Evaluation of the Use of an Electrical Gradient as a Seal Deterrent

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Introduction

Pinniped populations have increased dramatically along the west coast of North America since being protected in the early 1970s. Seals and sea lions are opportunistic predators and tend to forage where fish are most concentrated and vulnerable. Salmon may be preyed upon while holding in rivers, entering ladders or counting fences, or removed from nets and impoundments, which has created conservation concerns and interfered with stock assessment activities. Effective deterrents for mitigating these localized interactions are not currently available.

Electrical fields have been successfully used to create barriers limiting fish and wildlife movements, and may have potential for deterring seals and sea lions. The barriers function by establishing an electrical gradient between an anode and cathode placed up to several meters apart. The response of animals entering the gradient is a function of body size. For example, a seal measuring 175 cm swimming through a gradient of 1 volt per cm would be exposed to a current differential of 175 volts, whereas a 30 cm fish swimming through the same field would experience a differential of only 30 volts. Given the size-specific differences in exposure, it may be possible to establish an electrical barrier that would repel seals and sea lions, without affecting the smaller prey on which they are feeding.

In recent years, the Pacific Salmon Commission Cottonwood and Whonnock test fishing operations have been severely impacted by seal presence and predation. Seals can remove a significant proportion of salmon caught — in some cases up to 100% of the catch. Also, even during high sockeye abundance, the presence of aggressive seals may affect the behaviour of fish in the vicinity of the net such that the proportion of fish caught in these test fisheries is significantly less than the historical averages or inter-annual range. The investigation of sources of error as a result of this problem has been identified as a PSC priority. A prototype electrical deterrence system was designed and manufactured by Smith-Root for the Pacific Salmon Commission for deployment on salmon gillnets to deter seal predation; however, further trials are required before its effectiveness can be determined. In addition, intense seal predation occurs on Chinook and coho smolts near the 5th Street Bridge on the Puntledge River.

In 2007, we received funding from the Southern Enhancement Fund to investigate the use of an electrical gradient as a deterrent to seal predation on salmon. This study responded to an objective of the Southern Enhancement Fund to fund projects on improved information for Fraser River sockeye and Pink salmon stock assessment through the elimination of nuisance seals from test fisheries. This study also responds to the mandate of the Southern Enhancement Fund for funding of enhancement activities. Our primary objectives were to assess the response of seals to an electrical gradient, and how foraging seals respond to electrical fields so as to be able to evaluate whether the method might be an effective and practical deterrent. While there is considerable information on the response of fish to electrical barriers, virtually nothing is known about the response of marine mammals. In the first phase of the study, we conducted experiments with captive seals at the Vancouver Aquarium to assess their response to electrical gradients. In the second phase of the study, the 5th Street Bridge in the Puntledge River provided an ideal location to field test the electrical deterrence system, because the gear could be fixed in location, and the response of seals that predictably congregate to forage below the bridge to electrical pulses could be easily observed. We conducted initial field trials at this location in April, 2007 when seals feed on out-migrating salmon fry and smolts. In the third phase of the study, we conducted trials at the Cottonwood and Whonnock test fisheries, to assess the practicality of operating mobile electrical deterrence gear to prevent seal predation on salmon caught in the gillnets and to reduce the activity of seals around the nets. During the captive experiments and field trials the seals were closely observed for signs of distress or harm in an attempt to assess the humaneness of the methodology. In addition, response thresholds and efficacy of the electrical barrier were assessed.

Phase I

Evaluation of an Electrical Gradient as a Seal Deterrent at the Vancouver Aquarium, March 27, 2007

In the first phase of the study, we conducted experiments with captive seals at the Vancouver Aquarium to asses their response to electrical gradients. During these experiments response thresholds and efficacy of the electrical barrier was assessed. In addition, the seals were closely observed for signs of distress or harm in attempt to assess the humanness of the methodology.

Methods

On March 26, 2007, a system was installed to create an electrical voltage gradient in a research pool at the Vancouver Aquarium (Figure 1). The anode and cathode of the system were located directly across from one another approximately 4.9 m on opposite sides at the west end of the research tank. The test seals could not simultaneously touch both electrodes. In addition, a non-electrified area within the pool was created. The electric field occupied approximately one third of the pool. Final calibration of the system was completed on March 27, 2007 and the voltage gradient in the field area was mapped following each trial. Electrical field density readings ranged between 0.10 - 0.32 Volts/cm. The conductivity of the test pool was approximately 600 microSiemens/cm. Two harbour seals (*Phoca vitulina*) were evaluated during separate trials in this study: Seal 1, a male weighing 92 kg and Seal 2, a male of 89 kg. The purpose of the trials was to determine the minimum voltage field that elicits a change in the behaviour of the harbour seals used in the study. The intensity of the voltage field was manipulated by varying pulse width.

The pulse frequency was fixed during the trials at 2.25 Hz. Pulse width was increased at approximately 5 minute intervals during the trials with steps beginning at 75 micro-seconds, 100 micro-seconds, 200 micro-seconds and 400 micro-seconds. Prior to the commencement of the trials, the test animals were allowed to acclimate to the research pool and the study equipment. During the acclimation, the animals showed no apparent interest in the equipment and their behaviour was judged normal by the Vancouver Aquarium marine mammal trainers and Dr. Martin Haulena, the Vancouver Aquarium veterinarian.

Results

The first study animal, Seal 1, demonstrated no change in behaviour at a pulse width of 75 micro-seconds (5 minute period) or at a pulse width of 100 micro-seconds. The seal swam into all areas of the pool and used haul-outs on both ends of the pool. However, at a pulse width of 200 micro-seconds, he demonstrated a noticeable change in behaviour by swimming in a tight little circle (less than one body length in diameter) near the edge of the electric field and exiting to the non-electrified portion of the pool outside of the voltage gradient. During the 5 minute interval at a pulse width of 200 micro-seconds, the seal approached the electric field 4 times demonstrating active avoidance of the electrical gradient area on each occasion. At this point the electrical gradient was turned off and Seal 1 resuming normal swimming patterns in the area that was previously avoided at the 200 micro-second pulse width setting.

The second study animal, Seal 2, demonstrated no change in behaviour at pulse width settings ranging from 75-200 micro-seconds (5 minute periods each). However, at a pulse width of 400 micro-seconds, he demonstrated a noticeable change in behaviour by turning around at the edge of the electric field and returning to the area outside the voltage gradient. The seal approached the electric field 18 times demonstrating apparent avoidance of the voltage gradient areas on each occasion. This animal did not demonstrate the same behaviour as the previous animal, which swam in a quick, tight little circle each time it entered the voltage gradient. As in the previous trial, at this point the electrical gradient was turned off and Seal 2 resumed swimming in the area that was avoided at the 400 micro-second pulse-width setting. The study was repeated with Seal 2 using a pulse frequency of 1.32 Hz with the same avoidance behaviour noted at 400 micro-second pulse width with resumption of normal swimming patterns after the gradient was removed. Seal 2 was more active throughout the study than was Seal 1.

In this short study, both seals demonstrated avoidance responses at voltage gradients and pulse width settings much less than typically required for freshwater fish (Dave Smith, Personal communication, Smith-Root Inc). At the conclusion of each of the trials, the study animals demonstrated no negative effects of the experiment as judged by the marine mammal trainers and Dr. Haulena. The animals resumed feeding 3 hours after the experiment and exhibited no abnormal behaviour.

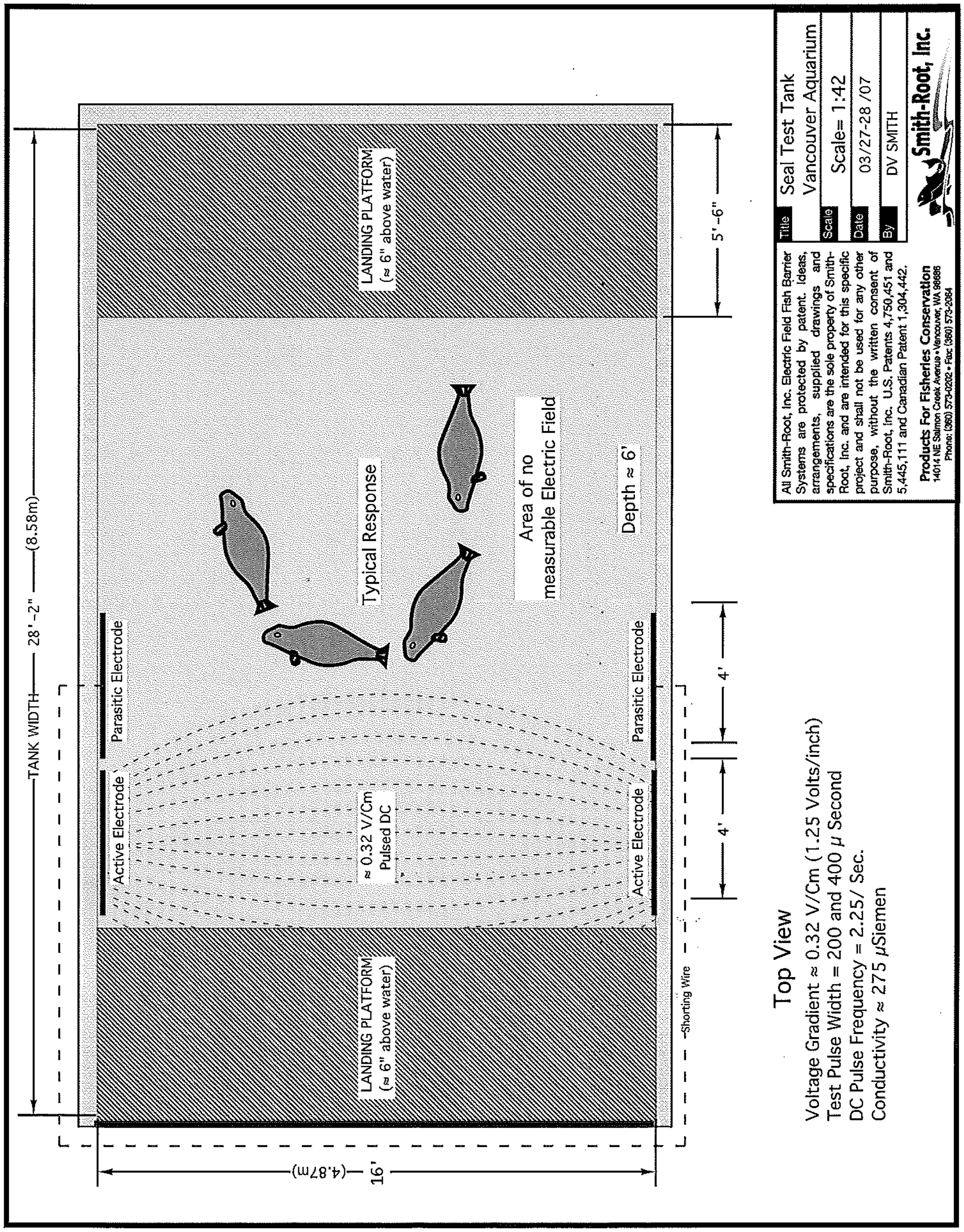

Figure 1: Schematic plan of the electrical gradient array deployed in the research pool at the Vancouver Aquarium March 26, 2007.

Phase II

Evaluation of an Electrical Gradient as a Seal Deterrent Puntledge River Study, April 10-24, 2007

In the second phase of the study, the 5th Street Bridge in the Puntledge River provided an ideal location to field test the electrical deterrence system, because the gear could be fixed in location, and the response of seals could be easily observed. We conducted initial field trials at this location in April, 2007 when seals feed on out-migrating salmon fry and smolts. As in the study at the Vancouver Aquarium, response thresholds and efficacy of the electrical barrier were assessed. Also, the seals were closely observed for signs of distress or harm in an attempt to assess the humaneness of the methodology.

Methods

From April 10 – 25, 2007, an electrical deterrent system was installed to create an electrical voltage gradient across the Puntledge River, in Courtenay, B.C. During March – May harbour seals (*Phoca vitulina)* typically enter the Puntledge River around dusk and use the light-shadow boundary from the lights on the 5th Street Bridge to forage for out-migrating juvenile salmon. The Puntledge River at the 5th Street Bridge was considered to be an ideal location to field test the electrical deterrent system: 1) it is freshwater, 2) the gear can be fixed, and 3) the response of harbour seals, that predictably congregate to forage on out-migrating Chum salmon fry (*Oncorhynchus keta*), can be easily observed. Our primary objective was to assess how foraging seals respond to electrical fields so as to be able to evaluate whether the method might be a humane, effective and practical deterrent. The Animal Care Committee, Department of Fisheries and Oceans, Canada (DFO) approved the Animal Use Protocol for the Puntledge River study and Marine Mammal Scientific License 2007-10 was issued by DFO.

The electrical array was installed into the Puntledge River between April 10 and April 12, 2007. The 5th Street Bridge crosses the Puntledge River approximately 1 km upstream from Comox Harbour. The river has been channelized upstream and downstream of the 5th Street Bridge. At the 5th Street Bridge the river depth and flow are influenced by tide, but salt water intrusions have not been observed at this location (personal communication, Brian Munro, DFO). Water conductivity in the Puntledge River was 25.5 µSiemen/Cm, considerably lower than at the Vancouver Aquarium. The bottom gradually sloped towards mid channel, although the water was slightly deeper on the south or right bank side of the river. The bottom substrate consisted primarily of rocks of varying size. The mid channel depth ranged from approximately 1.5 meters at low tide to 2 – 3 meters at high tide, with the current velocity being the greatest at low tide and little or no flow at high tide. The respective night time high tides at Comox Harbour were at 03:07 (4.6 m.), 03:43 (4.7 m.) and 04:13 (4.7 m.) on April 12 – 14 and 00:15 (4.9 m) and 01:19 (4.8 m) on April 23 & 24.

The electrodes of the array consisted of 4, half-inch copper cables spaced 1.8 meter apart with plastic PVC cross-members every 4.6 Meters. (Figure 2). Eleven PVC cross-members were spaced at 4.6 meter intervals, perpendicular to the cables and parallel to the flow, across the 49 meter width of the Puntledge River. The electrical array was floated into place, sunk and anchored on the bottom of the river. The downstream edge of the array was located approximately 3 meters upstream from the 5th Street Bridge. The array measured approximately 5.5 meters in width by 49 meters in length and lay on the bottom of the river below the area where seals are known to congregate and forage. The entire 5.5 m x 49 m water column directly above the array could be energized when the power was turned on. The array was designed by Smith-Root to produce a graduated electric field at a very low level of pulsed direct current (DC). The copper cables were attached to 3 Smith-Root 1.5 POW DC Pulse Generator units powered by a portable 5.5 KW, AC generator. The pulse frequency was fixed during the trials at 2 Hz. The intensity of the voltage field was manipulated by varying the pulse width. Final calibration of the system was completed on April 12, 2007 and the voltage gradient in the field area was mapped prior to testing. Electrical voltage gradient readings ranged between 0.12-0.28 volts/cm. By design, the highest field strength was at the most upstream edge of the array.

Results

The first series of trials were conducted on April 12 - 14, 2007. During the evening of April 12, 2007, the parameters of the electric field were reviewed with Vancouver Aquarium veterinarian, Dr. Martin Haulena; DFO Marine Mammal Coordinator, Marilyn Joyce; DFO Marine Mammal Biologist, Peter Olesiuk; Dr. Christine MacWilliams, DFO Veterinarian; Puntledge River Hatchery Manager, Chris Beggs, and staff from Smith-Root and the Pacific Salmon Commission, and it was agreed that the study could proceed. The initial pulse width setting was 200 micro seconds. With the power turned off to the electrical array at 00:00 (midnight) on April 13, 3 seals were observed from the 5th Street Bridge. Two of those seals appeared to be actively feeding within the array area. At 00:15 the power was turned on to the array. Both seals showed an abrupt change in behaviour and both seals left the vicinity of the electrical array. At 00:16 1 seal was observed, and 16 seconds later the seal swam within the electrical field. After 12 seconds the seal swam downstream and out of sight. At 00:20 1 seal was observed above the array and at 00:21 the seal quickly swam upstream and out of sight. At 00:30 power was turned off. At 00:34 1 seal was observed upstream and after a few seconds swam upstream and out of sight. At 00:38 1 seal was observed within the array area, but within a few seconds the seal swam away and out of sight. This same pattern of behaviour occurred twice over the next 10 minutes. With no seals observed after an additional 45 minutes of observations the trials were concluded at 01:25, April 13. Dr. Martin Haulena did not identify any behaviour by the seals that would indicate the animals were distressed during, or immediately following the period that the electrical equipment was turned on. Seals resumed usual behaviour during the time that they occupied the area 10-20 meters upstream of the apparatus. No seals were observed on the following evening, April 13/14. This may have been due to heavy rain, high water levels, high river velocity, and high turbidity.

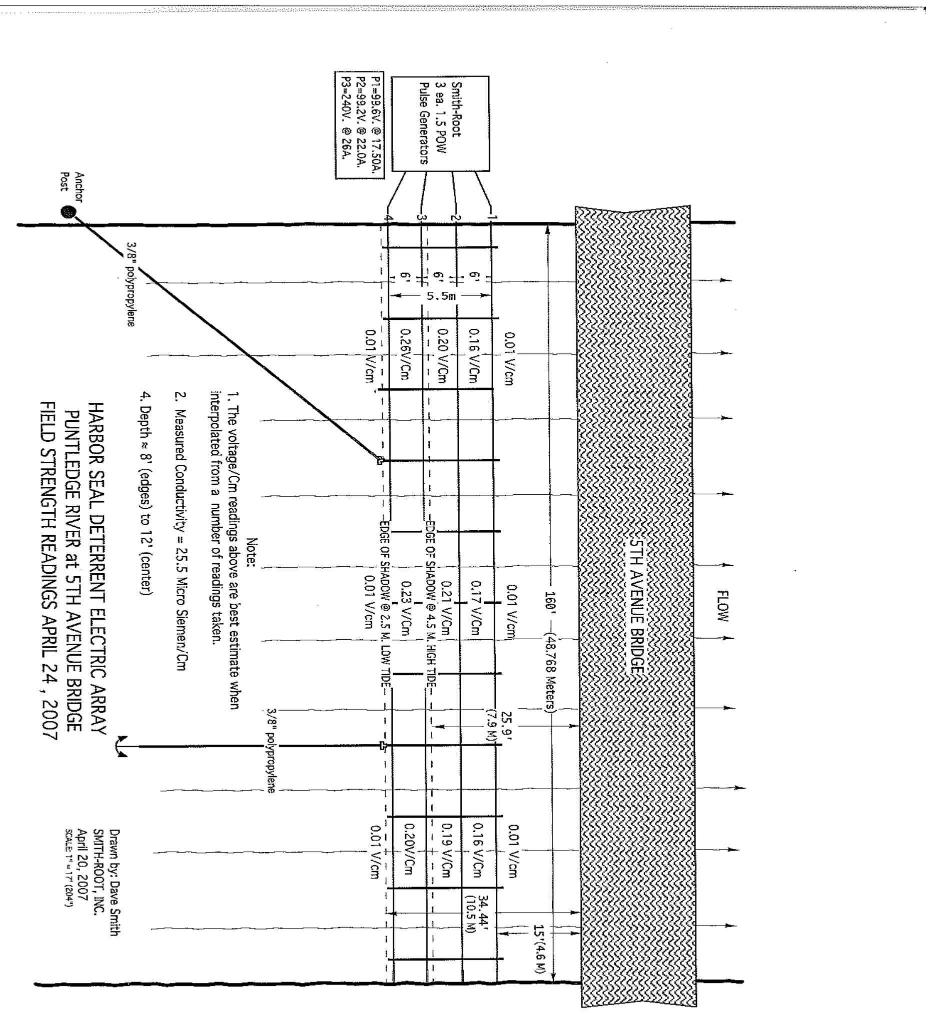

Figure 2: Schematic of electrical deterrent array situated upstream of the 5th Street Bridge on the Puntledge River. Field Strength readings are for April 24, 2007

A second series of trials were conducted during the evening hours of April 23–24 and April 24-25, 2007. Prior to April 23rd several seals were observed foraging beneath the 5th Street Bridge as well as upstream of the Bridge. Present during the April 23 – 24 trials were Keith Forrest (PSC), Chris Beggs (DFO), Brian Munro (DFO), Peter Olesiuk (DFO), Dr. Martin Haulena (Vancouver Aquarium), Lisa Harlan (Smith-Root), Lee Carstensen (Smith-Root). The electrical voltage gradient readings ranged between 0.16–0.26 volts/cm. On April 23, at 21:30 7 seals were observed feeding within the array area in addition to several other animals feeding upstream of the 5th Street Bridge. The seals were observed for 30 minutes prior to turning on the power to the array. The power was turned on to the array at 22:07. The pulse width was set at 500 micro-seconds. At 22:10 3 seals were present upstream of the array. At 22:11 1 – 2 seals remained in the vicinity of the array. The observed seals were no longer feeding. At 22:13 the power was turned off to the array and 2 seals appeared from upstream. At 22:19 3 seals were present in the array area and by 22:24, 4 seals were present. The seals did not appear to be foraging as vigorously compared to earlier observations. Over the next 30 minutes, the number of seals observed from the 5th Street Bridge ranged between 2 – 8 animals. In addition to the 5th Street Bridge observations 7 seals were observed approximately 200 meters upstream from the Bridge. At 23:00 there were 4 seals present within the array area and the power was turned on. The pulse width was set at 1 millisecond. The 4 seals responded abruptly, splashed and immediately left the area. At 23:06 1 seal briefly swam into the array, but turned way immediately. At 23:08 the power was turned off to the array. No seals were observed over the next 45 minutes and trials were concluded at 23:43 pm.

On April 24, 2007 the power was turned on at 19:00, 1.5 hours before dark. The pulse width was set at 1 millisecond. From the 5th Street Bridge the array was continually monitored and observations upstream of the Bridge were conducted every 30 minute intervals. At 20:55 1 seal turned around as it approached the array from downstream. At 21:10 a second seal turned around as it entered the array area from downstream. At 21:30 a third seal turned around as it swam upstream into the array area. One seal was observed upstream of the array and at 22:30 1 seal was observed swimming downstream towards the array. Between 21:15 and 22:00 several seals were observed downstream of the 5th Street Bridge. At 23:00 the power was turned off to the array and by 23:30 there were 10 – 12 seals actively feeding upstream of the Bridge (near the tennis courts). At 00:30 no seals were present beneath the 5th Street Bridge, however 10 – 12 seals remained feeding upstream of the Bridge. With the array removed from the Puntledge River, on April 26, 2007 at 00:01 9 seals were observed feeding slightly upstream of the 5th Street Bridge light shadow in addition to 6 seals feeding upstream of the Bridge.

In conclusion, during this study an avoidance response of the seals to the array area was demonstrated at pulse width settings of 200 and 500 micro-seconds. However continuous deterrence of seals from foraging was not demonstrated at these settings. A clear avoidance response was evident at a pulse width setting of 1 millisecond and seals avoided moving upstream through the electrical field. The voltage gradient and pulse width settings are much less than required for an effective barrier of freshwater fish migration (Dave Smith, Personal communication, Smith-Root Inc). The one seal that was observed upstream of the electrical array, on April 24th, may have swam through the electrical field unobserved, or the animal may have already been upstream prior to turning the power on to the array at 7:00 pm. There did not appear to be any lingering or adverse effects of the electric field on the seals as they were observed swimming and feeding normally within the array area shortly after the power was turned off and during the evenings that followed.

Factors such as water conductivity, pulse width, voltage gradient, the size of animal, species, motivation and habituation to electric field could influence the avoidance response by individual animals. Additional pilot studies will be required to ascertain how these factors may influence the avoidance response of seals and other pinnipeds to a DC-pulsed electric voltage gradient. However, this feasibility study indicates that this technology has potential for deterring marine mammal predation on fish.

Phase III

Evaluation of an Electrical Gradient as a Seal Deterrent Fraser River Gillnet Study

Introduction

The Pacific Salmon Commission annually operates two drift gillnet test fisheries in the Fraser River. The Cottonwood test fishery is located approximately 30 km upstream from the Fraser River mouth, between the Alex Fraser Bridge and the Deas Tunnel. The test fisheries typically operate from late June to mid-late September and they are used to assess Fraser River sockeye and pink salmon upstream migration abundance. The Cottonwood test fishery operates during daylight hours, at low slack tide, and depending upon catch and abundance fishes one, or two, 30 minute sets per day. The Whonnock test fishery also operates during daylight hours, and at low slack tide, and generally fishes two 20 minute sets per day. In recent years the number of harbour seals observed during these test fisheries has reached twenty, or more, animals. The seals congregate and forage on salmon that are caught in the test gillnets. Reduced salmon landings has compromised the integrity of Fraser River gillnet test fisheries and the information they provide for Fraser River Panel management. During Phase III of this project, we installed and tested an electrical deterrent system to create an electrical voltage gradient within a Fraser River drift gillnet August 14-September 11, 2007,.

The primary objective of the gillnet study on the Fraser River was to assess how foraging harbour seals (*Phoca vitulina)* respond to an electrical voltage gradient so as to be able to evaluate whether the method might be a humane, and effective method to deter seal predation of salmon caught in a gillnet. An experimental gillnet with a built-in electrical deterrent system was constructed. The net was divided into two 50 fathom sections: a *control* section receiving no treatment and a *treated* electric section (Figure 3). The electrical deterrent system was designed by Smith-Root Inc. to produce a graduated electric field of low-voltage DC. A portable 3.5 KW AC generator, attached to a Smith-Root 1.5 POW DC Pulse Generator unit, located onboard the test fishing vessel, supplied the electrical power to the system. Based on the observed seal responses during the initial feasibility studies, the pulse generator was adjusted to produce, on average a voltage gradient of 0.35 V/cm, at a pulse frequency of 2 Hz and a pulse duration of 1 millisecond. These parameter settings were held constant throughout the Fraser River gillnet study. Even though the Cottonwood test fishing site is affected by the tides, daily water conductivity measurements (106 µSiemen/Cm) at the Cottonwood site were uniform and showed no evidence of salt water intrusion. The electrical voltage gradient measurements surrounding the gillnet revealed that the voltage gradient declines with increasing distance from the electrode wires. The electrical gradient readings at the surface ranged between 1.2 V/cm, near the electrode to 0.15 V/cm at 1 m from the gillnet.

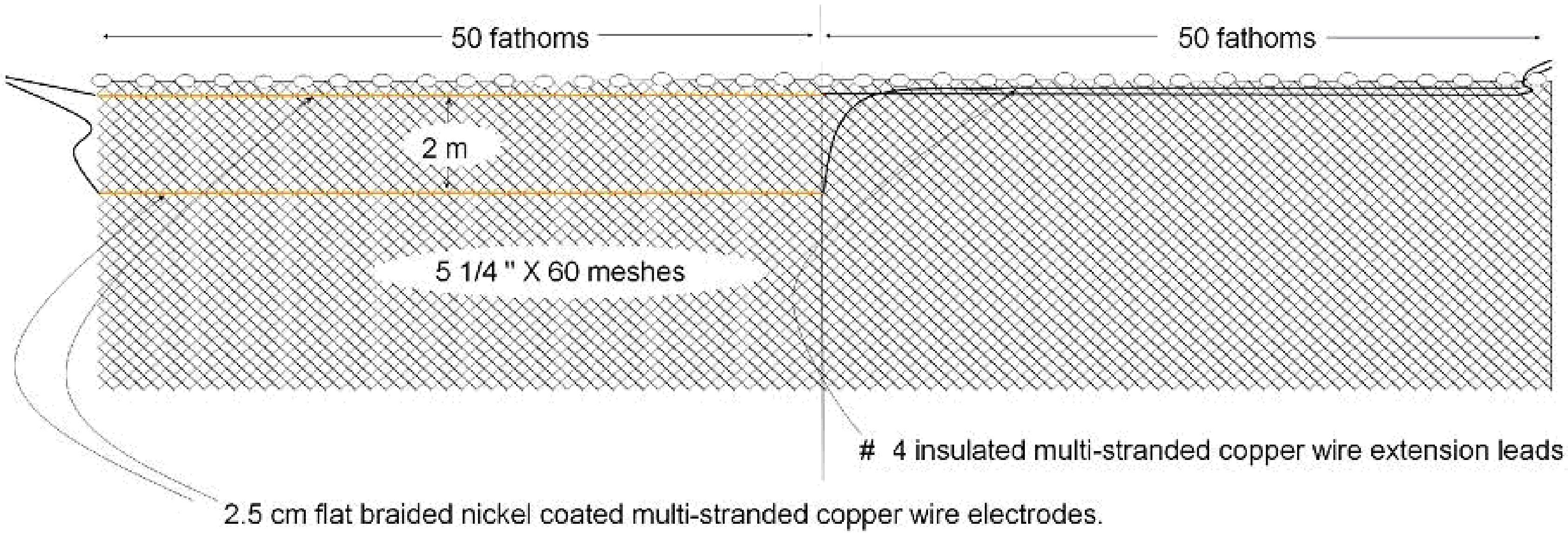

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Figure 3. The experimental seal deterrent electric test fishing gillnet was constructed from 11 gauge, 5 ¼" (diagonal mesh size) x 60 meshes deep. It was divided into two 50 fathom sections; a control section, receiving no treatment and a treated section. The treated electric section contained two 2.5 cm flat braided nickel coated multi-stranded copper wire electrodes. The extension leads consisted of #4 gauge insulated multi-stranded copper wire.

From August 21-September 11, three 20-minute fishing sets were conducted daily at low slack tide, at the lower Fraser River Cottonwood test fishing site, totaling 66 fishing sets in 22 days. To evaluate differences in fish distribution (and catch rates) between the shore and channel portions within the river, we attempted to alternate the control and treated sections of the gillnet between the shore and the channel portions of the river. To evaluate differences in seal and/or fish behavior due to the proximity of the test fishing vessel, the vessel's location could be alternated between the control and treated section ends of the gillnet. The decision to alternate the gillnet position and vessel position (relative to the shore and net section end) was determined by the affects of the wind, river conditions and vessel traffic on the gillnet shape and drift speed, thus the number of fishing sets in any particular position was limited. Catch and fishing effort were reported by set for the control and treated net sections. The observer on board the fishing vessel recorded the position of the net sections, relative to the vessel and the shore. The observer recorded seal numbers, distribution, behaviour, seals with salmon in their possession, the number of landed damaged fish and net repair time.

The data obtained from the experiment were analyzed using factorial analysis of variance design (ANOVA) whereby the effects of several independent variables (electric versus control section, net position in relation to the shore, and vessel position in relation to the net) were calculated for the dependent variables (catch and CPUE). Catches could vary because of differences in salmon abundance, seal abundance, weather, etc. To account for the differences between days due to environmental heterogeneity, the fishing day was included as an additional independent variable within the factorial ANOVA. This resulted in a randomized block (day) design whereby we assumed that environmental conditions were more similar within blocks (days) than between blocks (days). The factorial ANOVA was expanded into a factorial ANCOVA analysis by including covariates that could explain the differences between days such as the daily salmon abundance estimates from a hydroacoustics program located approximately 30 km upstream of the test fishing site and the number of seals observed on any given day. The number of observed seals, salmon abundance estimates, salmon catch data and CPUE data were log-transformed prior to incorporating them in the factorial ANOVA and ANCOVA analyses in order to ensure variances were homogeneous.

Results

Daily average CPUE data for sockeye and pink salmon are presented in Figure 4. Total salmon catches and cumulative CPUE were substantially larger for the treated (electric) section of the fishing net (1108 salmon, 298.9 CPUE) versus the control section (272 salmon, 50.7 CPUE). Pink salmon constituted the most abundant species caught (treated section = 867 pink salmon, 236.5 CPUE; control section = 189 pink salmon, 35.5 CPUE), followed by sockeye salmon (treated section = 211 sockeye salmon, 54.4 CPUE; control section = 76 sockeye salmon, 13.4 CPUE). The marginal median salmon catch and CPUE were significantly larger for the treated electric net versus the control section and there was no overlap between the 95% confidence intervals of the two treatments (Figure 5).

The factorial ANOVA analysis indicated that the electric treatment of the gillnet, vessel position relative to net section and the fishing day all have a significant effect on CPUE (Table 1). There was no significant effect of the position of the net relative to shore, on the CPUE. Also the various interactions terms were non-significant. Similar results were obtained for the salmon catch data.

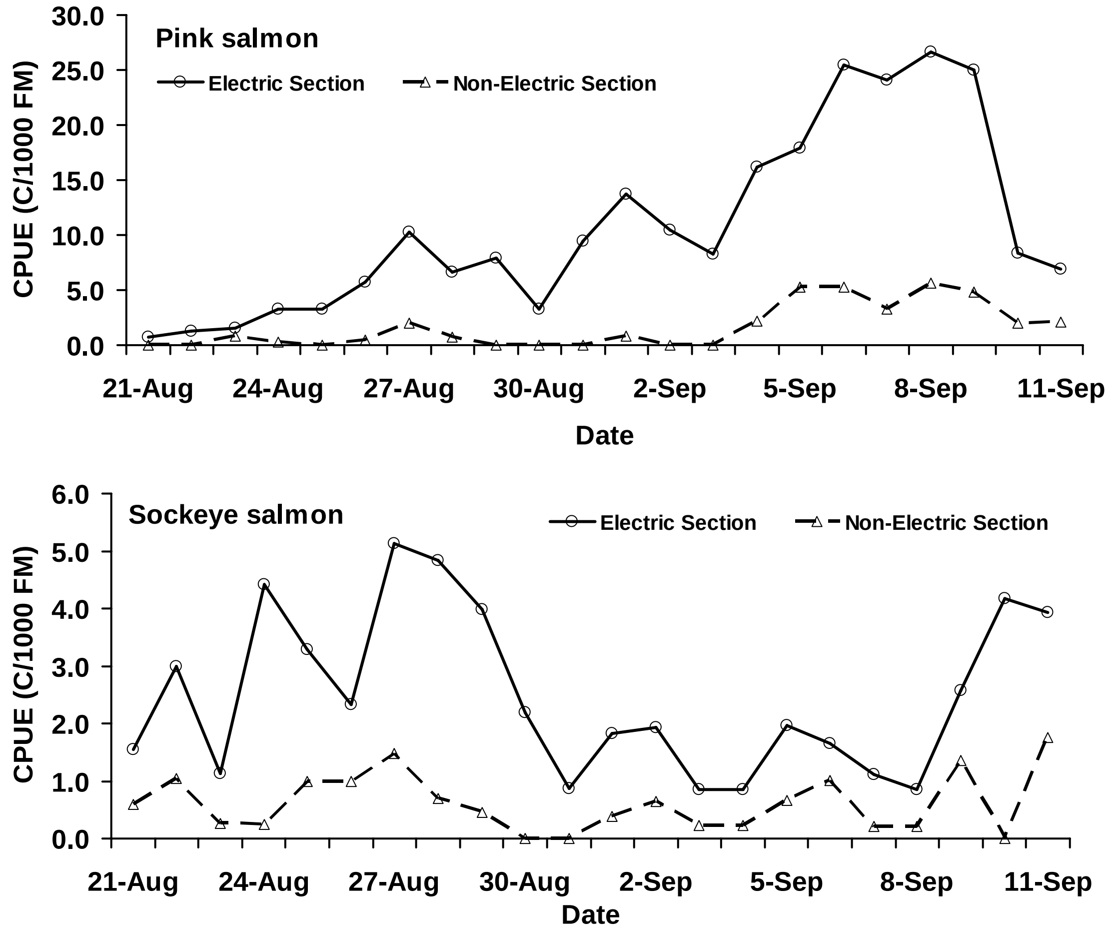

Figure 4. Daily average pink and sockeye salmon CPUE from gillnet test fishery data collected in the lower Fraser River at Cottonwood, showing differences between the control section of the net and the treated section (having the experimental electric seal deterrent system).

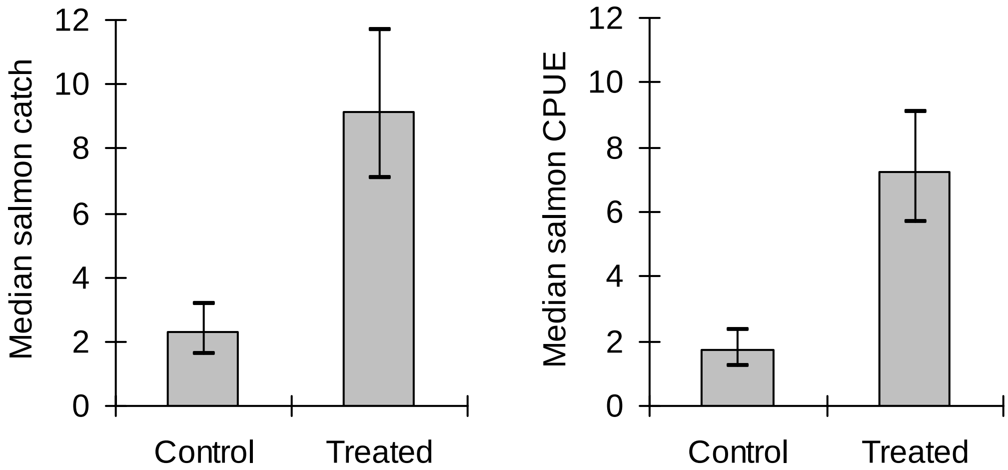

Figure 5. Marginal median estimates and 95% confidence intervals for the salmon catch and CPUE for the treated (electric) net section and the control net section used at the Cottonwood test fishing location in the lower Fraser River.

Table 1. Results of the analyses of variance (ANOVA) and covariance (ANCOVA) for the independent variables (electric vs. control section of the net, net position relative to shore, and vessel position relative to the net) on two dependant variables (salmon CPUE and catch). To account for differences between fishing days the fishing day is included as an additional independent variable within the ANOVA. The ANOVA is expanded into an ANCOVA by including covariates that could explain the differences between days such as salmon abundance (transformed to a lognormal scale).

Variable	Salmon CPUE				Salmon Catch			
	ANOVA		ANCOVA		ANOVA		ANCOVA	
	F-ratio	P-value	F-ratio	P-value	F-ratio	P-value	F-ratio	P-value
Main affect								
Electric vs. control section	**65.60**	**0.00**	**57.70**	**0.00**	**57.36**	**0.00**	**49.88**	**0.00**
Net position relative to shore	0.02	0.90	0.01	0.91	0.08	0.78	0.07	0.80
Net position relative to vessel	**15.82**	**0.00**	**13.91**	**0.00**	**14.44**	**0.00**	**12.56**	**0.00**
Fishing day	**3.93**	**0.00**	-	-	**4.00**	**0.00**	-	-
Interaction affect								
Electric vs. control section x net position relative to shore	0.10	0.76	0.42	0.52	0.05	0.82	0.50	0.48
Electric vs. control section x net position relative to vessel	2.44	0.12	**6.33**	**0.01**	2.44	0.12	**5.67**	**0.02**
Net position relative to shore x net position relative to vessel	0.05	0.83	1.03	0.31	0.03	0.87	0.99	0.32
Covariate								
Salmon abundance	-	-	**40.09**	**0.00**	-	-	**39.56**	**0.00**

significant results (at the 0.05 level) are highlighted in bold.

Including daily salmon abundance estimates within the analysis to account for some of the daily variability, the ANCOVA results indicated significant effects of the net section, vessel position relative to net section and daily salmon abundance on CPUE and catches (Table 1). In addition there was a significant, but weak interaction between the net section and vessel position relative to net section. Overall, catches and CPUE in the treated electric section of the gillnet were affected by the position of the test fishing vessel relative to the net section.

Discussion

This study demonstrates that seals can be deterred from foraging at a gillnet by a pulsed, low-voltage electrical gradient. The treated electric gillnet section had significantly higher catches and CPUE than the untreated section. Onboard observer records indicate that the majority of seal foraging activities occurred at the far end of the gillnet and therefore the landed salmon catch was dependant on the net section, as well as the vessel position relative to the net section. Also, seals foraged at the treated electric section of the net after the treated electric section was deactivated to allow safe handling and picking of fish from the net. We made no attempt to estimate the number of fish removed after the electrical system was deactivated. The length of the gillnet (approximately 183 meters) was a small proportion of the total river width at the Cottonwood test location (approximately 1 km) and all the fishing sets were made closer to the south shore to avoid vessel traffic. The limited spatial coverage of the gillnet relative to the width of the river at Cottonwood, may not be sufficient to detect a significant difference in salmon (or species) distribution within the river. The effect of an electric gradient on catch levels (marginal median estimate) is illustrated in Figure 5. For 2008 we intend to improve the handling and fishing ability of the gillnet and reduce seal predation while the net is being picked.

Olesiuk *et al.* (1990) estimated that the number of harbour seals in the Strait of Georgia increased from 2,170 in 1973 to 15,810 in 1988 and that Fraser River seal numbers increased by 9.4% during the same period. PSC Fraser River gillnet test fishing observers at Cottonwood recorded an increase in the average number of seals from 0.5 seals per trip in 1978 to 10 seals per trip in 2007, and the maximum number of seals observed per trip increased from 2 seals in 1978 to 18 seals in 2007. In the past decade test fishery catches have declined. During periods of low salmon abundance, seals can remove 100% of the catch from the nets. From 1988 to 1996 the Cottonwood gillnet test fishing catchability (relating abundance to CPUE) averaged 3.46×10^{-4} (SD = 3.81×10^{-5}). Since 1996 the gillnet test fishing catchability has decreased substantially and become highly variable (average = 1.52×10^{-4}; SD = 9.28×10^{-5}). The decrease in catchability coincides with an increase in the number of seals observed per trip. The substantial declines in catchability since 1996 are far greater than could be explained by direct consumption and removal of salmon by seals. Thus the increased presence of seals, in the vicinity of the test fishing gillnets, also influences salmon behaviour and affects the number of salmon that are caught by the net. In their attempt to avoid the predators in the vicinity of the gillnet, salmon inevitably avoid the fishing net.

The behavioral response of individual salmon to the electric fields may be influenced by factors such as water conductivity, pulse width, pulse frequency, size of the animal, species, motivation and habituation to electric fields. In September 2007 we used a DIDSON imaging sonar (Xie et al. 2005) to evaluate the swimming behaviour of pink salmon in the presence of an electrical gradient. Two parallel electrodes were laid on the river bottom, extending approximately 30 m perpendicular from shore. This study indicated that pink salmon demonstrate a change in swimming behaviour at electrical field densities (0.4 V/cm; 0.5 Hz.;

0.5 milliseconds) lower than those used for the gillnet seal deterrent study. It is still unclear however how salmon behaved in the vicinity of the treated electrical section of the gillnet and how catches may have been affected by the electrical gradient in the absence of seals.

The electrical deterrent system advocated in this paper has the potential to be a safe and practical deterrent to seals foraging on endangered salmonids in freshwater systems (e.g. Skeena, Columbia and Puntledge rivers) and to our knowledge this study represents the first documented account of the use of an electrical gradient to deter marine mammal predation and behavior. Unfortunately this technology has limited use in marine situations, because the conductivity of seawater approaches or exceeds the conductivity of the animal (Reynolds 1996). As a result the transfer of threshold power is reduced causing little or no effect (Reynolds 1996; Kolz 1989). Future work should be directed towards investigating applications in other systems and also towards the response of fish and other animals to electric fields of similar intensity. The innovative technology we describe represents a novel approach in developing non-lethal methods to deter marine mammal predation on populations of anadromous fishes. The ability to reduce marine mammal predation at gillnet test fisheries benefits data quality at these sites and has meaningful implications for fishery managers.

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