 observed over all control periods and 831 during the treatment periods. The number of fish we observed ranged from 81 during the 0.32 V/cm treatment (sample time = 0.5 h) to 642 fish during the 0.6 V/cm treatment with all blocks combined (sample time = 4.5 h).

Overall, 83% of the fish we observed during the control periods passed through the array when it was off. This percentage was significantly higher (*z*-tests, $P < 0.0001$) than all the values estimated from groups approaching the array when it was energized, including 0.6 V/cm (4%), 0.32 V/cm (4%), and 0.14 V/cm (5%; Figure 6). During control periods, 33% of the fish hesitated briefly at the entrance of the array before passing through. Some fish (9%), however, did drift back downstream. During the treatment periods, 77% of the fish hesitated at the entrance to the array and their behavior was dramatically different after they entered. At the lowest surface voltage gradient tested (0.14 V/cm), fish entering the array tended to spend more time in it, but they eventually drifted back downstream as they approached or swam over the energized electrode. Conversely, as the surface voltage gradients increased to 0.32 or 0.6 V/cm, fish entering the array would quickly turn around and burst back downstream instead of drifting down like fish observed in other trials.

Discussion

Our results indicate that a high percentage of feral, upstream migrating adult salmonids—probably mostly Chinook salmon and steelhead—refused to pass through a weak field, pulsed

DC electrical array installed in part of a fish ladder at Bonneville Dam, even when the array was energized at or below minimal levels known to deter pinnipeds. Our results are in stark contrast to those of Mesa and Copeland (2009), who showed that hatchery-reared steelhead readily passed through a smaller array energized at levels similar to our tests. These contrasting results probably reflect behavioral and physiological differences between actively migrating adult salmonids and fish that have been in a hatchery for some time. Clearly, most fish moving upstream in the UMT were highly sensitive to even very low levels of electricity in the array and immediately sprinted downstream upon encountering the electric field. The hatchery fish used by Mesa and Copeland (2009), however, were quite habituated to humans and other disturbances and perhaps were more inclined to pass through a mild electric array under a variety of conditions. Regardless, our results were striking and unequivocal and prompted regional fish managers to stop our tests. In the end, deploying a large-scale electric array in the tailrace of Bonneville Dam to deter predaceous behavior by pinnipeds does not appear feasible because it will probably impede the upstream migrations of anadromous salmonids and perhaps other fishes.

Our estimates of fish passage and behavior during the tests were hindered somewhat by hydraulic conditions within the UMT, the size of UMT itself, and some behavioral characteristics of the fish. One of the challenges we faced was deploying the DIDSON within the UMT in a position to capture images over the length of the array. In ideal conditions, the DIDSON is capable of capturing images up to 12 m away, which was the length of the array. However, due to a plethora of air bubbles in the water, we were only able to capture clear images over a range of about 4.5 m. Thus, we positioned the camera to achieve a FOV starting about 1.85 m downstream from the entrance of the array to 2.65 m into the array, just below the first

energized electrode. With this camera position, we were able to clearly see fish as they approached the array and either entered it or drifted back downstream, but we could not view complete passage events and instead inferred successful passage when fish left and did not return to the most upstream edge of our FOV. On several occasions—particularly during control periods—a fish would enter the array, swim beyond our FOV, drop back down out of the array after about 20-60 s, and then reappear and pass. However, since we could not identify individual fish, we were never sure that it was the same fish and this may have resulted in some fish being counted twice. Another factor that impacted our estimates of passage and observations of fish behavior was when groups of fish (i.e., 4-7 individuals) would enter the array at about the same time. These groups of fish typically occurred during the treatment periods and after the array had been energized for a while. We hypothesize that fish began to congregate downstream of the DIDSON camera as more and more fish attempted to cross the energized array, turn around or drift back downstream. This made it difficult to accurately count fish and to distinguish behavioral responses of individuals. To minimize the impact of this group behavior, the video clips showing this were reviewed by two biologists until a response was agreed upon. In the end, because of limitations with the FOV of our camera and some problems dealing with fish behavior or groups of fish, our estimates of fish passage were probably biased in some way, but not severely so.

Hesitation was a common behavior observed in both control and treatment groups and they may have been responding to the presence of the array itself within the UMT or to the change in water velocity and turbulence the array created. In addition, fish during the treatment periods may have hesitated in part because of somewhat more severe voltage gradients near the bottom of the array. Voltage gradients within the array varied vertically and horizontally, being

high near the bottom and low at the surface and low near the outer edge of the array and high in the center. Although we could not tell, we suspect that most fish were swimming less than 1 m from the bottom based on observations made at viewing windows in the UMT and fish ladder. Therefore, fish may have been exposed to voltage gradients much higher than the nominal target values for our treatments. Fish were probably able to sense these voltage gradients before entering the main part of the array, which resulted in a higher rate of hesitation.

Finally, we acknowledge that our tests were done with the array always energized, which contrasts with the intermittent operation of the array proposed by SRI. Thus, our tests could be considered worst case scenarios. However, what really matters is what happens at the instant a fish encounters the electric field—which has nothing to do with whether the array is energized constantly or operated intermittently. Future tests of these low intensity electric arrays may reveal some potential for using them as barriers to keep fish or other animals out of certain areas, such as turbine intakes.

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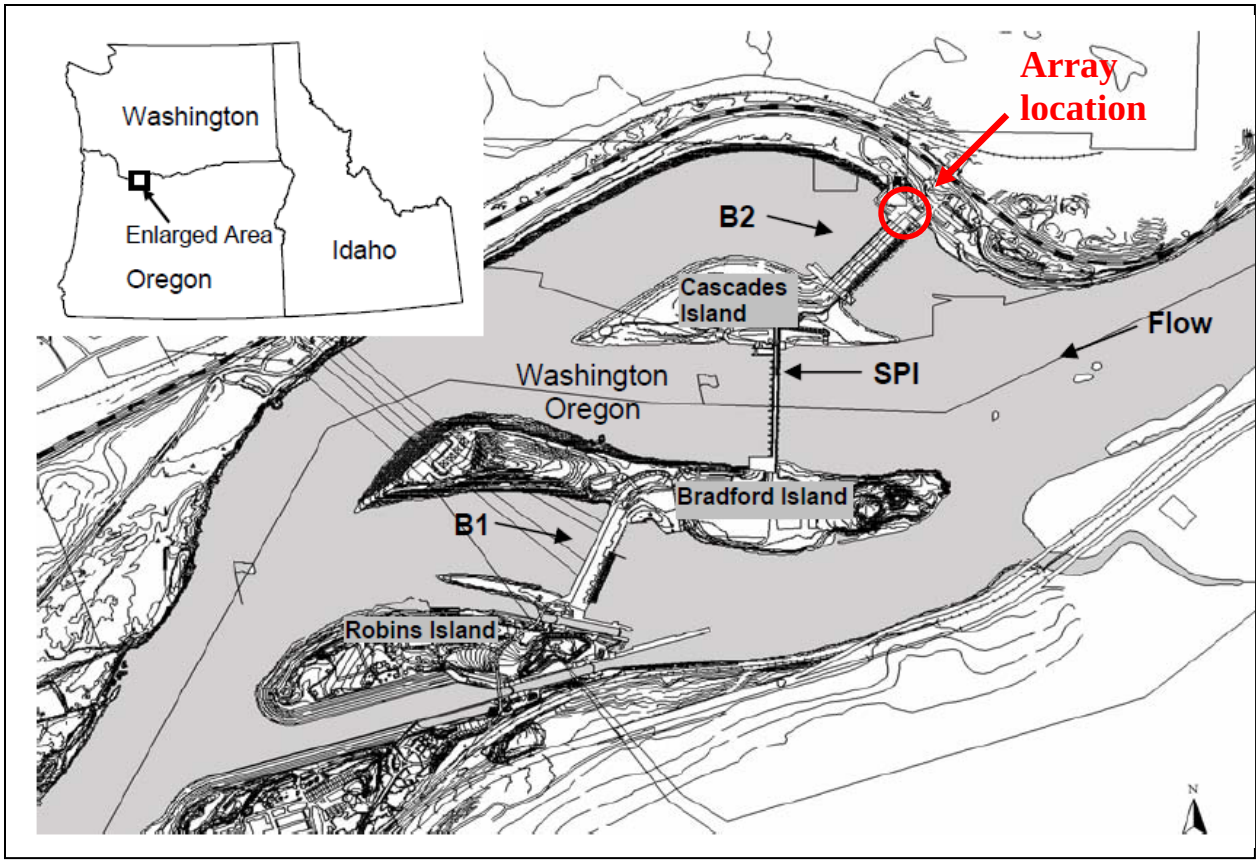
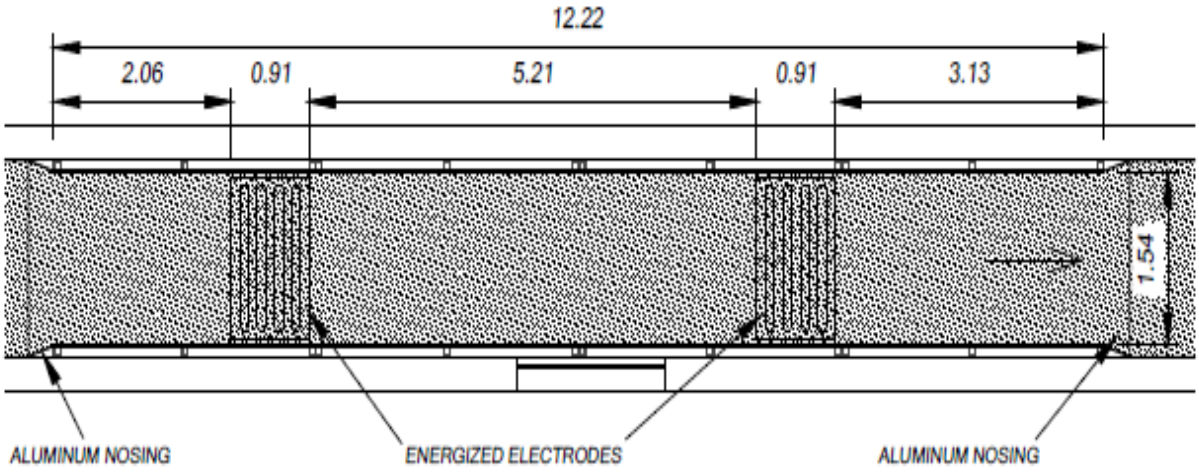


Figure 1.—Overhead schematic of Bonneville Dam on the Columbia River, showing first powerhouse (B1), the spillway (SPI), and second powerhouse (B2). The electric array was located at the northern end of the upstream migrant tunnel just before the junction with the Washington shore fish ladder. Image source: U.S. Army Corps of Engineers.

(a)



(b)

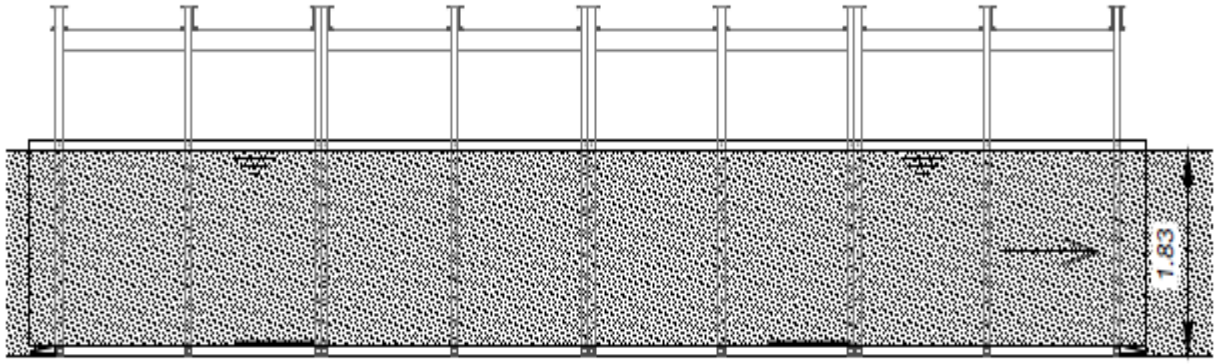


Figure 2.—Overhead (**a**) and side view (**b**) schematic diagrams of the electrical array in the upstream migratory tunnel at Bonneville Dam. Measurements shown are in meters. Image source: Smith-Root, Inc.

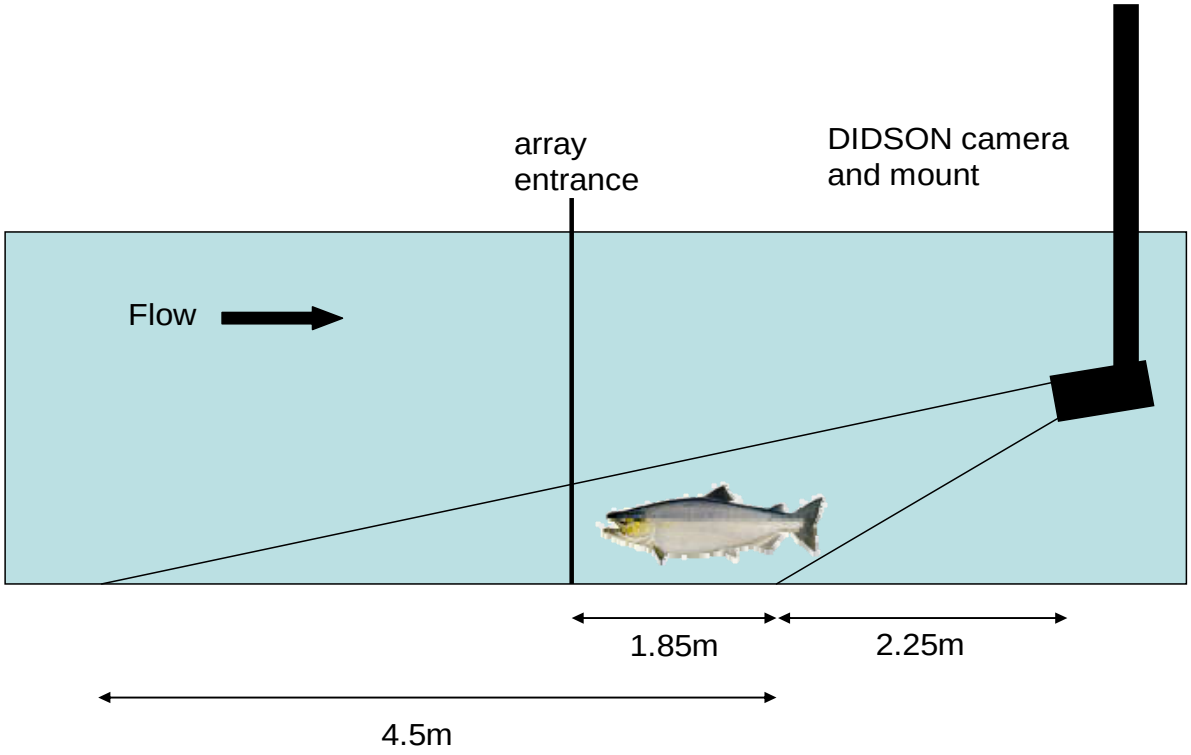


Figure 3.—Side view of area captured by the DIDSON camera in the upstream migratory tunnel at Bonneville Dam.

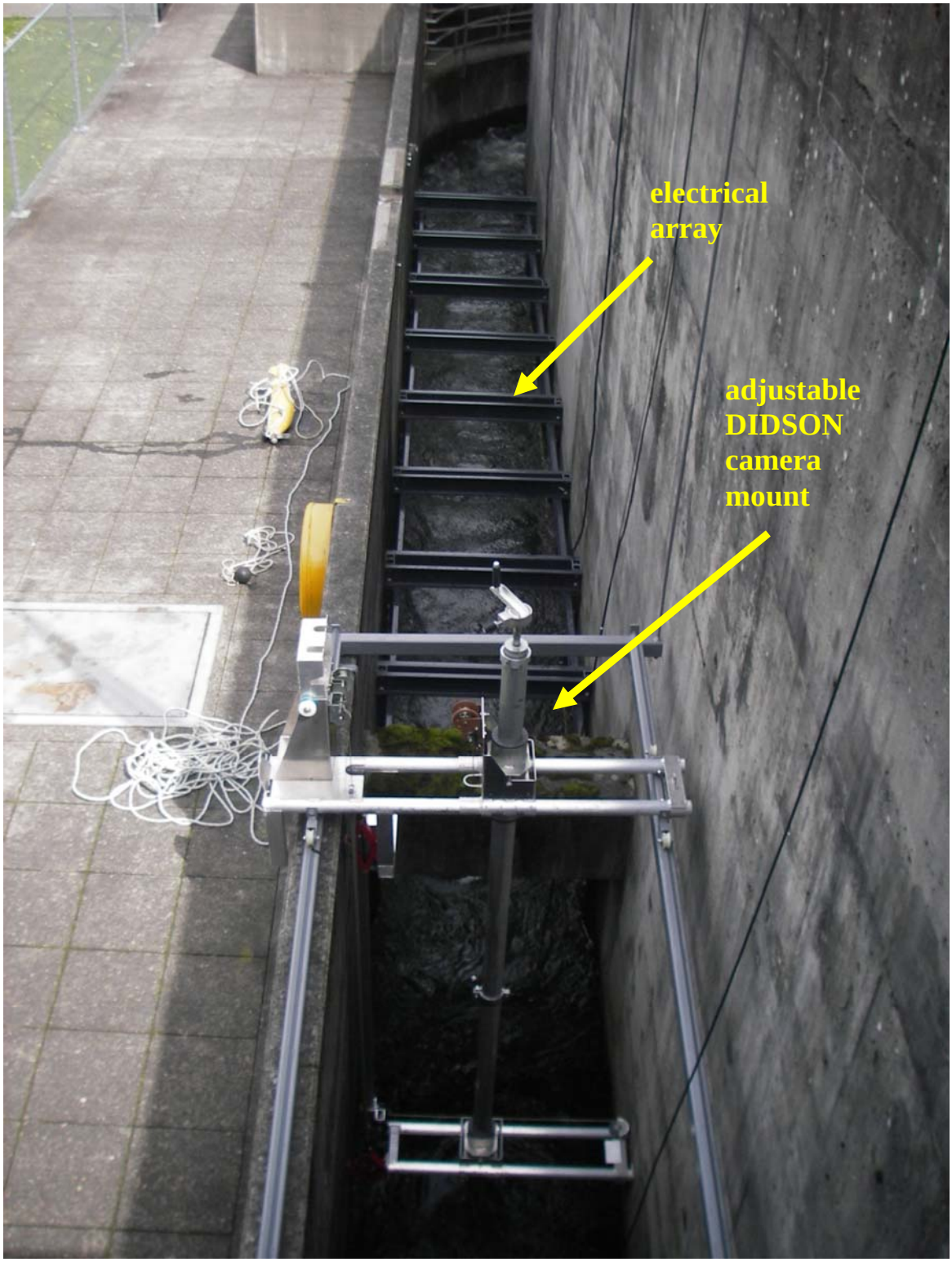


Figure 4.—Overhead view (looking upstream) of the electrical array and adjustable DIDSON camera mount deployed in the upstream migratory tunnel at Bonneville Dam.

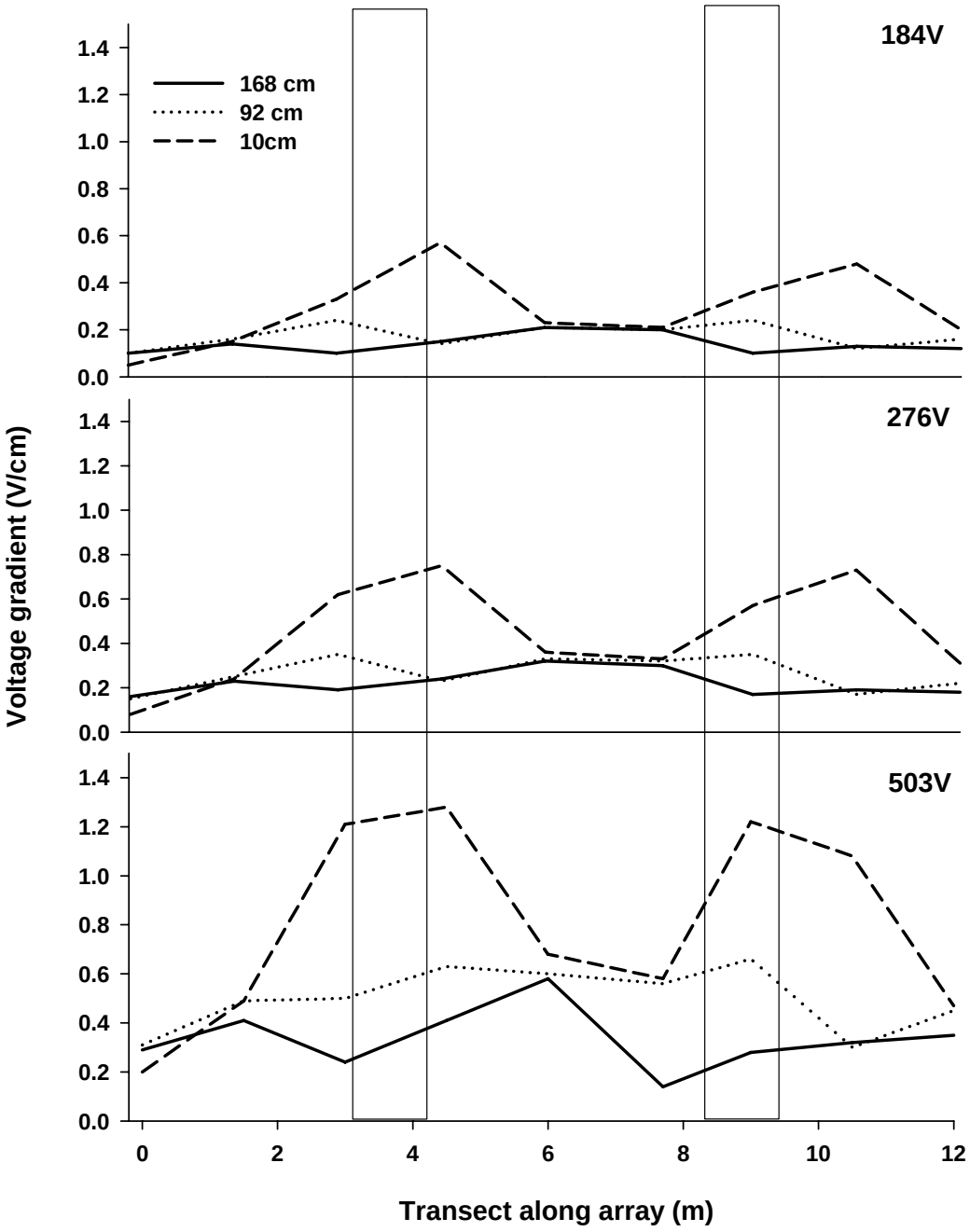


Figure 5.—Profiles of voltage gradients within the electric array at Bonneville Dam for different applied voltages and depths measured from the bottom. Vertical bars represent energized electrodes.

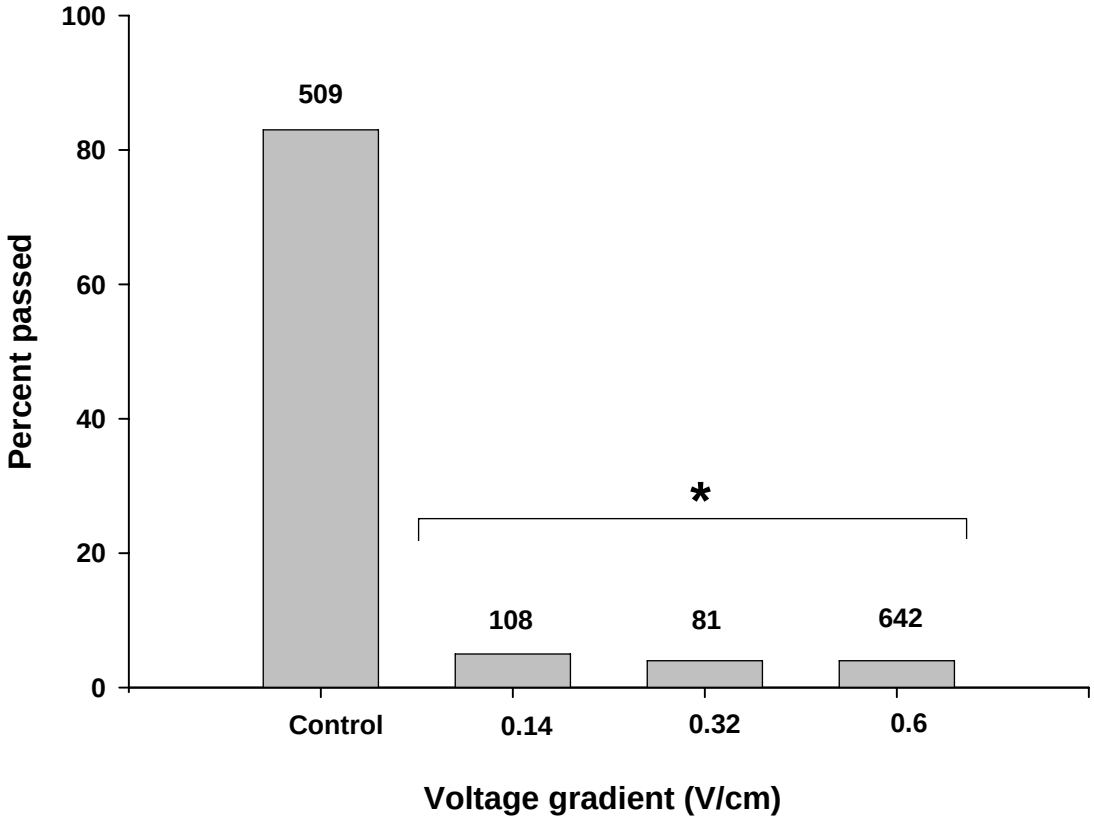


Figure 6.—Percent of adult salmonids that passed through an energized electrical array at different surface voltage gradients. The asterisk denotes that the mean passage rates of fish when the array was energized were significantly ($P < 0.05$) lower than that of control fish. Total time of DIDSON video footage reviewed was 5.5 h for control groups, 0.5 h for the 0.14 V/cm treatment, 0.5 h for the 0.32 V/cm treatment, and 4.5 h for the 0.6 V/cm treatment. Numbers above bars show the fish observed within each group.