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EFFECTS OF EXPLOSIVES DETONATED IN ICE ON NORTHERN PIKE, KUSKOKWIM RIVER, 1970

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INTRODUCTION

The Alaska District, Corps of Engineers in 1966 instigated a research program aimed at ice jam prevention in the Yukon and Kuskokwim rivers. The objective was to find some economical method of weakening the river ice at traditional jam points prior to spring breakup. Other cooperating agencies in this program included the Alaska Disaster Office, U.S. Army and Air Force and the Alaska National Guard.

One method recently under study has been the use of explosives detonated in the ice to produce a weakened shear plane. Such an experiment was undertaken in the lower Kuskokwim River below Bethel in the spring of 1969 involving a line of explosives extending 1,072 feet (Operation Foresight in 1969 Alaska, Alaska District Corps of Engineers). A much more extensive flood control "experiment" was planned for several Kuskokwim River locations during the spring of 1970 involving approximately nine miles of shot lines.

Upon learning of the increased scope of the 1970 program, the Alaska Department of Fish and Game expressed immediate concern regarding possible adverse effects to fishery resources in the area. The lethal pressure effects on fish from detonations of certain explosive materials are well documented (Hubbs and Rechnitzer, 1952, Rulifson and Schoning, 1963).

During a meeting of representatives from the Alaska Department of Fish and Game, U.S. Bureau of Commercial Fisheries (now National Marine Fisheries Service), Corps of Engineers and Alaska Disaster Office, it was concluded that the use of explosives could proceed only if it could be determined that fish would not be adversely affected. Since ice conditions were deteriorating rapidly due to the advent of the spring thaw, it was decided to immediately conduct a live fish experiment using the planned blasting methods.

The planned flood control program using explosives was not carried out

by the Corps of Engineers in 1970. The decision to cancel the program was probably based on the lateness of the season and results covered in this report.

Table 1 includes all species of fish found in the Kuskokwim River basin and the time of year that each frequent the study area. Nearly all of the listed species are extensively utilized by native residents of the Kuskokwim River basin. This area supports the largest subsistence fishery in the state. The recorded annual subsistence salmon harvest normally exceeds 250,000 fish. Subsistence utilization of non-salmon species is largely undocumented, but is probably more important than the salmon harvest. A Department survey of the village of Napakiak on the lower Kuskokwim River during October 1967 - March 1968, revealed a subsistence harvest of at least 3,347 whitefish, 9,610 pike and 655 other species.

The Kuskokwim River commercial salmon fishery has expanded considerably in recent years and in 1970 the harvest of 80,000 fish contributed at least $250,000 to the local economy.

METHODS AND MATERIALS

Live Fish Experiment

The study area was located in a 1,800 foot wide channel of the Kuskokwim River about 18 miles downstream from Bethel (Figure 1). The experiment was conducted approximately 450 feet from the south shore of the channel where water depths ranged from 20-30 feet and the river bottom was fine sand. Water temperature during the study period was 32° F. Tidal influence in the area was minimal and not recorded. River current velocity was also not recorded, but was estimated at 2 knots per hour. The ice layer was approximately 36 inches thick, consisting of an 8-inch crystallized top layer, followed by 4 inches of wet ice and 24 inches of hard, dry ice.

Northern pike were the only species of fish readily obtainable during the brief time available to conduct the experiment. Study specimens were captured April 19 at the mouth of the Johnson River by subsistence fishermen using lures fished through the ice. Only those fish with minor hook damage were selected.

As soon as the fish were captured, they were either placed in a 40-gallon holding tank or in a large shallow pool of overflow water. Tank and water temperatures were 32° F. Pike were transported to the study site (approximately 1,400 feet in distance) in the 40-gallon tank which was towed

Table 1. List of Kuskokwim River fish.

Scientific Name	Common Name	Occurrence in Study Area
Entosphenus tridentatus	Pacific lamprey	Adults (fall); larvae (1/)
Lampetra japonica	Arctic lamprey	Adults (winter);larvae (1/)
Salmo gairdneri	Rainbow trout	Not present
Oncorhynchus gorbuscha	Pink salmon	Adults (June-Aug); smolt (spring)
Oncorhynchus keta	Chum salmon	Adults (June-Aug); smolt (spring)
Oncorhynchus kisutch	Coho salmon	Adults (July-Sept); smolt (spring)
Oncorhynchus nerka	Sockeye salmon	Adults (June-Aug); smolt (spring)
Oncorhynchus tschawytscha	Chinook salmon	Adults (May-Aug); smolt (spring)
Salvelinus malma	Dolly Varden	1/
Thymallus arcticus	Arctic grayling	Not present
Hypomesus olidus	Pond smelt	Adults (May-June); juveniles (1/)
Thaleichthys pacificus	Eulachon	Adults (May-June); juveniles (1/)
Dallia pectoralis	Alaska blackfish	Year-round
Esox lucius	Northern pike	Year-round
Lota lota	Burbot	Year-round
Pungitius pungitius	Ninespine stickleback	1/
Coregonus autumnalis "complex"	Arctic cisco	Year-round
Coregonus lavaretus "complex"	Humpback whitefish	Year-round
Coregonus nasus	Broad whitefish	Year-round
Coregonus sardinella "complex"	Least cisco	Year-round
Stenodus leucichthys	Inconnu	Year-round

1/ Information not available.

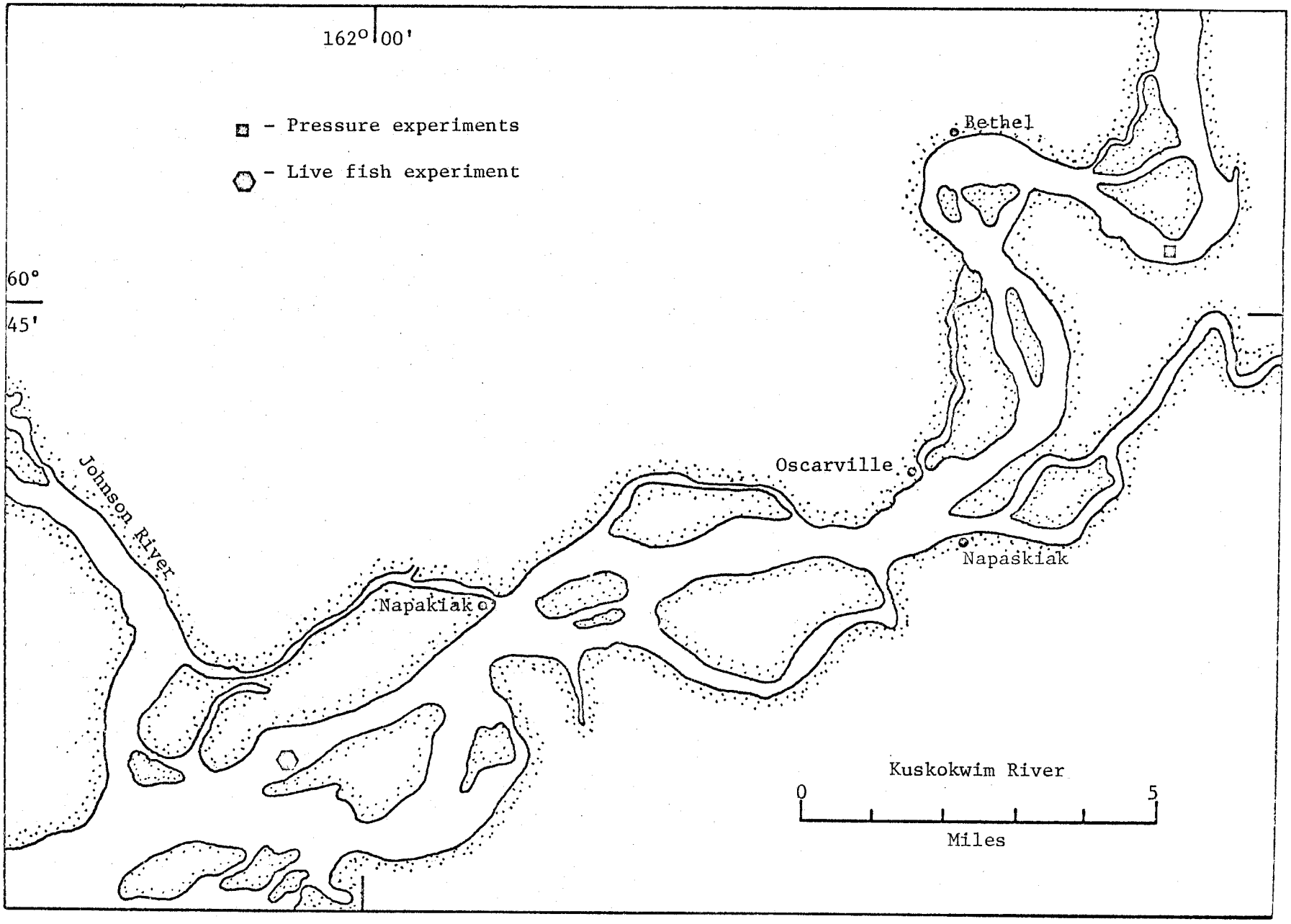

Figure 1. Study area locations, Kuskokwim River, April 1970.

on a sled by a snowmachine. At the study site the fish were tagged and lowered to position on anchored lines within 20 minutes of capture.

A numbered spaghetti type tag was inserted through each fish just below the insertion of the dorsal fin. The ends of each tag were tied in an overhand knot to form a loop. A foot long nylon tether line was tied to the loop which in turn was attached to an anchored nylon line that extended from the ice surface to the bottom of the river. By using this method, pike were easily inserted through five-inch diameter holes cut in the ice, could be placed at any desired depth and were afforded reasonable freedom of movement.

Air temperatures during the tagging and subsequent handling operations were about 35° F., which was not cold enough to freeze or harm the fish.

A total of 17 pike was used in the experiment. Figure 2 shows the placement of test and control fish in relation to explosive charges. Six groups of test fish were placed at 10-foot intervals (holes A through F) perpendicular to the shot line. Fish in hole A were immediately below the shot line, while fish in hole F were approximately 50 feet from the shot line. Hole A contained four fish suspended at depths of 3, 9, 15, and 21 feet. These and all other depth positions in the report were measured from the underside of the ice layer (water depths). Holes B through F each contained two fish at depths of 3 and 15 feet. The control group, located about 240 feet upstream from the shot line, consisted of three fish suspended at depths of 3, 15 and 25 feet.

A 50-foot shot line with six explosive charges, holes 1 through 6, 10 feet apart was employed in the live fish experiment (Figure 2). Holes 1-1/2" in diameter drilled 24 inches in the ice were loaded with two 1-1/2 x 8 inch sticks of Atlas Farmex Ditching Powder primed with primacord extending beyond the collar. Explosive materials were supplied by the Corps of Engineers. Each stick of ditching powder weighed approximately 46 pounds. According to Corps of Engineer reports, Atlas nitroglycerine 60 percent dynamite can be substituted for ditching powder for approximately equivalent results. The two sticks of ditching powder (about 16 inches in length) extended from 8 to 24 inches below the ice surface. The holes filled with water which was free in the crystallized ice layer. The primacord extending from each hole was tied to a main primacord trunk and the entire shot line was detonated with one electric blasting cap. The design of this shot line was identical to that in the planned Corps of Engineers program, except its length was considerably shorter.

Test and control fish were placed in position between 12 noon and 1:15 p.m. on April 19. All fish were checked for general condition about 27 hours later between 3:50-3:54 p.m. on April 20 when the shot line was being charged with explosives. The shot line was detonated at 3:55 p.m. on April 20. Immediately after detonation, all fish were again checked, condition recorded and

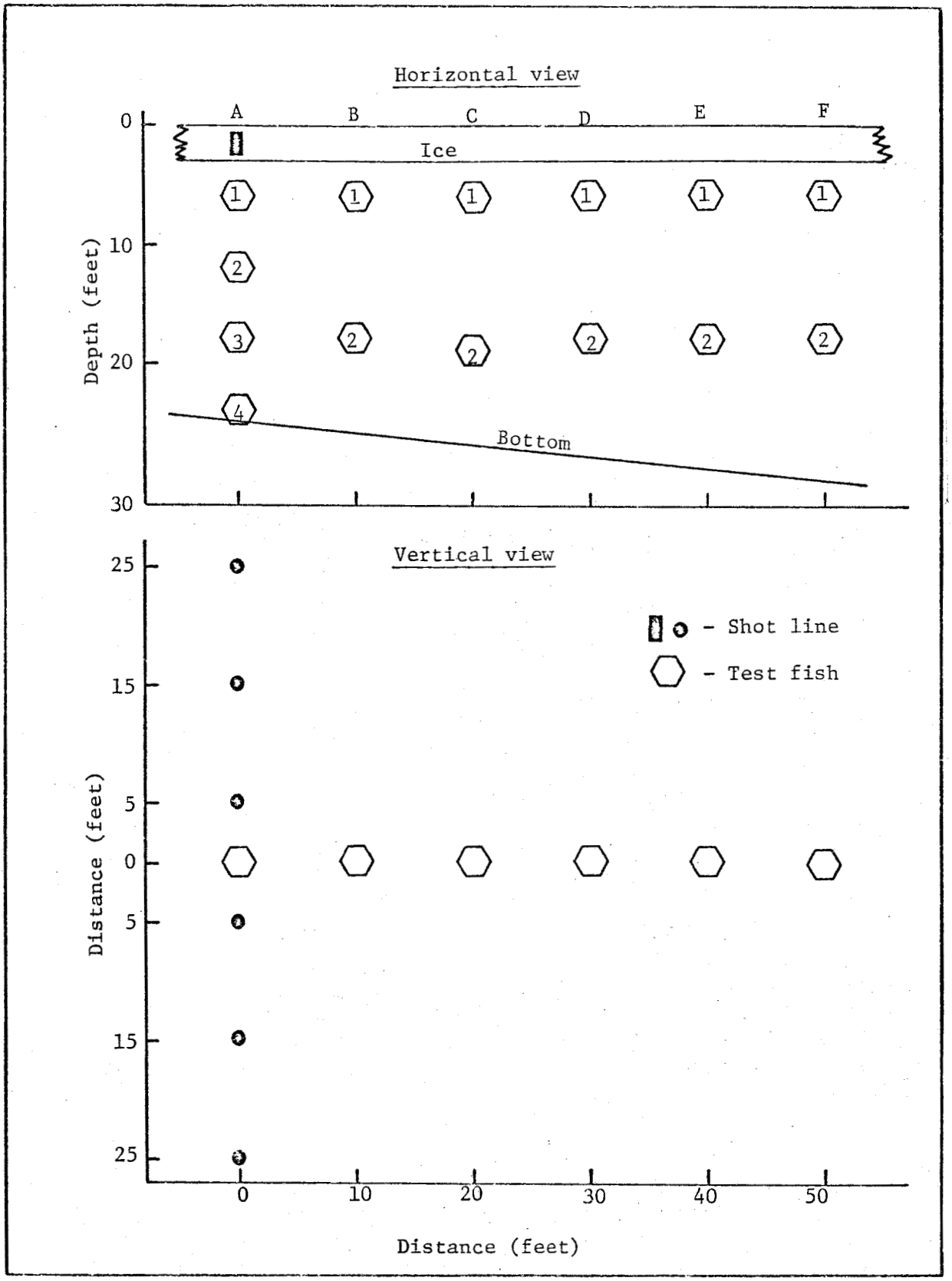

Figure 2. Diagrams showing positions of test fish and explosives in live fish experiment conducted April 19-20, 1970, Kuskokwim River.

returned to their respective positions. Final retrieval was made at approximately 11:40 a.m. on April 21 and all fish were returned to Bethel for autopsy.

Just prior to autopsy, snout lengths and weights were recorded for each fish. External damage to skin, eyes, mouths, and gills were noted. Fish were then carefully eviscerated and the condition of the air bladder, kidneys, liver, and gonads was recorded.

Pressure experiments

Originally it was intended to use monitoring equipment to record pressures concurrently with the live fish experiment but due to deteriorating ice conditions it was decided to conduct the live fish experiment prior to arrival of pressure monitoring instrumentation and personnel. As ice conditions worsened downriver, subsequent pressure experiments were conducted beginning April 23 near Bethel. Unfortunately fish were not obtainable in this area for use in these experiments.

The study area for the experiments was located about two miles above Bethel on the main Kuskokwim River channel (Figure 1). Water depths ranged from 30-35 feet and the river bottom was of fine sand. The area was adjacent to an eddy and there was little current. The ice layer was 37 inches thick, consisting of a 7-inch crystallized top layer followed by 30 inches of hard ice.

All experiments used the ditching powder previously described. Experiment I used the same explosive size and placement as in the live fish experiment. Several other experiments (II through IX) were conducted to measure resulting pressures of varying explosive sizes and placements.

Passive pressure type transducers, manufactured and supplied by Dunegan Research Corporation of Livermore, California, were used to record peak pressures in pounds per square inch (p.s.i.). The transducer sensing element is a clamped diaphragm that is deformed beyond its plastic limit by the pressure to be measured (Dunegan, unpublished report). It is then repressurized with a known pressure source while the acoustic pulses emitted by the diaphragm are recorded. This method is based on the phenomenon of irreversible acoustic emission. The pressure at which acoustic emission is observed to begin during repressurization corresponds precisely to the pressure produced by the detonation. The transducers were placed at varying distances and perpendicular to the shot line, usually at water depths of 7 feet.

Other Equipment Used

A Department of Fish and Game snowmachine was used to locate the downriver study site and provided transportation for explosives and live fish. A chartered Cessna 180 airplane transported personnel to and from Bethel and was used in bringing fish to Bethel for autopsy. A Department pickup truck was utilized for transportation between Bethel and the upriver site. A gasoline powered 5-inch ice auger and a hand operated 1-1/2 inch auger were used to cut holes in the ice. Steel measuring tapes were used to determine distances.

RESULTS

Live Fish Experiment

All test and control fish appeared to be active and in normal condition when examined just prior to detonation. However, the control fish at the 25 foot level was missing.

After detonation of the shot line, the control fish appeared to be in normal condition and identical to that just prior to detonation. Test fish in Holes A, B and C were obviously stunned, i.e., their bodies were rigid, except for trembling movements of a few fish, and their gill covers were extended. Test fish in Holes D, E and F were less affected, but their movements appeared to be weaker than just prior to the detonation. There was no evidence of external physical damage in any of the fish examined immediately after the detonation. There were also no apparent differences in condition between fish at various depths in the same hole.

When all fish were retrieved, approximately 20 hours after the detonation, all test fish in Holes A and B were dead, including the fish at the 9-foot depth in Hole A, which was lost upon retrieval. Fish in Holes C, D and E were still alive when retrieved, but appeared to be weak. Fish in Hole F and the control fish appeared to be in normal condition.

Upon arrival in Bethel, approximately 20 minutes after retrieval, the fish retrieved from Holes C and D were dea, fish from Hole E were weak but still alive and fish from Hole F and the control fish were still quite lively. All fish were returned in an open box without any attempt to keep them alive.

Autopsy results are summarized for each fish in Table 2 in addition to age, weight and sex data, position and general condition information.

The 15 pike that were retrieved for autopsy averaged 476 mm in length

Table 2. Effects of explosives on pike during live fish experiment conducted April 19-20, 1970, Kuskokwim River.

Position number 1/	Snout length (mm)	Weight in pounds	Sex	Water depth	Distance from center of shot line	General Condition			Autopsy Results
						Immediately after detonation	After 20 hours	Arrival in Bethel	
A-1	436	1.1	F	3	4.5 ft.	Stunned	Dead		small subcutaneous hemorrhages; ruptured gill capillaries; liver and kidney with ruptures and hemorrhages; ruptured air bladder; gonads ruptured with eggs partly free
A-2				9	11.5	Stunned	Dead	Lost	
A-3	440	1.3	M	15	16.5	Stunned	Dead		same as A-1
A-4	481	1.6	M	21	22.5	Stunned	Dead		small subcutaneous hemorrhages; ruptured gill capillaries; liver badly ruptured (pulpy); kidneys ruptured with extensive hemorrhages; air bladder ruptured; gonads badly ruptured (pulpy)
B-1	465	1.6	F	3	11.0	Stunned	Dead		hemorrhages of gill capillaries; hemorrhages and ruptures of liver and kidney; ruptured air bladder and gonads
B-2	393	0.9	M	15	19.3	Stunned	Dead		hemorrhages of gill capillaries, liver, kidney and gonads; rupture of air bladder
C-1	501	1.7	F	3	20.5	Stunned	Weak	Dead	kidney with hemorrhages; ruptured air bladder; gonads with ruptures and blood clots
C-2	443	1.4	M	15	25.9	Stunned	Weak	Dead	kidney and gonads with blood clots; ruptured air bladder

Table 2. Effects of explosives on pike during live fish experiment conducted April 19-20, 1970, Kuskokwim River (continued).

Position number 1/	Snout length (mm)	Weight in pounds	Sex	Water depth	Distance from center of shot line	General Condition			Autopsy Results
						Immediately after detonation	After 20 hours	Arrival in Bethel	
D-1	508	1.8	F	3	30.3	Moving weakly	Weak	Dead	hemorrhages of gill capillaries, liver, kidney and gonads; rupture or air bladder
D-2	500	1.8	F	15	34.2	Moving weakly	Weak	Dead	hemorrhages of gill capillaries; kidney with blood clots; blood clots on gonads with one gonad ruptured; ruptured air bladder
E-1	545	2.4	F	3	40.2	Moving weakly	Weak	Weak	kidney and gonads with blood clots; air bladder ruptured (1/2 length)
E-2	597	3.5	M	15	43.3	Moving weakly	Weak	Weak	kidney and gonads with blood clots; air bladder ruptured with one hole
F-1	406	1.0	M	3	50.2	Weak	Normal	Lively	blood clots in posterior kidney; air bladder normal in appearance but tears easily
F-2	468	1.5	M	15	52.6	Weak	Normal	Lively	small blood clot in posterior kidney; air bladder normal in appearance but tears easily
Control	421	1.0	F	3	Approx. 240	Normal	Normal	Lively	slight hemorrhage in posterior abdominal wall at margin of kidneys; air bladder normal in appearance and membrane tough

Table 2. Effects of explosives on pike during live fish experiment conducted April 19-20, 1970, Kuskokwim River (continued).

Position number 1/	Snout length (mm)	Weight in pounds	Sex	Water depth	Distance from center of shot line	General Condition			Autopsy Results
						Immediately after detonation	After 20 hours	Arrival in Bethel	
Control	537	2.3	M	15	Approx. 240	Normal	Normal	Lively	normal including tough air bladder membrane
Control					Approx. 240	Lost			

1/ Refer to Figure 2, cross-section view.

and 1.7 pounds in weight. Eight of the fish were males and seven were females. All were in an advanced stage of maturity and would have spawned later in the spring.

One or more internal organs of all test fish showed evidence of physical injury. Generally the degree of injury decreased with distance from the shot line. The greatest injury was sustained by the fish at the 21-foot depth of Hole A. The liver and gonads of this fish were completely broken up and pulpy.

Kidney damage, as evidenced by hemorrhages or blood clots, was observed in all test fish. Air bladder ruptures occurred in all test fish except those at Hole F. Although unbroken, the air bladder membrane of Hole F fish would tear quite easily. Fish at Hole F were also the only members of the test group that did not sustain gonadal damage. Liver damage and subcutaneous hemorrhages were noted only in fish at Holes A and B.

The control fish at the 3-foot depth had a slight hemorrhage in the posterior abdominal wall at the margin of the kidneys, but was otherwise in normal condition. This slight injury was probably the result of handling. The other control fish showed no signs of injury.

Pressure Experiments

Table 3 shows peak pressures in p.s.i. recorded from Experiment I, which employed a shot line identical to that used in the downriver live fish experiment. Ice thickness, water depth and river bottom composition at both sites were similar. The transducers, at 7-foot water depths, recorded pressures of greater than 500 p.s.i. immediately under the center of the shot line (Hole A), 275 p.s.i. at a distance of 21.7 feet (Hole C) and less than 50 p.s.i. in the 30-50 foot range (Holes D-F).

Table 4 shows peak pressures recorded for Experiment II, which was similar to the aforementioned experiment except that each hole contained only one stick of ditching powder with each stick extending to the bottom of the ice layer. Pressure measurements were also similar except that a 175 p.s.i. reading was obtained at the 31.2 foot distance.

Table 5 summarizes pressure data for several other experiments that varied in size and placement of explosives.

Table 3. Pressure Experiment I data, Kuskokwim River, April 23, 1970[1/].

Transducer[2/] location	Distance from center of shot line	Depth in water	Peak pressure (p.s.i.)
Hole A	8.5 ft.	7 ft.	More than 500
Hole C	21.7 ft.	7 ft.	275
Hole D	31.2 ft.	7 ft.	Less than 50
Hole E	40.9 ft.	7 ft.	Less than 50
Hole F	50.7 ft.	7 ft.	Less than 50

1/ Design identical to live fish experiment: 2 sticks ditching powder/hole; total of 6 holes, 10 ft. apart connected with primacord; sticks extended from 8-24 inches in ice.

2/ Corresponds to location of test fish in live fish experiments.

Table 4. Pressure Experiment II data, Kuskokwim River, April 23, 1970[1/].

Transducer[2/] location	Distance from center of shot line	Depth in water	Peak pressure (p.s.i.)
Hole A	8.5 ft.	7 ft.	Much greater than 500
Hole C	21.7 ft.	7 ft.	280
Hole D	31.2 ft.	7 ft.	175
Hole E	40.9 ft.	7 ft.	Less than 50
Hole F	50.7 ft.	7 ft.	Less than 50

1/ One stick ditching powder/hole; total of 6 holes, 10 ft. apart connected with primacord; sticks extended to bottom of ice.

2/ Corresponds to location of test fish in live fish experiment.

Table 5. Pressures from various experiments varying in explosive size and placement, Kuskokwim River, April 23, 1970.

Experiment	Type	Total lbs. of explosive	Transducer distance from explosive	Transducer depth	Peak pressure (p.s.i.)
III	two sticks/hole; two holes 10 ft. apart at bottom of ice 1/	1.84	5 ft. 30 ft.	7 ft. 7 ft.	+ 900 185
IV	one stock on river bottom at depth of 28 feet 1/	.46	30 ft. 30 ft.	7 ft. 17 ft.	155 175
V	one stick at water depth of 12 feet 1/	.46	30 ft. 30 ft.	7 ft. 17 ft.	105 55
VI	one 1/2 stick/hole; two holes 10 feet apart at bottom of ice 1/	.46	5 ft. 30 ft.	7 ft. 7 ft.	± 800 less than 25
VII	one stick every 5 feet (total of 6) in shallow ice surface trench 1/	2.30	30 ft.	7 ft.	45
VIII	one stick, bottom of which extend 26 inches into ice 2/	.46	5 ft.	7 ft.	480-550
IX	same as VIII but air bubble introduced between ice and water 2/	.46	5 ft.	7 ft.	380

1/ Detonated with primacord.

2/ Detonated with electric blasting cap only.

DISCUSSION

Data from Experiment I indicated that peak pressures in the live fish experiment at test fish positions ranged from greater than 500 p.s.i. immediately under the shot line to less than 50 p.s.i. at distances greater than 30 feet. Because of limitations of the available pressure sensing equipment, accurate pressure reading could not be obtained above 500 and below 50 p.s.i. in the initial pressure experiments. Subsequent pressure experiments (II through IX) were conducted with different transducer diaphragms that allowed readouts in excess of 500 p.s.i. These experiments indicated that maximum peak pressure in the live fish experiment probably exceeded 900 p.s.i.

Exact lethal range and pressures in regards to pike could not be determined from the series of experiments conducted, but certain important assumptions can be made. First, pressures below 50 p.s.i. resulted in some internal injury to all fish in the test group. Due to the extent of internal injuries sustained and/or the condition of fish upon retrieval, the lethal radius of the detonation probably extended at least 43.3 feet from the center of the shot line. It was impossible to determine the long-term effects on fish in Hole F (up to 52.6 feet) which suffered slight internal injuries but appeared to be in good condition upon retrieval.

Lethal range and pressure probably depend on the interaction of several factors which include the position of fish in relation to pressure reflective surfaces. There was some evidence that fish located relatively close to the river bottom sustained the greatest injuries. For example, the test fish at position A-4 was located at the greatest depth (21 feet) and was closest to the river bottom. This fish sustained greater internal injuries than any other test fish, many of which experienced greater pressures.

The experimental shot line pressures were probably minimal in that the explosive charges extended only 25 feet in either direction from the "line" of test fish. The length of the experimental shot line in future studies should be more than double the suspected lethal range for fish. It is indicated that the shot line in this study should have been at least 120 feet in length.

Future studies regarding effects of explosives on fish should consider the following factors:

1. Comparative effects on other species and different sizes of fish.

2. Long-term effects on injuries sustained by fish.

3. Accurate means of recording both peak pressure and shock wave

amplitude is required.

4. Pressure decay rate in fresh water.

5. Different types of explosives should be tested.

6. Pressure effects on fish at varying distances from pressure reflective surfaces.

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