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FISH BEHAVIORAL AND PHYSICAL RESPONSES TO VIBROSEIS NOISE PRUDHOE BAY, ALASKA 2003

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Photos by William Morris ADNR, OHMP

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Provisional Draft – Subject to update with the addition of experiment specific sound pressure level data.

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Table of Contents

List of Tables

List of Figures

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Introduction

With the shift in seismic exploration techniques from use of explosives to the use of air gun arrays and vibroseis vehicles as the primary energy sources for seismic exploration in northern Alaska, risk to fish from seismic exploration has been greatly reduced. However, there have been concerns that these techniques may be harmful to fish and aquatic mammals. Considerable research on air gun array impacts, primarily to marine mammals but also to fish, exists. In contrast, no direct research has been conducted to investigate the potential impacts of vibroseis noise on fish. In April 2000, amidst local and agency concerns that vibroseis conducted over fish wintering in lakes and riverine pools may harm the wintering fish, WesternGeco, along with representatives from Greeneridge Sciences, Inc. and the Alaska Department of Fish and Game (ADF&G) (now the Office of Habitat Management and Permitting within the Department of Natural Resources) conducted a field test to record the sound pressure levels imparted to a water body from vibroseis. Two reports were generated from the work; 'Vibrator Sounds in a Frozen Arctic Lake During a Winter Seismic Survey' by Greeneridge Sciences Inc. and 'Water Column Pressures Induced by Vibrators Operating on Floating Ice' by Dave Nyland of WesternGeco (Greene 2000, Nyland 2002) .

While collectively, the information gathered suggested that overpressures produced in the water column (5 vibrators at 106 Hz for 6 s = 180 to 190 dB (re 1 µPa) as measured from 10 m away from source, (Greene 2000, Nyland 2002) were in the range of those known to cause avoidance behavior, physical damage to fish seemed unlikely because the calculated instantaneous change in pressure was below the ADF&G limit of 2.7 psi. However, no measurement had been made directly below the ice under a vibroseis machine. This left quantifying the maximum possible overpressure to extrapolation of the empirical data (possibly as a high as 201 db (re 1µPa)). Local and agency concerns regarding the potential impacts to fish from vibroseis were not fully satisfied by the 2000 data collection effort. In consultation with the Bureau of Land Management, North Slope Borough, individuals from the communities of Barrow and Nuiqsut, and WesternGeco, the Office of Habitat Management and Permitting (OHMP) developed a two part study to directly address the potential impacts to fish from vibroseis. The study was designed to address the potential physical effects to fish from the energy imparted to a water

body by vibroseis equipment and also to semi-quantitatively assess the magnitude of the behavioral disturbance caused to fish by operating the equipment in their proximity. The study was conducted northeast of Deadhorse, Alaska at an isolated and flooded gravel mine site and in the Sagavanirktok River (Figure 1).

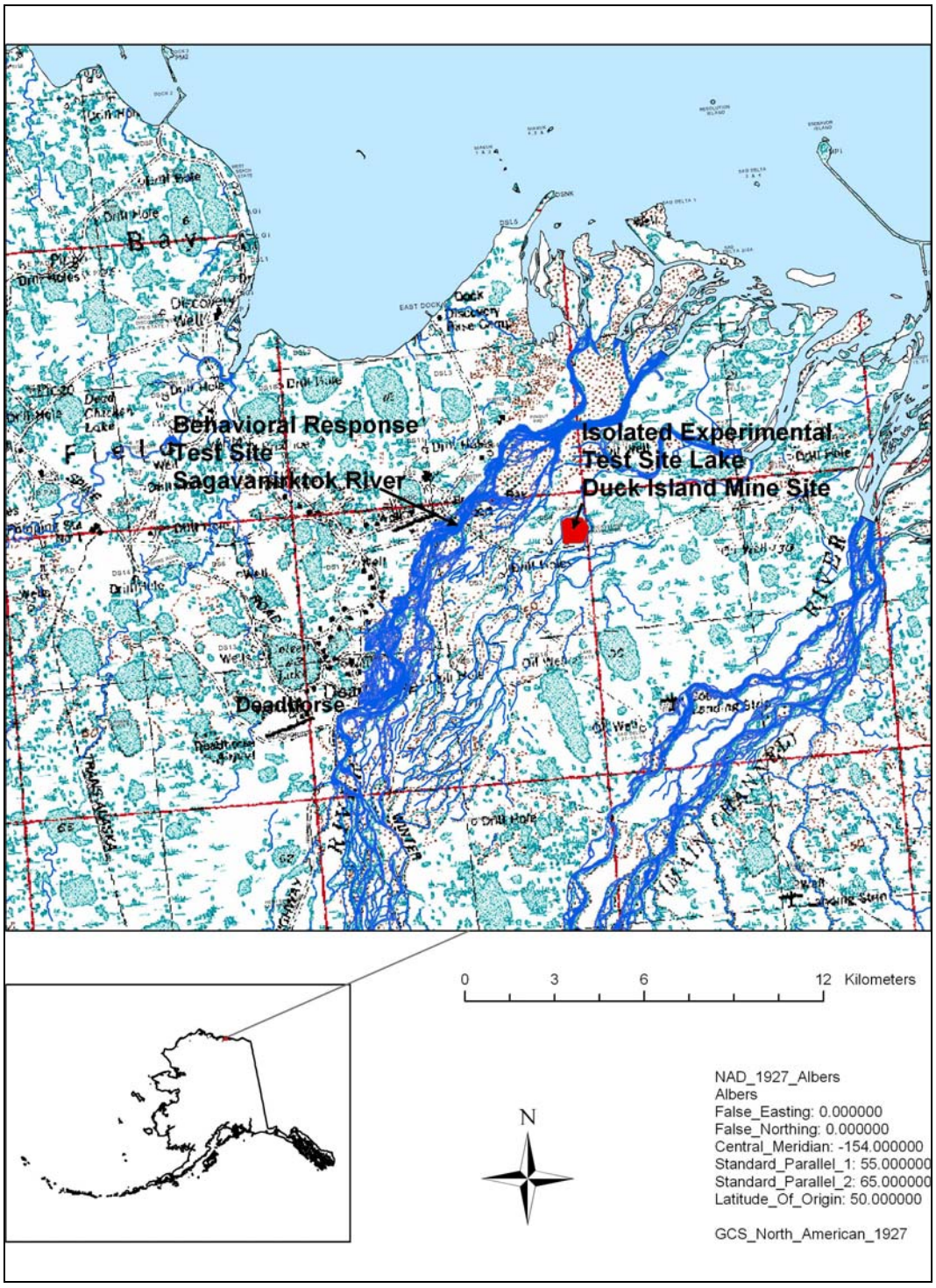

Figure 1. Experimental trials were conducted at an isolated flooded gravel mine site lake in the Sagavanirktok River delta and behavioral trials were conducted in a wintering hole in the Sagavanirktok River.

Methods

Physical Response to Vibroseis Experiment

Prior to conducting our field investigation we determined that we wanted to be able to detect a 10% vibroseis-induced injury rate if it were occurring. Given the low likelihood of injury, based on previous overpressure monitoring, we calculated that between 60 and 105 fish would be required for each trial to provide adequate power to detect our desired injury rate of 10% (Sokal and Rohlf 1969, Zar 1984). To accommodate the number of fish required per trial, 6 PVC coated minnow traps with 18" extensions were assembled and filled with a minimum of 18 fish each and lowered below the ice to the same location (Figure 2). The entrance throats to all traps were crimped closed to ensure fish could not escape. Each trap was fitted with two ropes, one for vertical orientation to allow traps to be retrieved through the ice and one for horizontal orientation during trials to ensure adequate space and dispersal of fish within each cage (Figure 2).

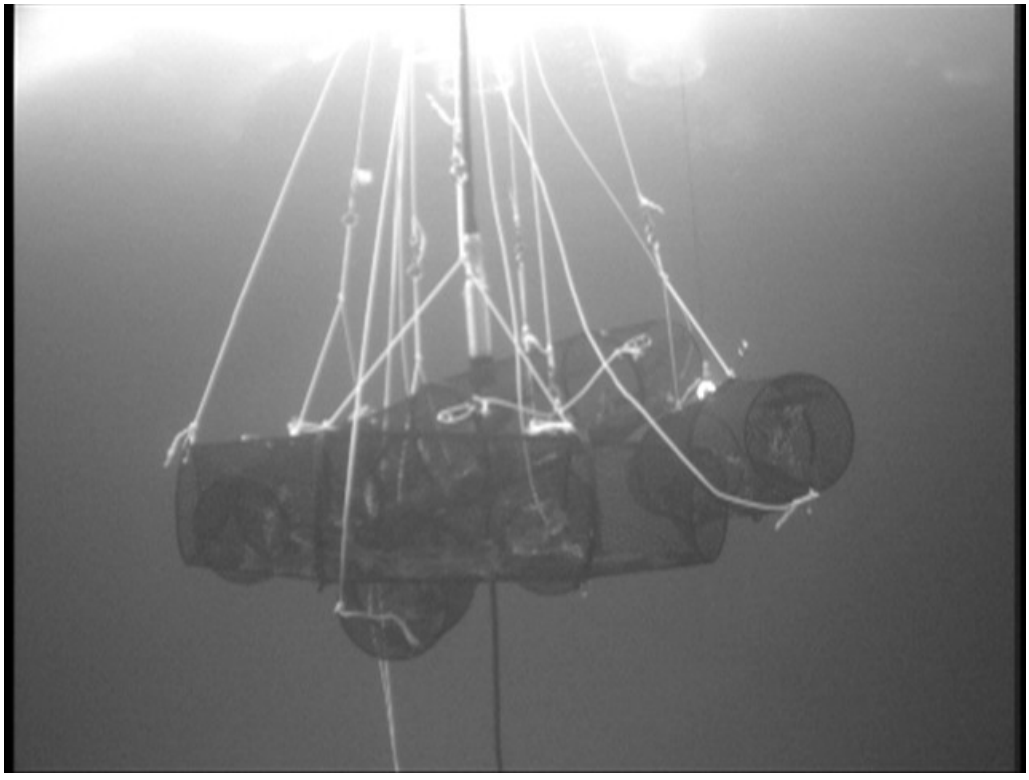

Figure 2. Six large traps with at least 18 fish per trap were lowered below the ice for both experimental and both control trials.

On April 26, 2003, BLM and OHMP representatives transported 600 Arctic char (*Salvelinus alpinus*) from the Ship Creek Hatchery in Anchorage, Alaska to Deadhorse, Alaska. Fish were loaded onto a BLM operated CASA in a 1.8 m X 1.2 m X 1.2 m high aerated transport tank at 1130 hours. Dissolved oxygen concentration in the tank was 118% saturated with 15 ppm oxygen. Dissolved oxygen concentration was monitored throughout the flight between Anchorage and Deadhorse to ensure that concentrations remained between 80% and 120% saturated. The tank was transferred to a pick up truck in Deadhorse for transport to the Duck Island Mine Site, a flooded 69 ha abandoned gravel extraction site with maximum depths between 7.5 and 9 m feet deep. The flooded mine site is completely isolated from any fish-bearing streams or rivers and contains no fish. Fish arrived at the study site at 1715 hours.

Four trials were conducted on site. The first trial was considered our preliminary control. A total of 108 fish, ranging in size from 108 mm to 288 mm were distributed equally between 6 traps and lowered into the water below the ice. Once all six traps had been placed below the ice they were removed in reverse order and transferred to a cooler with water. Fish were then euthanized with a high concentration clove oil solution. Fish in Control 1 were in the lake for 21 minutes each.

Experiment 1 was set up similarly to the first control. Six traps with 18 fish, ranging from 113 mm to 290 mm were lowered in the lake and positioned between the ice bottom and one meter below the bottom of the ice. Besides the main experimental group, one trap containing 10 fish was lowered approximately 5 m to the bottom of the lake. Two traps were also set 6 m to the side of the large group of fish, one between 0 and 1 m below the ice and one on the bottom of the lake (Figure 3). Each of these peripheral traps contained 10 fish. Once all traps were in place and all videography equipment was set up, one vibroseis rig was moved on top of the 108 fish sample location and operated in field-use configuration (presumably producing pressures similar to those found by Nyland 2002 and Greene 2000). The rig was immediately driven off the sample location and all fish were removed from below the ice. Fish from different trap locations were kept separate and bagged according to their location after being euthanized. All fish were placed into a cooler or bucket containing water and were briefly monitored for the presence of

blood before the fish were euthanized. Fish in Experiment 1 were in the lake for 48 minutes each.

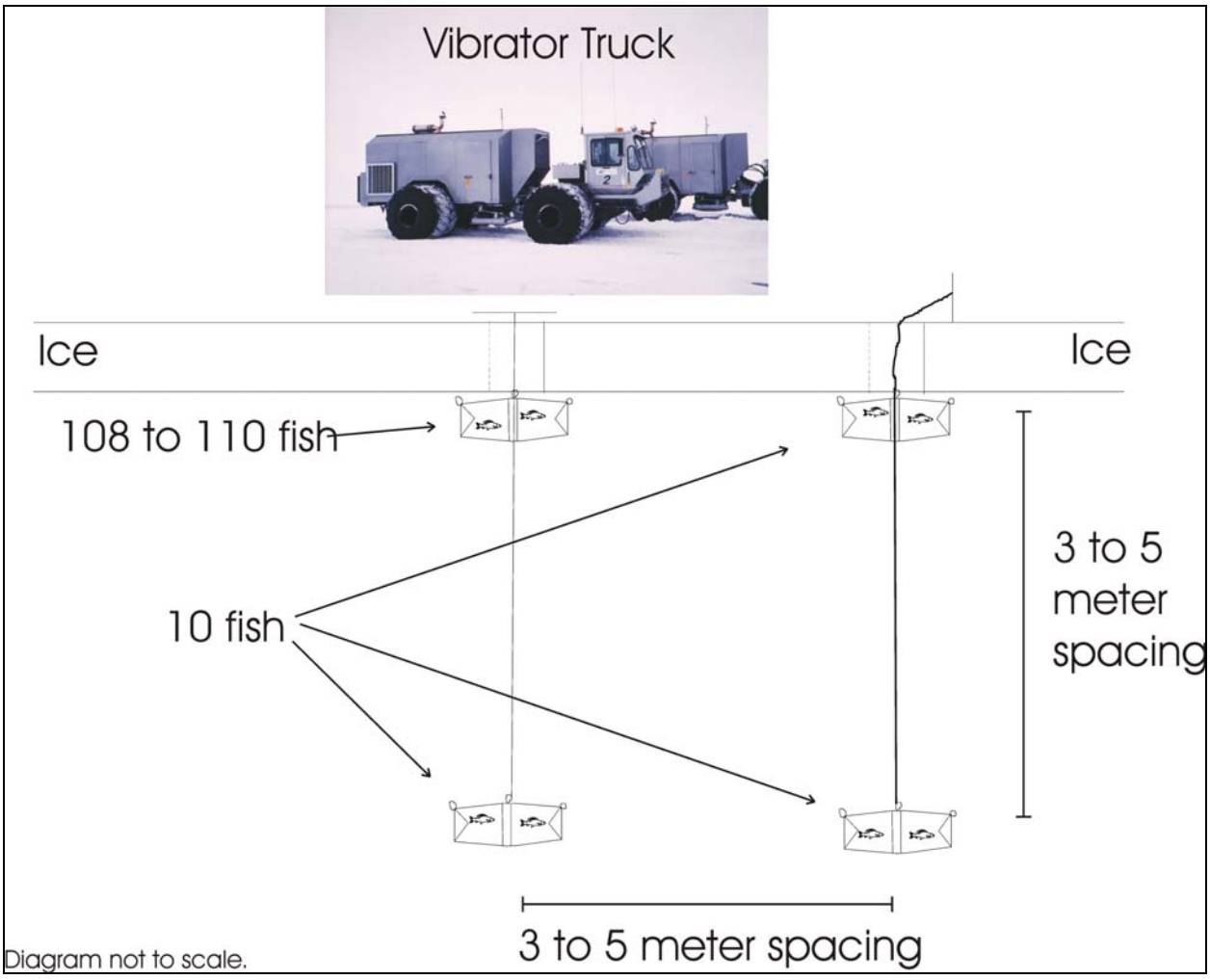

Figure 3. Experimental trials were configured to place the large experimental group of fish immediately under the center of the single and five vibrator trials. Controls groups were set up similarly. Three additional traps containing 10 fish each were set up during each experimental trial. One trap was placed below the center of vibrators, below the large group of fish, one trap was set 6 m to the side and an additional trap was set below the 6 m offset trap.

Experiment 2 was set up identical to Experiment 1 (Figure 3); however, 110 fish were used. Fish in the large experimental group ranged in size from 115 mm to 270 mm. For Experiment 2, 5 vibrator rigs, operating in a line as in field configuration, were centered over the large experimental group of fish. Unfortunately, one vibrator rig was fired inadvertently before the other four. We recorded the occurrence and location of the rig relative to the experimental groups of fish and proceeded to fire all five rigs simultaneously as in field operation at field

operation settings. Fish were removed from the water and treated as in Experiment 1. Fish in Experiment 2 were in the lake for 38 minutes.

Once all equipment had been removed from the lake we placed our final control group below the ice. One hundred ten fish from 105 mm to 275 mm long were used in Control 2. Fish in Control 2 were held in the lake for 50 minutes, approximately the longest time of lake exposure from the experimental groups (48 minutes in Experiment 1). Fish were removed from the lake and their cages and treated as in all previous trials.

Fish were kept cold but unfrozen and transported to Fairbanks for laboratory necropsy and photo-documentation. All necropsies were finished by 1800 hours on April 29, 2003. An individual not involved with the experiment covered all labeling on the coolers containing fish from each trial and gave each cooler an identification letter. Coolers were then arbitrarily selected and fish necropsied. Once all necropsies had been completed and results recorded, the label covers were removed and the initial labeling recorded with corresponding necropsy data.

Prior to necropsy, an individually numbered T-bar anchor tag was attached to each fish for identification purposes. Each necropsy consisted of an external examination of the body and eyes. Gross internal examination was then conducted. Each fish was examined primarily for damage to the swim bladder, the most likely organ to be damaged by vibroseis. The body cavity of each fish was photographed and all signs of injury were recorded. Statistical comparisons were all conducted using Statistix 8 by Analytical Software (Analytical Software 2003). Comparisons of trials were conducted using the Two-Sample Proportion Test (Fisher's Exact p) except where noted otherwise. All fish from Experiment 2, fish exposed to five vibrators, were x-rayed as well to determine if skeletal injury had occurred.

Behavioral Response

Once we had determined, from the experimental trials, that the likelihood of fish mortality from vibroseis was low, we proceeded with a behavioral response test using fish in a known wintering area in the Sagavanirktok River (Figure 1). On April 27, 2003 three underwater cameras were set up at a wintering area on the Sagavanirktok River. One vibroseis vehicle was moved into

place roughly between the three cameras. Once all camera operators were reporting fish in view, the vibrator rig was operated using the same vibratory pattern and energy as used in field survey operations. The vehicle was operated identically three additional times for a total of four energy bursts. Videotapes were later downloaded to a computer and time of disturbance after each operation of the vibroseis vehicle was determined using images from two of the underwater cameras; one camera did not successfully record footage during this trial.

Results

Physical Response to Vibroseis Experiment

A minimum of five of the smallest fish (100 mm to 170 mm) died in the holding tank while in transport and numerous additional fish within the smallest size class were observed in poor condition prior to conducting the experiment. During experimental trials, three mortalities of fish within the size class that died or were injured in transport were recorded. These mortalities were not recorded as vibroseis mortalities as they were likely injured in transport and inadvertently placed in cages dead. In at least one instance a dead fish can be seen in video footage prior to being subjected to vibroseis pressures. No bleeding from the gills was observed in any of the trials.

During necropsy, several types of injury were observed. Hemorrhaging within the musculature, body cavity, and in the eyes, was documented (Figure 4). However, we noted a complete lack of damage to the swim bladder (Figure 5). Other than a few fish in which the dissector cut the swim bladder, there was no evidence of damage to the organ in any fish. Damage to any particular portion of the anatomy was noted separately for analysis.

The Control 1 group, held for 21 minutes in the lake, had a 0.009 eye injury rate, a 0.065 muscle hemorrhaging rate, no body cavity hemorrhaging, and no swim bladder damage (Table 1). Fish in the Control 2 group, held for 50 minutes in the lake, had a 0.009 eye injury rate, a 0.073 muscle hemorrhaging rate, a 0.027 body cavity hemorrhaging rate, and no swim bladder damage. The Experiment 1 group, exposed to 1 vibrator operating immediately above them, had

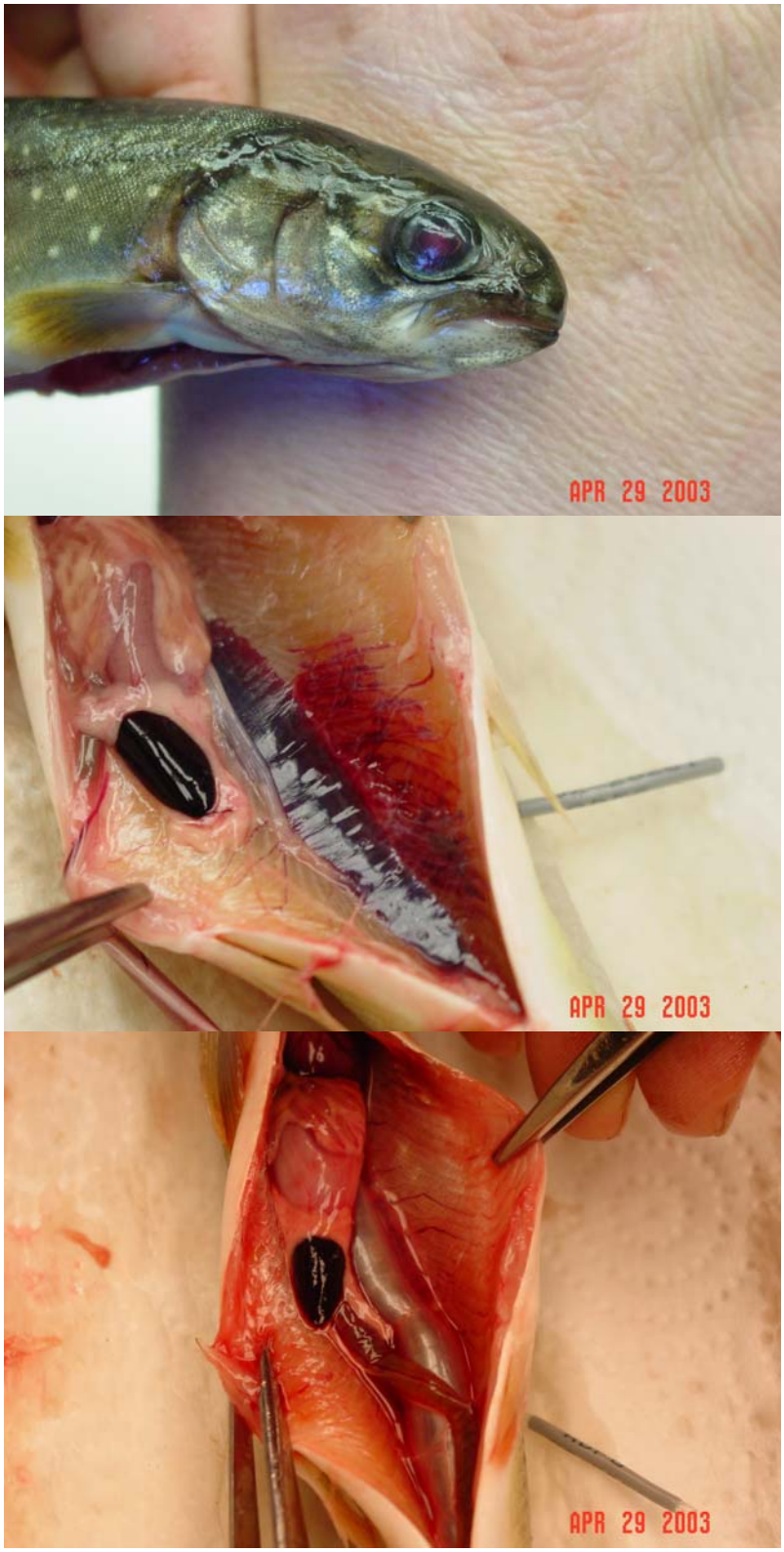

Figure 4. Photographs of types of fish injuries observed in the control and experimental groups. From top to bottom, injuries included eye hemorrhaging, muscle hemorrhaging, and general bloodiness of the body cavity.

Figure 5. No evidence of swim bladder damage was observed in any fish from the control or experimental groups. The top photograph shows an intact swim bladder in the body cavity at the time of initial incision into the body cavity. The bottom photograph shows an intact swim bladder removed from a fish.

a 0.037 eye injury rate, a 0.12 muscle hemorrhaging rate, and no body cavity hemorrhaging, and no swim bladder damage. Fish in the Experiment 2 group, exposed to five vibrators operating above them (plus one vibrator operated independently 5.5 m away prior to all five being operated), had a 0.07 eye injury rate, a 0.05 muscle hemorrhaging rate, a 0.027 rate of body cavity hemorrhaging, and no damage to the swim bladder (Table 1).

Table 1. Summary of observed injuries during necropsy.

	Injury Rate			
Trial	Eye Hemorrhaging	Muscle Hemorrhaging	Body Cavity Hemorrhaging	Swim Bladder Damage
Control 1	0.009259	0.0648	0	0
Control 2	0.009091	0.0727	0.0273	0
Experiment 1	0.037	0.1204	0	0
Experiment 2	0.0727	0.0545	0.0273	0

Results indicate that on a gross scale, with the exception of the eye injury rates, there were no discernible physical effects on fish from the vibroseis equipment in any trial. To ensure that size of fish within the trials were not a significant factor in determining injury rates in any one trial we compared the lengths of fish across all groups. Non-parametric one-way analysis of variance indicated that the distribution of fish lengths between the trials could not be distinguished from one another (KW = 1.76, $p = 0.6229$). Length of fish in any one group was therefore not a factor in determining differences in injury rates between trials. No evidence of differences between controls was detected for eye hemorrhaging rates (Fisher's Exact Test, $p > 0.9999$), body cavity hemhorraging rates (Fisher's Exact Test, $p = 0.2466$), or muscle hemorrhaging rates (Fisher's Exact Test, $p > 0.9999$). No swim bladder damage was observed in either control group. Comparison of the two experimental groups yielded similar results. Differences between experimental groups were not detected for eye hemorrhaging rates (Fisher's Exact Test, $p = 0.3742$), body cavity hemorrhaging rates (Fisher's Exact Test, $p = 0.2466$), or muscle hemorrhaging rates (Fisher's Exact Test, $p = 0.0971$).

Determination of vibroseis-induced effects between trials was analyzed individually. Experiment 1 and Experiment 2 groups were compared against Control 1 and Control 2 separately and then against the combined control results. Although experimental results were not different between the two groups, results were not combined as each represents a test of different scenarios under different experimental conditions. Necropsy results for the peripheral tests were not analyzed because the sample sizes were too small for statistical comparison and results from the main tests indicated that analysis of the peripheral tests were not warranted.

Injury rates in the Experiment 1 group did not differ significantly from the injury rates detected in either control group or the combined controls. Rates of eye hemorrhaging did not differ between Experiment 1 and Control 1 (Fisher's Exact Test, $p = 0.3691$), Control 2 (Fisher's Exact Test, $p = 0.2102$) or the combined control results (Fisher's Exact Test, $p = 0.0961$). Although no significant difference was detected in Experiment 1, the relatively low Fisher's Exact p value for the combined control comparison may be low enough to suggest a relationship between vibroseis and eye hemorrhaging in the experiment. No evidence of body cavity hemorrhaging was observed in the Experiment 1 or Control 1 groups. Muscle hemorrhaging rates did not differ between Experiment 1 and Control 1 (Fisher's Exact Test, $p = 0.2400$), Control 2 (Fisher's Exact Test, $p = 0.2587$) or the combined control groups (Fisher's Exact Test, $p = 0.1417$). Injury to the swim bladder or skeletal structure was not observed in fish from any of the groups.

Injury rates in Experiment 2 were generally similar to those observed in the controls, however; eye hemorrhaging rates were higher. Differences in body cavity hemorrhaging rates were not detected between Experiment 2 and Control 1 (Fisher's Exact Test, $p = 0.2466$), Control 2 (Fisher's Exact Test, $p > 0.9999$) or the combined control groups (Fisher's Exact Test, $p = 0.6678$). Similarly, no difference in muscle hemorrhaging rates were detected between Experiment 2 and Control 1 (Fisher's Exact Test, $p = 0.7826$), Control 2 (Fisher's Exact Test, $p = 0.7825$) or the combined control groups (Fisher's Exact Test, $p = 0.6463$). Eye hemorrhaging rates were significantly higher for Experiment 2 fish than in Control 1 (Fisher's Exact Test, $p = 0.0353$), Control 2 (Fisher's Exact Test, $p = 0.0353$) and the combined control groups (Fisher's Exact Test, $p = 0.0031$). The 95% confidence interval around the difference in eye hemorrhaging rates ranges from 11.3% to 1.3% higher than the combined controls, which encompassed the 10% injury rate we wanted to be able to detect if it were occurring. No damage to the swim bladder or skeletal structures of any fish was observed.

Behavioral Response

Fish behavioral response to vibroseis noise was recorded during the experimental trials and at a natural wintering area in the Sagavanirktok River. Underwater videography from two to three cameras was used to record responses at the experimental lake and river sites. We did not

measure the duration of behavioral disturbances in the experimental trials; however, fish reaction was immediate and intense as fish attempted to flee at the onset of vibroseis noise (Figure 6).

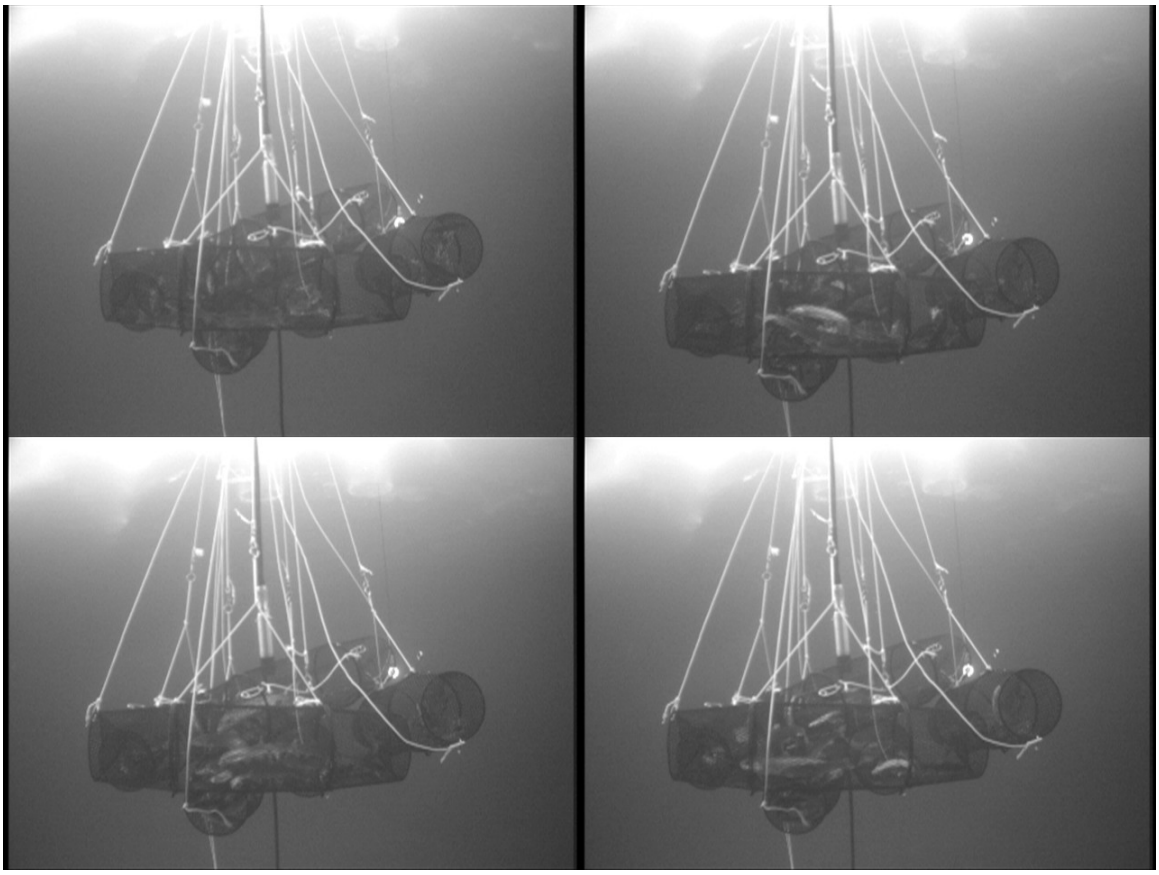

Figure 6. Photographic sequence captured from the video-footage of one of the experimental trials. Prior to exposure to vibroseis noise fish were generally quiescent (top left). Upon initiation of vibroseis noise, fish immediately initiated vigorous flight response until shortly after the vibroseis vehicle(s) had stopped operation.

Final video analysis of fish disturbance from the natural wintering area was primarily based on one video. One video camera failed to record during this trial and one other camera, located on the periphery of the wintering area only had fish in view during two of the four operations of the vibroseis vehicle; those results are included.

Upon initial set up of cameras under the ice on the Sagavanirktok River, most broad whitefish (*Coregonus nasus*) within view of the first camera were sedentary and showed minimal movement. As we continued to drill holes for additional cameras and move equipment onto the wintering area, fish became more active. Similar to the level of response observed by the caged fish, results from the wintering area indicate that fish response to vibroseis noise is immediate

and intense. Fish flee the immediate area of the disturbance rapidly but swimming speeds slow quickly and within 1 to 2 minutes fish slow to swimming speeds approximately equivalent to those observed just before the vibrator was operated (Figure 7). In this setting, a large isolated pool, fish tended to school back to the area of the vibrator within 1 to 2 minutes. Fish response tended to decrease with subsequent exposure to vibroseis noise as fish apparently became acclimated to the stimulus. Within 2 to 6 minutes of the fourth and final operation of the vibrator, fish were again moving slowly and some had already returned to a sedentary posture, similar to the observed behavior when the first camera was deployed. Table 2 shows the response times recorded from the video footage. Additionally, during the fourth and final vibrator operation, a slimy sculpin (*Cottus cognatus*) was in view of the camera located on the periphery of the wintering area. The slimy sculpin showed no indication that it was disturbed by operation of the vibrator, while proximate broad whitefish did show signs of disturbance.

Figure 7. Photographic sequence captured from video recorded during the behavioral trials on the Sagavanirktok River. Photograph at top left was taken at 6 minutes 23 seconds, just prior to vibrator operation. The photograph at top right was taken 4 seconds later (6 min 27 sec), just after the vibrator was operated. The photograph at the bottom left was taken 12 seconds after the initial picture (6 min 35 sec). Fish were in a large consolidated school and beginning to circle. By 7 minutes 38 seconds (1 minute 15

seconds later) fish had returned but were still schooling, but much more slowly than after the initial flight response from vibrator noise (bottom right).

Table 2. Behavioral response of fish in a wintering area in the Sagavanirktok River to operation of one vibrator vehicle on the floating ice above the wintering area.

Camera/Time	Notes
1/ 0 to 9 min 30 sec	Fish Sedentary - movement increasing, slow circling
1/ 9 min 32 sec	**Vibrator fires**, rapid flight response by all fish
	Fish form large school and have directed movement away from vibrator
	School slows rapidly and begins circling back
1/ 10 min 38 sec to 43 sec	All fish appear to have returned to vibrator area
	Circling slowly as in pre-vibratory circling
1/ 11 min 07 sec	**Vibrator fires**, rapid flight response by most fish
	Distance of flight is less and fewer fish flee long distance
	Some begin to return very rapidly
1/ 12 min	School returns to vibrator area and schools past camera
1/ 19 min 13 sec	**Vibrator fires**, brief rapid response, fish do not retreat as far
1/ 19 min 38 sec	Fish are circling slowly, some have returned to vibrator area
1/ 20 min 10 sec	Many fish back at vibrator area
1/ 20 min 25 sec	**Vibrator fires**, rapid short distance retreat, begin slow schooling immediately
	Most fish never left area of vibrator
1/ 21 min 29 sec	All fish appear to be back around vibrator area
1/ 25 min 15 sec	Most fish schooling slowly around vibrator area
	Some fish still disturbed and swimming at a higher speed
1/ 26 min 40 sec	Some fish still circling slowly
	Some fish beginning to hold in sedentary pattern like initial observations
Time Values Differ Between Cameras	
2/ 26 min 36 sec	**Vibrator fires**, rapid short distance flight response
	Slimy sculpin in front of camera shows no response
2/ 27 min 4 sec	Fish have slowed
2/ 27 min 46 sec	Fish in school swimming slowly
2/ 28 min 40 sec	Fish swimming slowly, similar to first observations of fish at this location with this camera

Discussion

Physical Response to Vibroseis Experiment

Corporate changes to WesternGeco occurred shortly after conducting this experiment and the company shut down Alaska operations prior to calculating the overpressure data associated with each trial. We know that the equipment was operated at typical setting used in the field and can

rely somewhat on the 2000 work and assume pressures at the fish cages immediately below the vibrator rigs were around 201 db (re 1 µPa) (Nyland 2002 and pers. comm.). This report is issued provisionally with the hope that at some point the pressure data will become available and be added to the analysis.

Results from the experimental tests provide little evidence that energy imparted to water bodies by vibroseis equipment will harm fish. Vibroseis appears unlikely to produce over pressures high enough or rapidly enough to cause physical damage to fish. Our results found no indication that vibroseis causes acute mortality in fish or causes injury to fish that would later cause mortality. We found no evidence of damage to swim bladders, muscle tissue or blood vessels in our analysis. We did find an increase in eye hemorrhaging attributable to Experiment 2 and data indicated that there may be some evidence for increased eye damage attributable to Experiment 1 (when compared against the combined control groups). However, from viewing the video footage it seems more likely that this discernible increase in eye injury rates for Experiment 2, is the result of the extreme behavioral response of the caged fish. In Experiment 1, fish were exposed to 1 vibrator operating one time, fish exhibited a flight response within their cages one time, and there was a near significant increase in eye injury rates above the controls. In Experiment 2, one vibrator inadvertently fired and fish exhibited a flight response. Fish in Experiment 2 were then subjected to a second stimulus when all five vibrators operated simultaneously; a second, vigorous flight response was observed. It is likely that injury to the eyes was occurring during the period of flight response as fish essentially swam rapidly into the sides of their cages in an attempt to escape. Accordingly, fish that tried to escape in Experiment 1 had only one opportunity to sustain eye damage while fish from Experiment 2 had two opportunities. The results suggest strongly that this is the case as eye injury rates in Experiment 2 are almost exactly double the eye injury rates from Experiment 1.

Behavioral Response

The behavioral response of wintering fish, primarily broad whitefish, to vibroseis noise is extreme but short in duration and appears to reduce in intensity with multiple exposures over a short period of time. However, the response is energy intensive for the fish. It is unlikely that a

vibroseis program disturbing fish in a wintering area in a river would have adverse effects on the wintering fish. In a river wintering area scenario, a group of fish would likely only be exposed to vibroseis noise once during the program as the shot line passed the wintering area. It is reasonable to expect that had we returned the next day, or possibly even a few hours later, these fish would have exhibited the same response. In a large lake scenario, it is possible that the same group of fish would be disturbed multiple times throughout a seismic program. While we have made no estimates of energy requirements associated with the observed responses, they were certainly energy intensive. Most fish wintering in the Arctic undergo a period of fasting over the winter and rely solely on reserves built up over the previous open-water season. Multiple disturbances of the magnitude observed could deplete fish energy reserves enough to reduce body condition and possibly jeopardize winter survival.

Management Implications

The lack of mortality and serious injury to fish from vibroseis suggests that vibroseis is generally a safe seismic technique for fish. Vibroseis is certainly an improvement over the use of explosives near and in water bodies containing fish. The behavioral response of fish to vibroseis indicates that disturbance is brief and limited to the time of operation of the equipment over wintering fish. However, the magnitude and vigor of the flight response observed suggests that multiple exposures over a winter season to vibroseis noise could have significant energetic consequences to wintering fish. Managers can safely authorize vibroseis seismic programs on fish wintering areas but should require that exposure be limited to work that can be conducted within one or two hours from initial to final sweep of the vibroseis rigs. It is still advisable to avoid wintering areas where possible; however, by limiting exposure, managers can be confident that they are being conservative and decreasing the likelihood of fish winter mortality.

Large wintering areas or large lakes that may require multiple vibroseis shot locations to acquire data should be limited to those that can be conducted in a relatively short time frame with minimal delay between shot locations. Situations requiring multiple days of vibroseis activity on the same wintering area or lake should be avoided as the energetic consequences to fish could be significant. Lakes containing especially sensitive fish at risk during winter, such as lake trout,

probably should be avoided in general, but clearly should not receive long duration vibroseis activity during winter.

Recommendations for Future Work

Our research employed Arctic char for the experimental trials. Arctic char represent a typical salmoniform body plan and should adequately represent most fish species likely to be present in North Slope lakes. However, species with more or less developed swim bladders and different body plans likely will be affected differently by vibroseis noise. This was shown clearly in our video footage at the Sagavanirktok River when the vibrator fired and the salmoniform fishes (broad whitefish) reacted swiftly, while the slimy sculpin, in view at the same time, showed no reaction. Additional research focusing on fish with morphologies different from the salmoniform body plan would be useful to provide information on affects for a broader range of fish. Burbot for example, may react differently to vibroseis noise than do salmoniform fish. Burbot are a freshwater cod, common in North Slope lakes and rivers, with a highly developed swim bladder with connections to organs in the brain to aid in hearing. This adaptation may make burbot more susceptible to vibroseis noise disturbance than other species.

While it seems clear that the increased eye damage observed in our two experimental groups were the result of the vigorous flight response and number of times fish were stimulated to flee, eyes are susceptible to damage from rapid overpressures. Additional testing could be conducted using soft sided cages to eliminate the cage as a source of eye injury. Our necropsy analysis was conducted on a gross scale. It is possible that histopathology on fish exposed to vibroseis noise could detect additional injuries that could lead to delayed mortality. Additionally, research has shown that some fish, when exposed to high-intensity noise, can receive damage to the hair cells within the saccules containing their otoliths (ear bones) (McCauley *et.al.* 2003). Some species can regenerate damaged cells but regeneration is likely related to the intensity of the noise received and to fish species (McCauley et. al. 2003). McCauley *et.al*. (2003), found that pink snapper (*Pagrus auratus*) exposed to air gun array noise with peaks above 180 dB (re 1 Pa) did not regenerate all damaged hair cells within a 58 day period and thus, hearing was impaired, possibly, for the long-term. It is possible that fish exposed to vibroseis noise could experience

similar damage to their hearing organs, potentially reducing their fitness. Additional research into the potential damage to hair cells may be warranted.

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