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Mortality of Northern Pike Captured and Released with Sport Fishing Gear

by

Alan Burkholder

March 1992

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ABSTRACT

The mortality of northern pike *Esox lucius* caught and released with commonly used terminal tackles was estimated for multiple captures and among tackle types. No significant (greater than 10 percent) mortality was observed in either experiment. In the multiple capture experiment no northern pike in the treatment groups died even though fish were caught and released as many as eight times. After northern pike were held for five days in the gear comparison experiment, mortality rate of fish caught with: (1) double treble hook lures was zero, (2) large treble hook lures was 3.33 percent, (3) single hook lures was zero, and (4) small treble hook lures was 4.80 percent. In the multiple capture experiment no significant difference ($P = 0.62$) was detected in the distribution of hook placement among the three tackle types; no significant difference ($P = 0.20$) was detected in the distribution of bleeding caused by the three tackle types; and, the likelihood of bleeding was significantly greater ($P = 0.05$) for fish caught in the gills than for fish caught in other areas of the body. In the terminal tackle comparison experiment a significant difference ($P < 0.001$) was detected in the distribution of bleeding caused by the four terminal tackle types; the likelihood of bleeding was significantly greater ($P < 0.001$) for a fish caught with a small treble hook than for a fish caught with the other hook configurations; the likelihood of bleeding was also significantly greater ($P < 0.001$) for fish caught in the gills than for fish caught in other areas of the body; and, no significant difference ($P = 0.13$) was detected in the distribution of hook placement among the four tackle types. Results for bleeding and hook placement relationships are ancillary since no significant (greater than 10 percent) mortality occurred.

KEY WORDS: Northern pike, *Esox lucius*, catch and release, fishing mortality, multiple capture, terminal tackle comparison.

INTRODUCTION

The percentage (82%) of northern pike *Esox lucius* caught and released by sport anglers in Alaska was higher than the percentage of any other sport fish species caught and released except Arctic grayling *Thymallus arcticus* (85%) during 1990 (Table 1). Information concerning overall mortality level and variables affecting this fishery-induced mortality caused from the catching and releasing of northern pike by recreational anglers is lacking. Only one study researching the mortality rates of caught and released northern pike has been found in a review of the literature. Falk and Gillman (1975) studied the effects of gear, hook type, hook placement, handling time, and amount of bleeding. Small sample sizes in their experiment limit the usefulness of their results. They did, however, report mortality rates of 5.3% and 10.5% for barbed and barbless hooks, respectively.

Conservation concerns exist in several Alaskan northern pike fisheries where extensive catch and release fishing takes place. For example, the estimated number of northern pike caught and released (Mills 1991) exceeded the estimated abundance of northern pike >449 mm in Harding Lake during 1990 (Burkholder 1991). If mortality rates of northern pike due to catch and release angling can be quantified, the viability of catch and release fishing of sub-legal fish (minimum length limit) or the entire stock (mandatory no kill fishing) as regulatory management options can be assessed.

This study (F-10-6, R-3-4c) was implemented to quantify mortality rates suffered by northern pike due to catch-and-release angling, and consisted of two experiments:

In the first experiment (multiple-captures) the objective was:

1. To test the hypothesis that repeated catching and releasing of northern pike has no cumulative effect on the mortality rate beyond that expected from independent effects of separate capture.

In the second experiment (terminal tackle comparison) the objective was:

2. To test the hypothesis that there is no significant mortality suffered by northern pike caught once with single hook artificial lures, small and large single treble hook artificial lures, and double treble hook artificial lures.

If the null hypothesis in the second objective was rejected for at least two terminal tackle types, then the gear that produced the highest mortality rate would be determined. In this case, the objective would be:

3. To test the hypothesis that the terminal tackles that produce significant mortality rates in northern pike produce equal mortality rates.

Table 1. Estimated sport fish harvest, catch, and percent of sport fish caught and released in Alaska in 1990[a].

Species	Scientific Name	Harvest	Catch	Caught and Released (%)
Arctic Grayling	*Thymallus arcticus*	64,814	420,227	85
Northern Pike	*Esox lucius*	15,985	89,316	82
Steelhead	*Oncorhynchus mykiss*	5,645	30,339	81
Sheefish	*Stenodus leucichthys*	750	3,360	78
Chum	*Oncorhynchus keta*	14,525	65,744	78
Rainbow Trout	*Oncorhynchus mykiss*	191,809	663,225	71
Cutthroat Trout	*Oncorhynchus clarki*	16,183	55,491	71
Brook Trout	*Salvelinus fontinalis*	450	1,548	71
Lake Trout	*Salvelinus namaycush*	12,602	42,443	70
Dolly Varden/ Arctic Char	*Salvelinus malma* *Salvelinus alpinus*	132,553	438,944	70
Chinook	*Oncorhynchus tshawytscha*	123,908	396,255	69
Pink	*Oncorhynchus gorbuscha*	205,602	598,379	66
Landlocked/ Coho Chinook	*Oncorhynchus kisutch* *Oncorhynchus tshawytscha*	37,831	95,924	61
Rockfish	*Sebastes* spp.	62,572	155,503	60
Sockeye	*Oncorhynchus nerka*	239,118	471,168	49
Halibut	*Hippoglossus stenolepis*	247,202	449,647	45
Coho	*Oncorhynchus kisutch*	325,936	530,999	39
Kokanee	*Oncorhynchus nerka*	2,071	3,340	38
Whitefish	*Coregonus* spp.and *Prosopium* spp.	15,595	22,266	30
Burbot	*Lota lota*	10,577	13,884	24
Smelt	*Osmeridae*	62,576	62,576	0

[a] Mills 1991

METHODS

Multiple Capture (Experiment 1)

The multiple-capture experiment was conducted with 63 marked (individually numbered Floy tag) northern pike at Colorado State University, between 4 April and 21 July of 1991. These fish were captured with gill nets in near by College Lake and initially released into two experimental ponds (32 fish in pond 13 and 31 fish in pond 12) located on the Foothills Campus of Colorado State University. As the experiment progressed 14 northern pike (four from pond 13 and 10 from pond 12) were moved to three adjacent ponds (five in pond 10, five in pond 9, and four in pond 8) with the expectation that catch rates would improve. It was thought that the low catch rates may have been a result of the influence of artificially high fish densities on fish behavior. Ponds 12 and 13 were more than 2.5 times as large as ponds 8, 9, and 10 (Table 2). Each pond also contained an abundant but unknown quantity of fathead minnows *Pimephales promelas*. The predominant aquatic vegetation in each pond was *Chara*.

The original experimental design was limited to only one terminal tackle type, the gear with the highest expected mortality rate (double treble hook artificial lure), but was changed to include other terminal tackle types (Appendix A) in an effort to increase catch rates. A Monte Carlo simulation of the experiment (Appendix B) was used to determine the number of test subjects, number of fish to capture, and the expected number of test subjects that would die. A cumulative effect of multiple captures could be expected to be detected with 60 fish and 350 captures with the probability of Type I error = 0.10 and Type II error less than 0.20 and a baseline mortality rate between 0.03 and 0.11. The number of subjects was then increased to 63 fish to allow for some gear avoidance behavior.

After each northern pike was reeled in, tag number, length of the fish measured to the nearest 1 mm fork length (FL), tackle type, hook placement (Figure 1), landing time, and level of bleeding using criteria established by Falk and Gillman (1975) were recorded. The fish was then returned to the pond and was available for capture again. Approximately 260 hours of fishing effort were expended to make 90 captures. At the conclusion of the experiment the ponds were seined and/or drained to determine the fate of the 63 test fish. The surviving fish were subsequently returned to College Lake.

Terminal Tackle Comparison (Experiment 2)

In this experiment, four types of terminal tackle were investigated: single hook artificial lures, single large treble hook artificial lures, single small treble hook artificial lures, and double treble hook artificial lures (Appendix C). These tackle types represent a range of legal gears used by anglers to catch northern pike in interior Alaska waters. The four tackle types were used to catch 240 northern pike (60 fish per tackle type) at George Lake during June 1991. After the hook was removed, each fish was tagged with an individually numbered Floy anchor tag and measured to the nearest 1 mm FL. In addition, tag number, terminal tackle type, hook placement, landing time, and level of bleeding were recorded as was done in experiment one. All fish

Table 2. Physical characteristics of the experimental ponds used for the multiple capture experiment of northern pike at the Foothills Campus of Colorado State University.

Pond[a]	Area (ha)	Volume (1,000 L)	Mean depth (m)	Maximum depth (m)
8	0.038	521	1.22	1.52
9	0.034	470	1.22	1.52
10	0.038	521	1.22	1.52
12	0.100	1,371	1.37	1.83
13	0.100	1,371	1.37	1.83

[a] Data for ponds 8, 9, and 10 are from Clark (1974). Data for ponds 12 and 13 are from personal communication with Stephen Flickinger, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado.

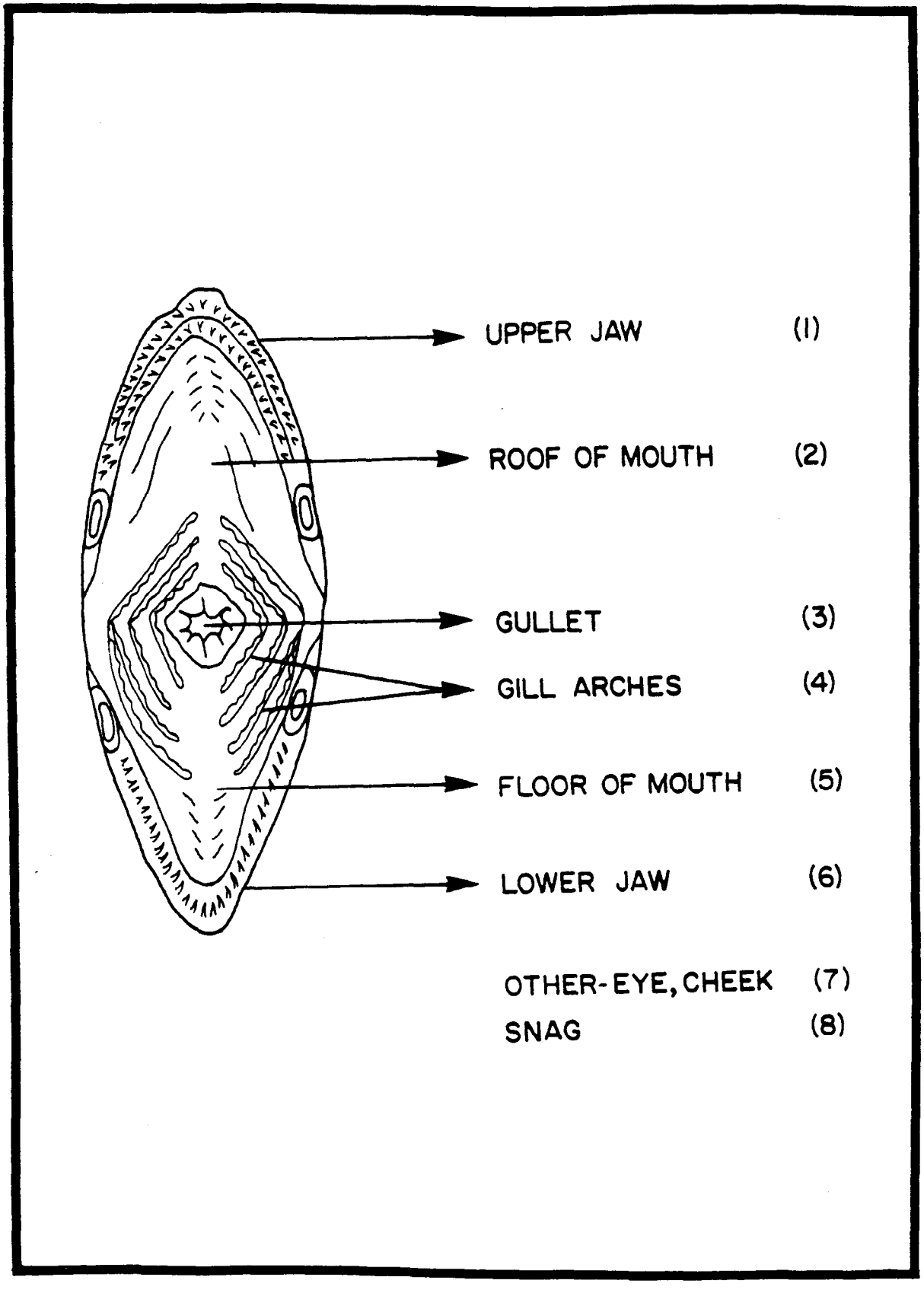

Figure 1. Description of hook placement used in the multiple capture and terminal tackle comparison experiments (adapted from Falk and Gillman 1975).

were then held in an enclosed area of George Lake for 5 to 16 days. The enclosure had a surface area of approximately 400 m^2, maximum depth of 1.25 m, and was constructed out of conduit panels. The enclosure was closely inspected at least twice a day for the presence of dead study fish.

A control for this experiment was difficult to design, but an estimate of handling mortality was to be obtained from a group of seined and Floy tagged northern pike.

Mortality rate was defined as the number of northern pike that died within five days of capture (by terminal tackle type) divided by the total number captured with each type of tackle:

$$\hat{m}_i = \frac{X_i}{n_i} \tag{1}$$

where:

m_i = the mortality rate of fish that were caught with gear i

n_i = the number of fish that were caught with gear i; and,

X_i = the number of fish caught with gear i that died.

The standard error of this rate was estimated by (Zar 1984):

$$SE[\hat{m}_i] = \left\{ \frac{\hat{m}_i \ (1 - \hat{m}_i)}{n_i - 1} \right\}^{\frac{1}{2}} \tag{2}$$

Binomial confidence intervals were calculated for each estimate of mortality due to each of the tackle types. The probability of a Type I error (α) was adjusted to 0.03, so that an overall $\alpha = 0.10$ could be maintained for the four comparisons. Binomial confidence intervals were calculated as (Zar 1984):

$$LCI_i = \frac{X_i}{X_i+(n_i-X_i+1)F_{\gamma 1, \gamma 2}} \tag{3}$$

$$UCI_i = \frac{(X_i+1)\ F_{\gamma 1', \gamma 2'}}{n_i-X_i+(X_i+1)\ F_{\gamma 1', \gamma 2'}} \tag{4}$$

where:

LCI_i = lower 90% confidence interval for the mortality rate of gear i;

UCI_i = upper 90% confidence interval for the mortality rate of gear i;

$F_{\gamma 1,\gamma 2}$ = probability from the F distribution with $\gamma 1, \gamma 2$ degrees of freedom where:

$\gamma_1 = 2(n_i - X_i + 1)$; and,

$\gamma_2 = 2X_i$.

$F_{\gamma 1,\gamma 2}$ = probability from the F distribution with γ_1, γ_2 degrees of freedom where:

$\gamma_{1'} = 2(X_i + 1)$; and,

$\gamma_{2'} = 2(n_i - X_i)$.

The highest mortality rate for northern pike reported by Falk and Gillman (1975) was 10.5%. With a sample size of 60 fish for each tackle type, differences in mortality rate of 10% or greater were expected to be detectable. Estimates of mortality rates from each of the four tackle types were tested with a one-tailed binomial test (Zar 1984). The null hypothesis was: each of the tackle types caused mortality of northern pike at a rate that is less than or equal to 0.10.

The length frequency distributions of northern pike captured with each of the tackle types were compared with the Anderson-Darling k-sample test (Scholz and Stephens 1987). A Kolmogorov-Smirnov test was used to compare the length frequency distributions of control versus treatment fish (all tackle types combined) at George Lake.

RESULTS

Multiple-Capture (Experiment 1)

During the course of the experiment, 90 captures were made. No mortality of northern pike resulted from catch and release angling. Out of the 63 original northern pike, 18 were never caught, 16 were caught once, 19 were caught twice, 8 were caught three times, 1 was caught four times and 1 was caught eight times. One northern pike that had never been caught died during the course of the experiment. Cumulative effect of multiple-capture on mortality rate of northern pike was not observed during the experiment. Estimated mortality rate for all catch and release treatments was zero. The experiment lasted 102 days. Sizes of northern pike captured (all tackle types pooled) ranged from about 400 to 900 mm FL.

Of the 90 captures, 64 occurred with double treble hook artificial lures, 18 with single large treble hook lures, and eight with single hook lures (Table 3). When hook placement data were collapsed into two general categories, there was no significant difference ($\chi^2 = 0.95$, $P = 0.62$) in the distribution of hook placement among the three tackle types (Table 3). When bleeding data were collapsed into two general categories, there was no significant difference ($\chi^2 = 3.18$, $P = 0.20$) in the distribution of bleeding caused by the three tackle types (Table 4). Bleeding was significantly greater ($\chi^2 = 3.64$, $P = 0.05$) for fish caught in the gills than for fish caught in other areas of the body (Table 5).

Table 3. Summary of hook placement by tackle type for northern pike captured at Colorado State University, 10 April - 19 July 1991.

	Tackle Type (Hook)					
	Double Treble		Large Treble		Single	
Placement	n	%	n	%	n	%
Upper jaw (1)	15	23.4	8	44.4	4	50.0
Roof of mouth (2)	1	1.6	1	5.6	2	25.0
Gullet (3)	0	0.0	0	0.0	0	0.0
Gill arches (4)[a]	5	7.8	2	11.1	0	0.0
Floor of mouth (5)	2	3.1	1	5.6	0	0.0
Lower jar (6)	13	20.3	2	11.1	2	25.0
Eye or cheek (7)	5	7.8	1	5.6	0	0.0
Snagged (8)	1	1.6	0	0.0	0	0.0
Combination (9)[b]	22	34.4	3	16.6	0	0.0
Gill arches	5	7.8	2	11.1	0	0.0
Other[c]	59	92.2	16	88.9	8	100.0
Total	64	100.0	18	100.0	8	100.0

[a] At least one hook placement was located in the gills.
[b] Hook placements were in more than one of Falk and Gillman (1975) hook placement categories 1, 2, 3, 5, 6, 7, and 8.
[c] Hook placement 1, 2, 3, 5, 6, 7, or 8 of Falk and Gillman (1975) and hook placement 9.

Table 4. Summary of bleeding by tackle type for northern pike captured at Colorado State University, 10 April - 19 July 1991.

	Tackle Type (Hook)					
	Double Treble		Large Treble		Single	
Bleeding[a]	n	%	n	%	n	%
None (0)	28	43.8	10	55.6	6	75.0
Slight (1)	22	34.4	2	11.1	2	25.0
Moderate (2)	8	12.5	4	22.2	0	0.0
Severe (3)	6	9.3	2	11.1	0	0.0
No bleeding	28	43.8	10	55.6	6	75.0
Some bleeding[b]	36	56.2	8	44.4	2	25.0
Total	64	100.0	18	100.0	8	100.0

[a] Bleeding levels are from Falk and Gillman (1975).
[b] Some bleeding is bleeding levels 1, 2, or 3 of Falk and Gillman (1975).

Table 5. Interaction between hook placement and bleeding in northern pike captured by lures with double treble hooks, large treble hooks, and single hooks at Colorado State University, 10 April - 19 July 1991.

	Hook placement			
	Gills[a]		Other[b]	
Bleeding	n	%	n	%
No Bleeding	1	14.3	43	51.8
Some Bleeding[c]	6	85.7	40	48.2
Total	7	100.0	83	100.0

[a] At least one hook placement was located in the gills.
[b] Hook placement 1, 2, 3, 5, 6, 7, and 8 of Falk and Gillman (1975) and hook placement 9.
[c] Some bleeding describes slight, moderate, or severe bleeding of Falk and Gillman (1975).

Terminal Tackle Comparison (Experiment 2)

The number of days northern pike were held varied for each terminal tackle category, however the minimum time held was five days (Table 6). No fish in the double treble or the single hook treatment groups died, whereas two fish in the large treble and three fish in the small treble treatment groups died within five days of capture. One control fish died within five days of capture (Table 7). After being held for five days, mortality rate of northern pike caught with: (1) double treble hook lures was 0.00%, (2) large treble hook lures was 3.33%, (3) single hook lures was 0.00%, and (4) small treble hook lures was 4.84%. Mortality rate for control fish after being held for five days was 1.37%. No terminal tackle type had a mortality rate significantly greater than 10% (single-tailed binomial test, $P > 0.1$).

When hook placement data were collapsed into two general categories, there was no significant difference ($\chi^2 = 5.64$, $P = 0.13$) in the distribution of hook placement among the four tackle types (Table 8). When bleeding data were collapsed into two general categories, there was a significant difference ($\chi^2 = 27.31$, $P < 0.001$) in the distribution of bleeding caused by the four tackle types (Table 9). The likelihood of some bleeding was significantly greater ($\chi^2 = 26.30$, $P < 0.001$) for a fish caught with a small treble hook than for a fish caught with the other hook configurations. Bleeding was also significantly greater ($\chi^2 = 28.90$, $P < 0.001$) for fish caught in the gills than for fish caught in other areas of the body (Table 10).

Sizes of northern pike captured with lures (all gear types pooled) ranged from 265 to 935 mm FL. A significant difference in size distribution of northern pike caught with the four terminal tackle types was detected (Anderson-Darling k-sample test: $T_{kn} = 4.54$, $P < 0.01$). The double treble hooks tended to catch larger fish (Figure 2). No significant difference was detected between lengths of fish seined versus fish caught with hook and line (DN = 0.073, P ~ 1.00; Figure 3).

DISCUSSION

The hypothesis that repeated catching and releasing of northern pike has no cumulative effect beyond the independent effects of separate capture could not be tested. However, the results of the experiment indicate that northern pike can be caught more than once in a three month period without causing significant mortality. The question of whether or not the effect of multiple hook and release is cumulative or not is therefore somewhat moot.

The experiment that examined mortality among different types of terminal tackle showed that northern pike of varying sizes can be caught with several types of terminal hook arrangements without suffering significant (> 10%) mortality. Mortality rates of northern pike five days after capture were compared in the terminal tackle experiment because fish in each treatment group were held for at least five days. Comparisons between treatments held for longer periods of time is difficult; however, mortality did occur after five days in all categories. Even with the additional mortality documented

Table 6. Number of northern pike captured with seines and for types of terminal tackle in George Lake that were held for a given number of days in an enclosure[a].

Holding Time (days)	Control	Terminal Tackle (Hook)			
		Double Treble	Large Treble	Single Hook	Small Treble
	n	n	n	n	n
5	--	--	--	--	4
6	--	--	--	--	2
7	--	--	--	--	4
8	--	--	--	--	8 (1)
9	--	--	--	--	9 (2)
10	--	--	--	1	33 (8)
11	--	--	5	42 (4)	--
12	--	--	20 (3)	5	2 (1)
13	22	--	10 (1)	--	--
14	15	16 (4)	13 (4)	--	--
15	25	32 (7)	1	--	--
16	11	12	11 (1)	12 (1)	--
Totals	73	60	60	60	62

[a] The number of northern pike for each type of terminal tackle that had been seined and released in the lake (not the enclosure) prior to hook and line capture are in parentheses.

Table 7. The number of northern pike that died during the single capture experiment by terminal tackle type and time.

Days Until Death	Control	Terminal Tackle (Hook)			
		Double Treble	Large Treble	Single Hook	Small Treble
	n	n	n	n	n
0	--	--	--	--	1
1	1	--	--	--	--
2	--	--	1	--	1[a]
3	--	--	1	--	1
4	--	--	--	--	--
5	--	--	--	--	--
5 Day Totals[b]	1	0	2	0	3
6	--	--	--	--	--
7	--	1	--	--	--
8	1	--	1[a]	--	--
9	4	--	2[a]	--	1[a]
10	3	--	1	--	--
11	7	--	1	1[a]	--
12	4	1	--	--	--
13	3	--	--	--	--
14	--	--	--	--	--
15	--	1[a]	--	--	--
Totals	23	3 (2,1)[c]	7 (4,3)[c]	1 (0,1)[c]	4 (2,2)[c]

[a] The number of northern pike that died after being seined and released in the lake and then subsequently caught on hook and line gear from the lake.

[b] Mortality comparisons are made based upon cumulative mortality because all fish were held for at least five days (see Table 6)

[c] The number of northern pike that died after being caught with hook and line gear, the number of northern pike that died after being seined and subsequently caught on hook and line gear in the lake.

Table 8. Summary of hook placement by terminal tackle type for northern pike captured in George Lake, 1 - 12 June 1991.

	Terminal Tackle (Hook)							
	Double Treble		Large Treble		Single		Small Treble	
Placement	n	%	n	%	n	%	n	%
Upper jaw (1)	14	23.3	12	20.0	26	43.3	15	24.2
Roof of Mouth (2)	0	0.0	3	5.0	3	5.0	6	9.7
Gullet (3)	0	0.0	0	0.0	0	0.0	0	0.0
Gill arches (4)	1	1.7	4	6.6	5	8.3	8	12.9
Floor of mouth (5)	2	3.3	4	6.6	3	5.0	2	3.2
Lower jaw (6)	12	20.0	16	26.7	16	26.7	7	11.3
Eye or cheek (7)	3	5.0	3	5.0	6	10.0	1	1.6
Snag (8)	1	1.7	2	3.4	1	1.7	5	8.1
Combination (9)	27	45.0	16	26.7	0	0.0	18	29.0
Gill arches[a]	1	1.7	4	6.6	5	8.3	8	12.9
Other[b]	59	98.3	54	93.3	55	91.7	54	87.1
Total	60	100.0	60	100.0	60	100.0	62	100.0

[a] At least one hook placement was located in the gills.
[b] Hook placement 1, 2, 3, 5, 6, 7, or 8 of Falk and Gillman (1975) and hook placement 9.

Table 9. Summary of bleeding by type of terminal gear for northern pike captured in George Lake, 1 - 12 June, 1991.

	Terminal Tackle (Hook)							
	Double Treble		Large Treble		Single		Small Treble	
Bleeding[a]	n	%	n	%	n	%	n	%
None (0)	46	76.7	41	68.4	45	75.0	23	37.1
Slight (1)	7	11.7	11	18.3	7	11.7	28	45.2
Moderate (2)	2	3.3	3	5.0	8	13.3	3	4.8
Severe (3)	5	8.3	5	8.3	0	0.0	8	12.9
No bleeding	46	76.7	41	68.3	45	75.0	23	37.1
Some bleeding[b]	14	23.3	19	31.7	15	25.0	39	62.9
Total	60	100.0	60	100.0	60	100.0	62	100.0

[a] Bleeding levels are from Falk and Gillman (1975).
[b] Some bleeding is bleeding levels 1, 2, or 3 of Falk and Gillman (1975).

Table 10. Interaction between hook placement and bleeding in northern pike captured by lures with double treble hooks, large treble hooks, single hooks, and small treble hooks in George Lake, 1 - 12 June 1991.

	Hook placement			
	Gills[a]		Other[b]	
Bleeding	n	%	n	%
No Bleeding	1	5.6	154	68.8
Some Bleeding[c]	17	94.4	70	31.2
Total	18	100.0	224	100.0

[a] At least one hook placement was located in the gill arches.
[b] Hook placement 1, 2, 3, 5, 6, 7, and 8 of Falk and Gillman (1975) and hook placement 9.
[c] Some bleeding describes slight, moderate, or severe bleeding of Falk and Gillman (1975).

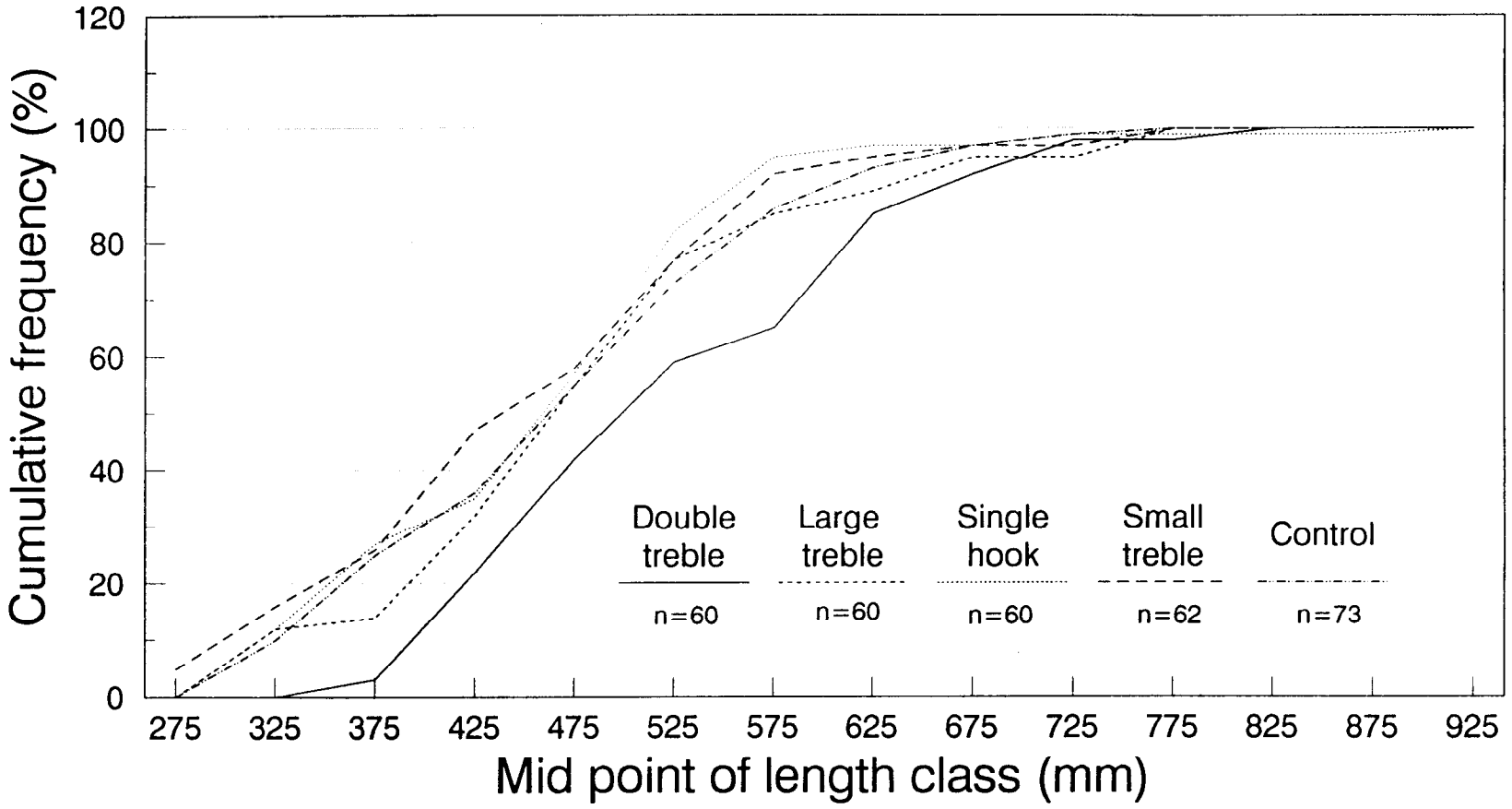

Figure 2. Cumulative length distributions of northern pike captured at George Lake with seines and by types of terminal tackle.

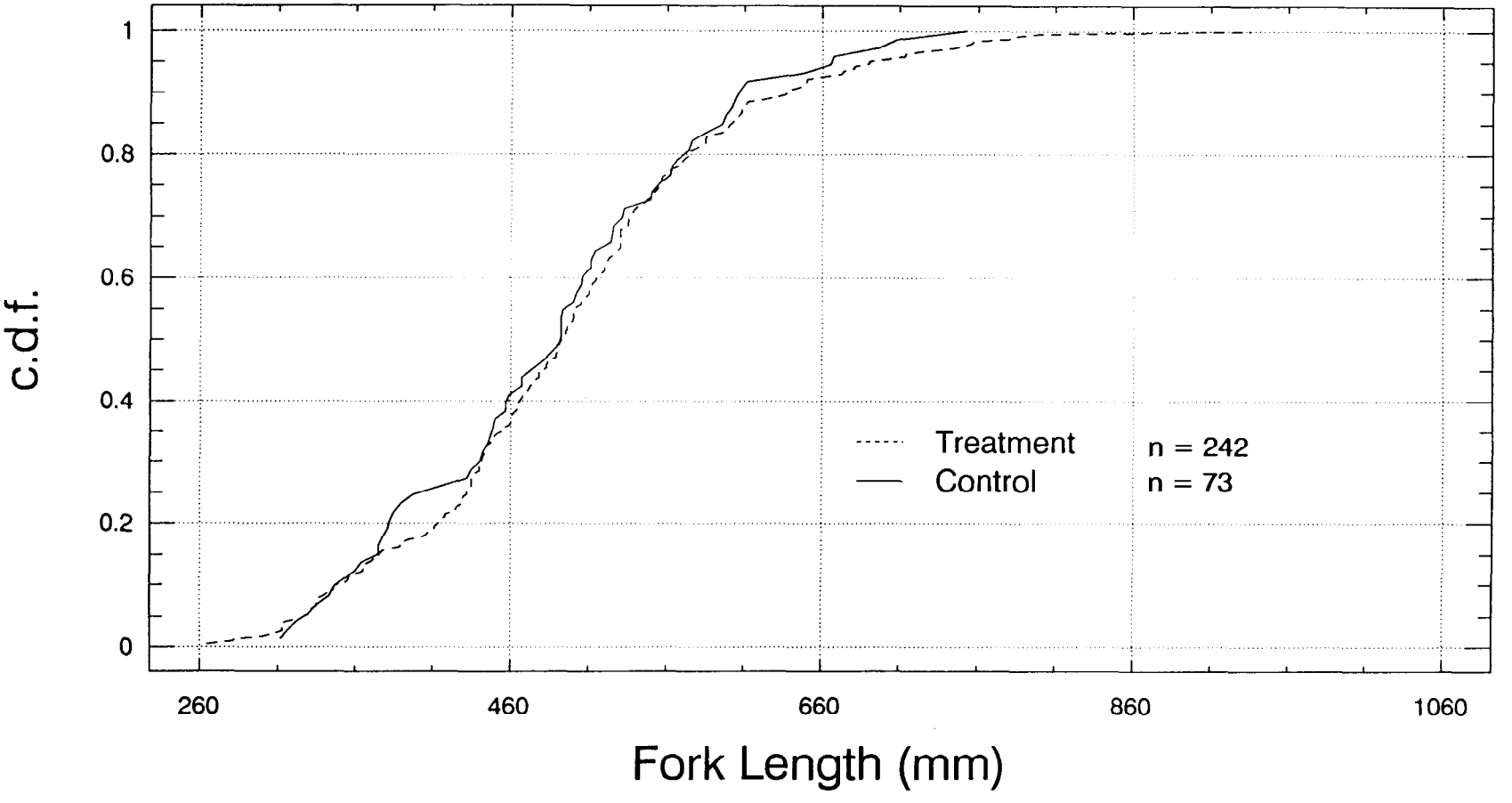

Figure 3. Cumulative length distribution functions (c.d.f.) of northern pike in the treatment groups (all types of terminal tackle combined) and those northern pike seined (control) at George Lake, 1991.

for northern pike held up to 16 days, fish in each treatment group did not suffer significant mortality. When mortality occurs in these kinds of experiments, the question of causation arises. A significant proportion of the mortality may have been due to holding stress or a combination of catch and release fishing and holding stress. In addition, some of the fish caught with hook and line gear in this experiment had previously been seined during a mark and recapture experiment. One of these fish died during the first five days of holding and a few more (six) died after 6 to 16 days of holding. Perhaps stress associated with seining contributed to the death of these fish. Exclusion of these fish from the analysis only reinforces the conclusion of this study: that catch and release fishing of northern pike resulted in no significant mortality.

Although lengths of fish differed significantly among terminal tackle types, the range of fish sizes is considered representative of what would be caught by the average angler and overall mortality was low. Catch and release studies on other species have also found fish size to be unimportant to mortality (Clapp and Clark 1989; Quinn 1989; Schill et al. 1986; and Wertheimer 1988).

Bleeding of study fish was more likely to occur when the fish was caught with a small treble hook and when fish were caught in the gills. While more bleeding occurred for fish caught with small treble hooks, no significant (> 10%) mortality occurred. None of the fish in either of the two experiments were caught in the gullet. It is likely that if bait fishing had been included as a method of hook and line fishing, that hook placement in the gullet would have occurred.

If these experimental results are representative of catch and release fishing by sport anglers, then length limits and mandatory no kill fishing practices invoked by the regulatory process would be useful management options for protecting a portion or all of a stock of northern pike.

The catch rate (0.34 fish per hour) for northern pike in the multiple capture experiment was much lower than expected considering the initial stocking density equivalent of 320 fish per hectare. In hind sight it is hypothesized that the low catch rate may have been a result of the influence of artificially high densities on fish behavior. If these types of experiments are conducted in the future I would recommend that fish densities be significantly reduced. In a multiple capture experiment a reduction in fish density would hopefully increase the catch rate and in a terminal tackle experiment a reduction in fish density would reduce the effect of holding stress on mortality rates.

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APPENDIX A

Appendix A. Lures used to capture northern pike in the multiple capture experiment.

Terminal Tackle		
Double Treble Hooks	Large Treble Hooks	Single Hook
Jointed Rapala (J-11-G)	Daredevil (1 oz)	Mr. Twister Grub (1/4 oz)
Countdown Rapala (CD-9-G)		
Storm Thinfin Silver Shad (T-64)		
Redeye Wiggler[a] (1 oz)		

[a] This lure has one treble hook and one double hook.

APPENDIX B

Appendix B. The Monte Carlo simulation used to determine sample sizes for the multiple capture experiment.

Monte Carlo simulation was used to determine sample sizes for the second experiment. The simulation is a computer program that mimics the outcomes of the experiment; outcomes are produced in that different sets of random numbers will produce different outcomes. The simulation begins with a fish being drawn at random from a group of N fish (the fish has been caught). A random number between 0-1 is then drawn. If the number is at or below a mortality threshold M, the fish "dies" and is removed from the experiment; if the number is above M, the fish "survives" and is returned to the group. The threshold M_{ij} for an individual fish i on capture j is a function of the expected mortality rate M_o from being caught once and the number of times the particular fish was previously captured (j-1):

$$M_{ij} = 1 - e^{-z[1+b(j-1)]}$$

where $Z = - Ln(1 - M_o)$. For example, if a fish has been captured once before, its probability of dying as expressed through the instantaneous mortality rate is twice that of a fish that had been caught for the first time when b = 1, three times when b = 2, etc. After disposition of the first fish, a second fish is randomly drawn and is processed in the same way as the first. A third fish is processed, a fourth, etc., until a sample of C fish have been caught (or all fish are dead). At the end of the simulated experiment, survival rates for fish that had been caught once, twice, thrice, etc. are calculated and are changed into instantaneous rates of mortality [$z_j = - Ln(S_j)$ where j is the number of times caught. The slope of the relationship between the z_j and j is then calculated with a weighted regression[1]. The null hypothesis that the slope is equal to zero is tested with procedures from Steele and Torrie (1980, Section 10.6). If the null hypothesis is not rejected, the decision is tallied as a Type II error. The computer program is reset, and the whole process is repeated to produce another slope coefficient and a test, repeated again for a third coefficient and a test, a fourth, etc. through K iterations.

Inputs to the simulation are:

1) a seed for the random number generator;

2) the number of fish in the experiment N;

3) the number of fish to be caught C;

-continued-

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[1] From Steele and Torrie (1980, Section 10.13), the weights are n/V[z]. From the delta method, the approximate variance of the z_j is $V[S_j]/S_j^2$. The variance of S_j is $S_j(1-S_j)/(S_n-1)$.

4) the effect of multiple captures β;[2]

5) the number of iterations desired K; and,

6) the Probability of a Type I error (options for α are 0.20, 0.10, 0.05, and 0.01).

Outputs from the simulation are:

1) average number of fish never caught;

2) average number of fish killed;

3) number of simulations in which all fish were killed;

4) number of simulations in which too few fish were caught enough times (>2) for the regression to have a solution;

5) average number of captures $[\Sigma^{K} \max(j)_k/K]$;

6) average slope in regressions;

7) number of simulations with good regressions (complement of Item 4 above);

8) number of simulations with slopes greater than zero (physically, not necessarily significantly greater than zero); and,

9) power of the test $(1 - \beta)$, the Probability of a Type II error).

[2] The increase in the instantaneous mortality rate is calculated as $z_j = Z + bZ(j-1)$. The expected slope in the weighted regression is bZ.

APPENDIX C

Appendix C. Lures used to capture northern pike in the terminal tackle comparison experiment.

Terminal Tackle			
Double Treble	Large Treble	Single Hook	Small Treble
Jointed Rapala (J-11-G)	Daredevil (1 oz)	Daredevil (3/4 oz)	Hotrod (1/4 oz) Krocodile (3/8 oz) Blue Fox (Aqua)