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Gilling in Trap-Net Pots and Use of Catch Data to Predict Lake Whitefish Gilling Rates

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ABSTRACT

Gilling of lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*) in trap-net pots was investigated for three commercial nets set during the fall of 1980 in northern Lake Huron. Approximately 73% of observed gilling occurred as nets were being lifted. Consequently, high percentages of gilled fish were alive when fishermen harvested their catch. More than two-thirds of the gilled fish were located in side netting, while smaller proportions of gilled fish were found in the back, front, top, and bottom of the pot. A regression model was developed to predict the number of lake whitefish gilled based on total catch. Independent variables for the statistically significant ($P < 0.001$) model were the number of lake whitefish caught and the square root of the number of lake trout in the pot. Lake whitefish schooling behavior associated with the approach of spawning season was regarded as an important factor in explaining gilling rates. The number of gilled whitefish could be reduced by increasing the frequency of net lifts if it were found to be economically feasible.

Commercial use of trap nets in the Great Lakes began in the early 1900's, yet certain problems associated with this gear persist today. One such problem involves gilling of both target and non-target species (Fig. 1) in the pot portion of the trap net (Van Oosten et al. 1946). Lake whitefish (*Coregonus clupeaformis*) is a target species commonly exploited by Michigan trapnetters. An important non-target species, frequently associated with lake whitefish in trap-net catches, is the lake trout (*Salvelinus namaycush*). Market value of gilled lake whitefish is reduced if fish are disfigured or mutilated and they may not be salable if the duration of gilling results in death and subsequent decomposition. Gilling of lake trout can be wasteful of a highly esteemed sport fish, creating bad relations between commercial and sport fishermen, and complicating the management and stocking programs of various state and federal agencies. Removal of gilled fish can be difficult and time consuming and can cause damage to nets. Furthermore, nets may not fish as well when gilled fish are present because fish that would normally lead into the pot may be repelled if they detect the presence of either dead or struggling gilled fish.

Some net modifications have been tried which reduced gilling of lake trout (Eshenroder 1980; Miller et al. 1980) but, in general, gilling within the pot is poorly understood. In our study, we sought to derive a clearer picture of various aspects of the gilling phenomenon, and we developed a model whereby the number of lake whitefish gilled in a trap-net pot can be predicted from catch data.

METHODS

Three commercial trap nets (see Table 1 for details) were deployed in Lake Huron at Hammond Bay (latitude 45°30′, longitude 84°05′) near Ocqueoc, Michigan from 25 September to 28 October 1980. Pots were situated at a depth of approximately 7 m. Leads extended from the pots toward shore in a line perpendicular to the beach. Each net was lifted twice each week (on Mondays and Thursdays) from 25 September to 13 October; thereafter, lifts were less regular because catch surpassed boat-holding capacity, and only one or two nets could be lifted daily. In total, data were gathered from 31 separate trap-net lifts. Catch data recorded for lifts included: number and size range of each species caught; total weight of lake whitefish caught; and number, species, location in net, and condition (live vs. dead) of gilled fish. Weather conditions, water temperature, secchi-disc reading, and wave height also were recorded at the time of each lift.

Direct observations of fish behavior within the pot were made by scuba divers. During each of

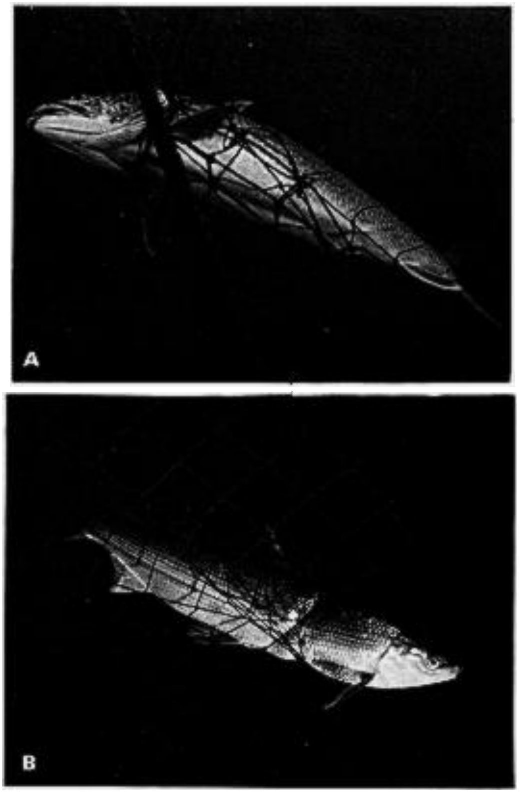

Figure 1. Fish gilled in commercial trap-net pots in northern Lake Huron 1980. (A) Lake trout. (B) Lake whitefish.

31 dives, fish were observed, counted, and their swimming patterns noted. Number, location, and condition of gilled fish also were recorded by divers. On two occasions, divers counted the number of gilled fish immediately prior to a lift, then observed fish behavior while nets were being lifted.

The regression model to predict the number of gilled lake whitefish was developed by analyzing catch data (some of which are listed in Table 2) using the Michigan Interactive Data Analysis System (MIDAS) described by Fox and Guire (1973). Independent variables considered for the model included: lake whitefish catch (numbers); lake trout catch (numbers); total catch (all species); total number of gilled fish; total weight of lake whitefish captured; secchi-disc reading; and water temperature. Variables chosen for the regression equation resulted from the analysis, consideration, and further manipulation of preliminary variables selected by the step-

Table 1. Summary of specifications for trap nets fished from 25 September to 25 October 1980 in Hammond Bay, Lake Huron. Pots were in 7-m deep water. Net-part nomenclature from Miller et al. (1980).

Net part	Twine size (thread)	Stretch-mesh size (mm)	Length (m)	Height (m)	Width (m)
Pot	15	118	11	6	6–8
Lead	15	356	201–377	2–6	
Wing	15	152	5	6	
Heart	15	152	18	6	
Winker	15	152	15	6	
Big door	15		4	6	
Small door	18		2	6	

Table 2. Selected catch statistics for three trap nets fished from 25 September to 28 October 1980 in Hammond Bay, Lake Huron.

	Number caught		Number gilled		Percent total catch comprised of lake whitefish[a]
Date	Lake trout	Lake whitefish	Lake trout	Lake whitefish	
25 Sep	82	276	6	1	74
25 Sep	112	87	9	2	39
25 Sep	89	17	2	0	15
29 Sep	81	392	1	4	82
29 Sep	137	152	12	1	50
29 Sep	160	116	5	1	41
2 Oct	62	232	2	2	78
2 Oct	70	116	6	1	59
2 Oct	100	65	0	0	38
6 Oct	107	768	5	9	86
6 Oct	114	203	15	4	61
6 Oct	173	334	5	0	63
9 Oct	67	652	1	17	90
9 Oct	97	254	9	6	70
9 Oct	64	210	8	4	74
13 Oct	81	921	7	24	91
13 Oct	112	450	13	18	77
13 Oct	156	594	3	12	77
16 Oct	32	783	1	53	96
16 Oct	78	696	3	19	87
17 Oct	61	580	2	35	90
17 Oct	20	348	2	9	93
20 Oct	39	957	3	56	95
20 Oct	57	377	4	29	85
21 Oct	56	812	2	30	91
21 Oct	4	493	0	31	99
23 Oct	26	609	2	33	92
23 Oct	26	261	0	8	58
27 Oct	28	1,102	1	87	96
27 Oct	19	783	2	51	95
28 Oct	14	841	0	27	96

[a] All species of fish included.

wise regression program available through MIDAS.

For the regression equation generated, an analysis of residuals was performed through MIDAS, and model assumptions of normality and equal variances appeared to have been adequately met. Normality was evaluated from skewness and kurtosis coefficients, from plotting standardized/normalized residuals, and from the Lilliefors test for goodness-of-fit (Conover 1971). Equal variances were indicated by a plot of residuals vs. predicted values of the dependent variable. A problem with the assumption of independence was evident from a plot of the dependent variable over time, but this problem is not likely to affect the hypothesis test for significance because the regression was found to be highly significant. Confidence and tolerance intervals were also calculated (Neter and Wasserman 1974).

RESULTS

General Observations

In general, numbers of lake whitefish caught increased with time over the duration of the study (Table 2), while mean length of whitefish caught remained quite stable ($\bar{x}$ = 532 mm; range = 481–560 mm) over the same period. Trap-net catches were dominated by lake whitefish (Table 2), while lake trout were second in abundance; these are the two species which are of greatest interest to commercial or sport fish managers. Numbers of other species captured were considered negligible.

When the net was stable, lake whitefish and lake trout were observed by divers to swim slowly and easily within the pot, usually in schools segregated by species. Easy swimming was disrupted when a net lift was initiated. As the pot was winched to the surface and drawn across the boat, net movement and rapid reduction of space within the pot caused trapped fish to become highly excited and concentrated in the crib portion of the net. Various gilling statistics indicated that most gilling in trap-net pots occurred during lifts. For example, during 14 dives performed at various times between lifts when the net was stable, only 4.4 lake whitefish and 1.7 lake trout (averages) were observed to have been gilled, while the numbers of gilled fish counted from 31 lifts averaged 18.5 whitefish and 4.2 trout.

Dives also were performed immediately prior to net lifts (two occasions) so that numbers of gilled fish counted before and after lifts could be compared. For both species combined, 83 of 113 fish (73%) were gilled as the nets were lifted and the total number of gilled fish represented about 6% of the total catch.

Catch data in which live vs. dead fish were noted indicated that 94% of the gilled lake whitefish (N = 437) and 73% of the gilled lake trout (N = 79) were alive when fish were harvested from the nets. The amount of time that fish remained alive while gilled was not determined and probably was different for the two species, but the high percentages of live gilled fish were at least an indication that many of these fish were recently gilled. Nets lifted between 2 and 21 October contained 20 lake trout which already were dead from gilling. Three nets were fishing during this time and they were lifted 18 times. Thus, dead gilled lake trout occurred at a rate of 0.33 fish/day/net or 1.1 fish/lift.

Mapping of gilled fish indicated that the relative distribution of these fish at various locations around the pot was similar for both lake whitefish and lake trout. If the front panel of the pot is considered the side which connects with the wings and leads, then most gilled fish were located in the sides (68%); fewer gilled fish were found in the top (19%), rear (11%), and front (2%) panels. No fish were observed gilled in the bottom. Compared with those gilled during lifts, fish gilled during the interval between lifts were 11% more prominent in the rear panel, but 17% less prominent in the top of the pot. Gilling in the side panels occurred at approximately the same rate both before and during lifts.

Divers made a few observations which may be interpreted as evidence for some degree of association between fish inside and outside the pot. On two occasions, divers noted fish that were gilled trying to enter the pot from the outside. This phenomenon could not be readily ascertained from the trap-net boat because of the way the pot collapsed on the boat deck when nets were lifted. On a different occasion, a lake whitefish small enough to pass easily through the pot mesh was seen to swim repeatedly in and out of the pot as the net was being lifted. Outside of the pot, small groups of three to five whitefish sometimes swam in proximate synchrony with larger schools inside the pot.

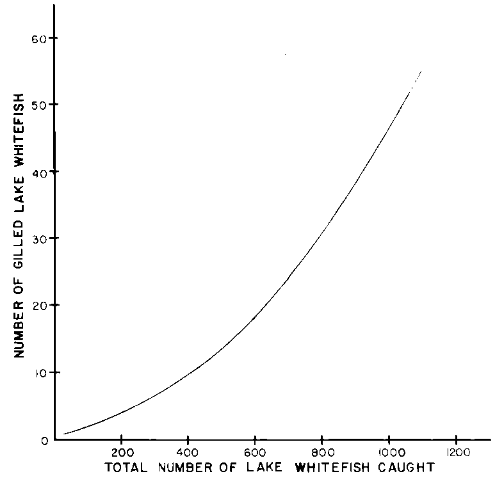

Figure 2. Relationship between the number of gilled lake whitefish and the total number of lake whitefish caught when the number of lake trout caught is held constant at a mean value of 67. Data were obtained from commercial trap-net catches in northern Lake Huron, 25 September–28 October 1980. See text for explanation of the regression equation.

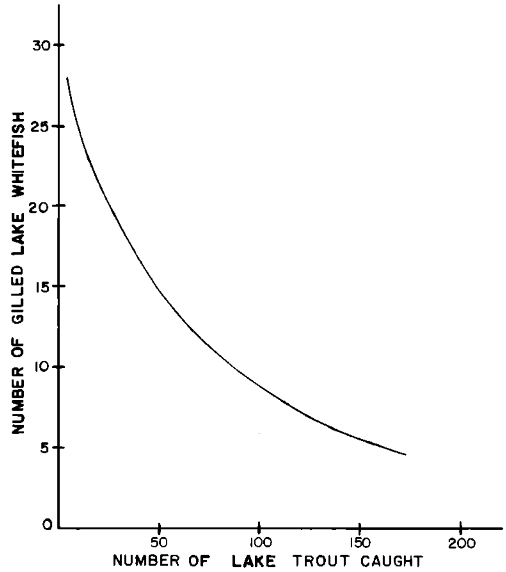

Figure 3. Relationship between the number of gilled lake whitefish and the number of lake trout caught when the total number of lake whitefish caught is held constant at a mean value of 467. Data were obtained from commercial trap-net catches in northern Lake Huron, 25 September–28 October 1980. See text for explanation of the regression equation.

The Model

A relationship was found between the square root of the number of gilled lake whitefish ($\sqrt{GLW}$), and two independent variables—total number of lake whitefish caught (LW) and square root of the total number of lake trout in the pot ($\sqrt{LT}$). Regression analysis indicated that the relationship was linear. The regression equation to calculate the number of gilled lake whitefish (GLW) was:

$$GLW = (3.116 + 0.006LW - 0.288\sqrt{LT})^2$$

Both the coefficient of determination ($R^2 = 0.84$) and the adjusted coefficient of determination ($R^2_{ADJ} = 0.83$) indicated that a high proportion of the variability seen in $\sqrt{GLW}$ was explained by the inclusion of the two independent variables in the model. The mean square error term (1.07) was small and showed that the model was fairly precise. The regression relationship, the coefficients for the two independent variables, and the value of the intercept were all highly significant ($P < 0.001$). The relationship between GLW and LW was geometrically proportional (Fig. 2), while the relationship between GLW and the total number of lake trout caught (LT) was inversely proportional (Fig. 3). Back-transformed values of the dependent variable indicated that the model was not a perfect representation of the gilling relationships for whitefish, especially when used to predict small numbers of gilled lake whitefish (Table 3). However, confidence and tolerance intervals were more acceptable when the regression was used to predict large numbers of gilled whitefish which would be of greatest concern to fisherman and fish managers.

DISCUSSION

Gilling of fish in trap-net pots may best be understood by integrating general observations of the gilling phenomenon with more specific gilling relationships suggested by the regression model. Insights drawn from such an integration

Table 3. Representative values for 95% confidence intervals and 95% tolerance intervals for the expected value of the number of lake whitefish gilled (GLW), given the number of lake whitefish caught and the number of lake trout caught.[a]

GLW	Confidence intervals	Tolerance intervals
0.37	6.35, 0	11.97, 0
0.76	6.60, 0	12.89, 0
12.53	27.77, 3.28	39.56, 11.16
42.77	73.27, 20.43	89.68, 13.03
67.24	94.48, 44.49	117.07, 31.14

[a] Values for GLW, 95% confidence intervals, and 95% tolerance intervals were back-transformed from values originally calculated from the regression equation.

may then inspire greater confidence in the legitimacy and usefulness of the model.

The relationship in the regression model between GLW and LW was geometrically proportional (Fig. 2) and a good correlation between GLW and total catch (all species) was not found. Therefore, neither density of whitefish nor total fish density adequately explained whitefish gilling rates in the pot. Inclusion in the model of the $\sqrt{LT}$ term showed that some kind of interaction occurred between lake whitefish and lake trout, but since the $\sqrt{LT}$ term is subtracted in the model, it appears that the presence of lake trout reduced whitefish gilling. Thus, the geometric increase in GLW at increasing values of LW requires an explanation in other terms.

Approximately 73% of the gilling occurred while the nets were being lifted, suggesting that certain interactions occur between trapped fish during lifts which involve some aspect of lake whitefish behavior. Schooling behavior may be the key to understanding whitefish gilling during lifts. Lake whitefish are generally regarded as schooling fish (Van Oosten 1938; Scott and Crossman 1973), and schooling behavior intensifies as spawning season approaches (Kennedy 1949). Inshore schooling by whitefish during fall months motivates fishermen to set their nets inshore starting in mid-September every year. As the water temperature drops, whitefish home into and congregate in shallow water and catches increase through October. Breder (1976) reported that schooling fish crowd each other, and their ability to swim in any direction was severely restricted by the mere presence of other fishes; this restriction became intense in dense schools. School densities increase when fish are alarmed because individual fish tighten the space around each other (Breder and Halpern 1946; Keenleyside 1955). Frightening stimuli can create panic situations in fish schools, and the ensuing confusion has been described as a "logjam" effect by Breder (1976) and an "avalanche-like" reaction by Radakov (1975). Lifting of a trap net would certainly represent a frightening stimulus which could cause whitefish within the pot to school more densely while attempting to escape the moving net. Fleeing schools would quickly encounter some face of the pot's netting, and some proportion of fish may be forced or crowded into the net by other members of the school. It seemed reasonable that, as school size increased, individuals within the school would be subjected to increased restriction of movement and greater crowding. As a result, greater proportions of fish could become gilled; this could be significant in understanding the geometrical relationship between GLW and LW.

Another factor that would help explain the relationship involves the reduction of visibility due to turbidity produced by fright responses of captive fish and net movement. When greater numbers of fish are trapped, turbidity resulting from their panicked swimming could reach a point at which many fish would fail to see or react to the net and a greater proportion of fish could thus become gilled.

The relationship between GLW and LT was found to be inversely proportional (Fig. 3). When relatively large numbers of lake trout were in the pot, relatively few lake whitefish were gilled; increased numbers of gilled whitefish were recorded when fewer lake trout were present in the pot. Scuba observations indicated that confrontations within the pot between schooling lake trout and schooling lake whitefish sometimes caused erratic, scattering behavior on the part of the whitefish. It may be that when relatively large numbers of lake trout were present in the pot, their tendency to break up schools of whitefish resulted in fewer lake whitefish crowding each other and becoming gilled when nets were lifted. Conversely, relatively few lake trout would have little effect upon large schooling masses of lake whitefish. Indeed, small numbers of lake trout may have of necessity become incorporated into large whitefish schools and been subject to the same panicked response as lake whitefish during net lifts.

The relatively small percentage of lake whitefish that were gilled during intervals between lifts was influenced by factors other than those affecting fish gilled during lifts, but again an aspect of their schooling behavior may be important. Keenleyside (1955), working with three species of fish, conducted "choice" tests in which two schools (differing in number) at opposite ends of an aquarium were presented to a single fish in the middle of the aquarium. It was clearly shown that single fish were most strongly attracted to the larger of the two schools. It seems conceivable therefore, that if small groups of fish swam by when the trap was relatively full, fish on the outside would be attracted to schooling masses within the pot. Fish gilled from outside the pot going in may thus have become entangled in the net in their efforts to join larger schools in the pot. Conversely, if fish density was low within the pot, gilling could occur when captured fish attempted to join larger schools that happened to swim by in close proximity outside the pot.

Sixty-eight percent of the observed gilling occurred in the pot sides which comprised about 36% of the total net surface area of the pot. During intervals between lifts, while the pot was stationary, the sides represented the most unobstructed interface between the inside of the pot and open water. The back of the pot presented a slightly more congested view to fish either inside or outside the net because of the gang of ropes from the corners of the pot leading toward the trap's back anchor. The front face would look even more congested because of the tunnel leading into the pot, and the wings, hearts, and leads directed toward shore. The top of the pot was only about 1.5 m below the surface, so that any kind of wave action probably would have made the net top a nonpreferential place because of the additional turmoil. The bottom of the pot rests on the lake bottom, so that gilling there was not probable while the net was set. Another consideration is that fish vision and locomotor mechanics operate primarily in the horizontal plane (Breder 1976). It would seem most likely that fish would run into vertical net faces (sides, back, and front) perpendicular to their line of sight and path of propulsion, and less likely that they would run into horizontal net faces (top and bottom). Thus it is understandable that, in this study, gilling between lifts was found to occur mostly in the sides, somewhat less frequently in the back, less frequently still in the front, rarely in the top, and never in the bottom of the pot.

The situation changed during net lifts in that relatively more fish gilled in the top and fewer fish gilled in the back of the pot. Back and bottom panels are areas which initially move and collapse most rapidly as nets are lifted, and this action may have repelled fish from these areas. Also, the bottom panels of the nets used in this study were constructed with shoaling twine over the first 2 m from the tunnel end, so potential for gilling there was reduced. Fishermen report that occasional gilling does occur in the bottom of the net when fish apparently attempt to dive down to escape the moving net, but such gilling was not observed during our study. During lifts, net sides would still appear to be the most unobstructed interface with open water, but because the lift changes the orientation of net faces with respect to horizontal and vertical planes, fish may view the top of the pot in the same manner that they see the sides in terms of a potential escape route. Space becomes increasingly restricted as the lift progresses, and fish may ultimately attempt to escape through any nearby netting.

Proportions of gilled fish in any given location were nearly identical for both lake trout and lake whitefish, indicating that both species reacted and behaved similarly in response to stimuli that caused gilling. Conformity of behavior between lake trout and lake whitefish may be due to the trout becoming incorporated into large whitefish schools, as was speculated earlier.

Data on live vs. dead gilled fish indicated that almost all gilled lake whitefish were alive and would still be marketable; they would not represent a wasteful loss to the fishery. Live, gilled lake trout, however, were not marketed but were set free, and survival of released fish would be affected by stress and damage incurred by gilling and handling. Survival rates of such fish are not known, so it was not possible to assess the number of released fish that would be lost to the fishery.

Counts of gilled fish which involved diver observations may have been somewhat inaccurate because the presence of the divers may have excited captive fish and provoked some gilling which normally would not have occurred. Influences on fish behavior from diver presence were discussed briefly by Hemmings (1971). However, every effort was made to avoid disturbance of fish and we feel that the conclusions drawn from our results were sound and would not be invalidated by the influence of diver presence.

The regression model we generated is useful because it allows prediction of the number of gilled lake whitefish whenever the catch is known or is predictable. This information is pertinent to fishermen and fish managers because the number of gilled whitefish could be decreased by increasing the frequency of net lifts (decreasing the time interval between lifts) as greater numbers of whitefish move inshore and larger catches are made. However, the economic feasibility of such an adjustment in frequency of net lifts would need to be considered. In addition, different net retrieval speeds (high and low) should be investigated as a possible method to reduce the gilling rate.

The model may require some modification if it is to be applied to trap-net catches during other times of the year or from other lakes. However, Van Oosten et al. (1946) found that the percentage of gilled fish was not affected by depth of water, month, or fishing grounds, so that the model may be widely applicable.

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