Size-related Hooking Mortality of Incidentally Caught Chinook Salmon, *Oncorhynchus tshawytscha*

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ABSTRACT—Mortality associated with the incidental catch and release by commercial trollers of two size classes of chinook salmon, Oncorhynchus tshawytscha, *was assessed. Observed cumulative mortality 4–6 days after hooking was 18.3 percent for sublegal-size fish (< 66 cm FL) and 19.0 percent for legal-size fish. Size of fish was not significantly related to mortality; however, when the results were combined with data from a previous experiment, there was a significant inverse relationship between fish length and mortality. Hooking mortality estimates calculated from tagging experiments and observed relative mortality of legal- and sublegal-size fish held in net pens, were used to derive a range for total hooking mortality of 22.0–26.4 percent for sublegal-size chinook salmon and 18.5–26.4 percent for legal-size chinook salmon.*

Introduction

To rebuild depressed and declining chinook salmon, *Oncorhynchus tshawytscha*, stocks of the northeastern Pacific rim, the Pacific Salmon Commission has established limits on the numbers of chinook salmon that can be landed in several commercial fisheries. One result has been a dramatic reduction in fishing seasons for chinook salmon in some areas. In Alaska, the summer season (April–September) for commercial trolling has been reduced from 179 days in 1980 to 12 days in 1988. A consequence has been an increase in chinook-only closures, during which fishing is directed primarily at coho salmon, *O. kisutch*, and all chinook salmon caught must be released. Fisheries managers require estimates of the mortality associated with such catch and release periods to assess their effect.

Previous estimates of hooking mortality for chinook salmon vary widely, from 12 percent (Butler and Loeffel, 1972) to 71 percent (Parker and Black, 1959). Reviewers of hooking mortality research have proposed estimates of ≤30 percent (Wright, 1970), 38 percent (Horton and Wilson-Jacobs, 1985) and 50 percent (Ricker, 1976). Most estimates focus on sublegal-size fish or do not consider size-related differences in mortality. Wertheimer (1988) concluded that hook and release mortality of sublegal-size chinook salmon is around 25 percent (agreeing with Wright's conclusion that "estimates of mortality higher than 30 percent are excessive"). Wertheimer (1988) also observed a lower mortality rate (20.5 percent) for legal-size chinook salmon; however, the sample size for this estimate was small and the 95 percent confidence interval was large (9–32 percent). To increase the sample size of legal-size fish, we carried out additional research on hooking mortality of chinook salmon to determine if the mortality rates are different between sublegal- and legal-size classes.

Methods

Gear

Three power trollers were chartered to fish 4–12 August 1987 at Whale Bay on the outer coast of Baranof Island in southeastern Alaska (Fig. 1). Each vessel fished four wire lines with 8–10 individual lures per line. To simulate fishing during chinook-only closures, the fishermen used their normal complement of coho salmon lures, including plugs, spoons, and hootchies (imitation squid) with flashers. Hook size was limited to 6/0 barbed, single hooks, the most common size used during chinook-only closures. The numbers of each lure type fished were recorded for each vessel throughout the fishing period.

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Processing the Catch

When a chinook salmon was caught, it was led by the fisherman to an electric basket (Orsi and Short, 1987) where it was simultaneously lifted from the water and immobilized by electric shock. The hook was removed by the fisherman who inserted a gaff hook along the curve of the lure hook and turned the gaff so the weight of the fish pulled it free of the hook. An observer noted lure type, depth fished, and location of the wound, and then rated the severity of the wound according to the following condition codes, after Davis et al., 1986: Condition 1, a minor injury, including hooking near the outer portion of the mouth and little or no bleeding; condition 2, a serious injury, including hooking in or near the gills or eyes, and severe bleeding; or condition 3, dead. Fork lengths (FL) of fish were measured to the nearest centimeter. On the basis of conversions given by Van Hyning (1951), FL of 66 cm was considered equivalent to the legal size limit of 70 cm total length. Fish were marked with a 2.7-cm numbered Floy[1] anchor tag inserted below the dorsal fin. Average processing time was less than 45 seconds. The observer also noted if a fish suffered severe handling stress such as abnormally long processing time, extensive descaling (>15 percent), or being dropped during transfer.

A high catch rate of chinook salmon made it necessary to limit the number of fish retained to avoid exceeding the holding capacity of the net pens. All legal-size fish were retained, and after the second day of fishing each boat was limited to retaining the first 15 sublegal-size fish caught each day. All coho salmon caught were killed, dressed, iced, and sold to help defray the cost of the project.

Each retained chinook salmon was placed in a covered 175-liter live tank with flowing seawater until it was transferred with a large dip net (84 × 51 cm, 6 mm knotless webbing) to a similar tank in a skiff. Typically, only one or two fish were held at a time in each live tank. Live fish were transferred from the skiff to a net pen by pouring the contents of the live tank into the pen. Transfer time from capture to the net pen varied from 6 to 40 minutes and averaged 18 minutes.

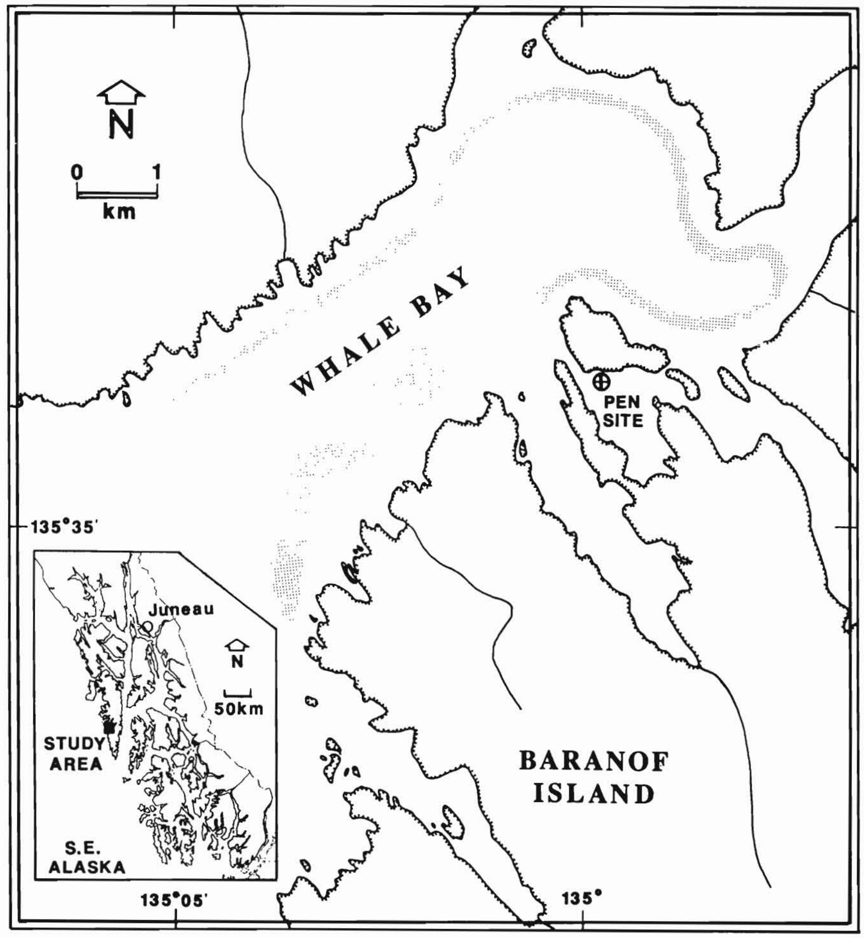

Figure 1.—Fishing areas (stippled) and net-pen site used for study in Whale Bay, August 1987.

Two net-pens, constructed of 2.5 cm knotless nylon mesh suspended from a 12.2 m^2 float frame, were used. Each pen had eight sides that were 12 m deep and were alternately 9.1 and 2.2 m long. The bottom sagged to a depth of 15 m; total volume was 1,700 m^3. Fish from the first 3 fishing days were placed in net pen 1 and fish from the next 3 fishing days were placed in net pen 2. At the end of the sixth fishing day, pen 1 was emptied by releasing the fish, then fish from the final 3 fishing days were placed into it. The fish in pen 2 were released at the end of the ninth fishing day, and the second group of fish in pen 1 were released 3 days later. Thus, all fish held were observed 4–6 days. The pens were checked by divers at the end of each fishing day and for 3 days after trolling ended; dead fish were removed and the tag number was recorded. Most (155 of 168) dead fish were examined postmortem and the location of the primary wound site was noted. Temperature and salinity profiles near the holding nets and on the fishing grounds were measured by bathymetric casts with a recording conductivity-temperature instrument.

Statistical Analysis

The BMDPLR stepwise logistic regression program (Dixon et al., 1983) was used to identify the independent variables significantly related with mortality (the binary response variable). For the logistic regression model the probability of mortality is:

$$e^u / (1 + e^u)$$

where u is a linear function of the independent variables. The variables considered in the regression model were injury location, fork length, vessel, lure depth, lure type, and transfer time. An independent variable could be included in the regression model if the improvement chi-square test, computed from the log e of the ratio of the likelihood function without the variable to the likelihood function with the variable, was significant ($P < 0.05$). Two stepwise regression analyses were performed based on when mortality occurred. In the first analysis, all

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

mortalities were included, and in the second, fish that were dead prior to transfer to the net pens were excluded from the model.

The relationship between fish length and mortality was examined using logistic regression and by generating smoothed curves of the mortality rates plotted against length, using the 4253H smoothing algorithm (Velleman and Hoaglin, 1981). It was necessary to pool the observations for smoothing into 3 cm increments to have sufficient (> 10) observations at each length increment. Data from this study and Wertheimer (1988) were examined.

Mortality was determined for each of seven time periods: Immediate (fish dead at landing or by the time of transfer to the net pens) and at the end of each of the 6 days that each group of fish were held. The BMDP3R nonlinear regression program (Dixon et al., 1983) was used to generate maximum likelihood estimates with associated standard deviations for each time period, and the correlation matrix for the estimates. Total mortality during the study is the sum of the estimates for each time period; the variance of this estimate is the sum of the variances for each time period plus the sum of the variance-covariance matrix (Mood and Greybill, 1963).

Estimates of delayed mortality of sublegal-size chinook salmon observed in this study were compared with estimates of delayed mortality recalculated from previous tagging experiments (Butler and Loeffel, 1972; Wright, 1970). The tag-recovery data was recalculated by replacing their assumption of no delayed mortality for the group with the highest tag recovery rate with a mortality rate observed in the present study. A recapture coefficient was calculated from the formula

$$r = n/(N' - D), \qquad (1)$$

where n is the number of recaptures for the group with the highest tag recovery rate, N' is the number of tags released from this group, and D is the number of delayed deaths for this group. The number of deaths due to delayed mortality in a particular category can then be determined by the formula

$$D_i = N_i' - n_i/r, \qquad (2)$$

where i is a particular wound location or condition. Delayed mortality expressed as the proportion of fish landed would be the sum of the D_i's divided by N, where $N = N' + I$ and I is the number of immediate deaths.

Results

A total of 550 legal- and 701 sublegal-size chinook salmon were caught and landed. All legal-size fish and 363 sublegal-size fish were included in the mortality analysis; 338 sublegal-size fish were tagged and released immediately following capture. All fish but one were caught at depths greater than 12 m; 99 percent of the legal-size fish and 98 percent of the sublegal-size fish were caught at depths greater than 15 m, the maximum depth in the pen. Most (83 percent) fish were caught in depths below 30 m; the maximum depth at which fish were caught was 58 m. Once in the holding pens, fish in good condition remained in the lower half of the net pen.

Water temperature was 1–2°C warmer in the lower half of the net pen compared with temperatures in Whale Bay at the depths most of the fish were caught. Temperatures in the net pens were 10.7–11.3°C at 5 m and 8.6–9.0°C at 15 m. Temperatures in the fishing area were 9.0–9.2°C at 30 m and 7.9–8.0°C at 60 m. Salinity was also slightly lower in the net pens. Salinity in the pens was 30.5–31.0‰ at 5 m and 30.5–31.3‰ at 15 m. Salinity in the fishing area was 31.5–31.6‰ at 15 m and 31.7–31.9‰ at 60 m.

Variables Affecting Mortality

In the stepwise logistic regression, only injury location entered and remained in the model in both analyses (Table 1). In the analysis that included both immediate and delayed mortality, the location, depth of capture, and lure type were significantly associated with mortality when the variables were considered in isolation, i.e., when each variable was entered in the logistic regression model independently (Table 1). In the analysis that excluded immediate mortality (to include transfer time as a variable), injury location and depth of capture were significantly associated with mortality when the variables were considered in isolation (Table 1). These results indicate that there is some correlation of injury location with lure type and depth fished.

The relationship between the location of the hooking injury and mortality is apparent from the observed mortality rates for both legal- and sublegal-size fish. Mortality for both size classes was 85 percent for fish hooked in the gills, and ranged from 0 to 10.9 percent for fish hooked in the snout, maxillary, and corner of the mouth (Table 2). When observations for the two size classes are combined, the injury locations can be grouped into three general categories according to degree of mortality (Fig. 2): Low—snout, maxillary, or corner of the mouth; intermediate—lower jaw, isthmus, cheek, or eye; and high—gills. In general, these groups correspond to the proximity of the wounds to the gills and the complex of blood vessels in the isthmus at the base of the gills. Postmortem examinations verified that the wound location influences mortality. Gill damage and eye or isthmus wounds were apparent in 95

Table 1.—Summary of stepwise logistic regression results for chinook salmon caught at Whale Bay in 1987. Analysis 1 included all observations of mortality in the model, and analysis 2 excluded observations of immediate mortality from the regression model and included transfer time as an independent variable. Improvement chi-square is shown only for variables that enter the stepwise model. Asterisks denote significant differences at $P < 0.05^*$ or $P < 0.001^{***}$.

Analysis and variable	Approximate F, no other variables in model	Step to enter model	Improvement χ^2
Analysis 1			
Injury location	24.10***	1	147.64***
Depth	5.70*		
Lure type	3.28*		
Vessel	2.01		
Length	0.04		
Analysis 2			
Injury location	17.83***	1	108.63***
Depth	5.70*		
Lure	1.97		
Length	1.50		
Transfer time	0.71		
Vessel	0.69		

percent of the fish examined after dying. Gill damage was observed in 76 percent of the fish examined postmortem, although only 21 percent of the fish that died were observed to have gill injuries at landing.

As indicated by the logistic regression analysis, the relationship between lure type and mortality was due to a correlation between lure type and injury location. Fish caught on plugs had lower mortality and were hooked more frequently in "low" mortality locations than fish caught on the other lure types (Table 3). There was considerable selection by the fish for plugs; although plugs comprised only 12 percent of the lures fished, they caught 34 percent of the fish (Table 3). In contrast, spoons comprised 58 percent of the lures fished but caught only 14 percent of the fish.

The relationship between injury location and depth of capture indicated by the logistic regression is not clear. One explanation is that different lure types were fished at particular depths, and because lure type and injury location are related, there is a relationship between depth and injury location. This explanation cannot be confirmed, however, because the relative proportions of lure types fished at particular depths were not recorded.

There was no evidence of direct increases to mortality due to transfer time or handling stress. If fish that were alive at landing, but died before transfer into the net-pen are included in the regression analysis that considers transfer time, there is actually a significant inverse relationship between time in the tanks and mortality. However, this does not mean that increasing transfer time will reduce mortality; higher mortality associated with shorter tank time is caused by mortality wounded fish that still show some respiratory response at landing, but die shortly after being placed in the holding tanks. For this reason, all fish that died prior to placement into the netpens were considered immediate mortality.

Mortality was lower for fish that were exposed to excessive handling stress relative to fish that were not exposed to such stress. Of 73 fish that were noted to have suffered severe handling stress, such as being dropped during transfer or descaled extensively, 15.1 percent died, compared with 18.7 percent mortality for fish exposed to normal handling. It is unlikely that increased stress reduces mortality; however, these data suggest that increases in handling stress did not result in greater mortality.

Condition at Landing

Of the 913 chinook salmon in the experiment, 53.8 percent (491 fish) were graded condition 1 (minor injury), 45.8 percent (418 fish) were

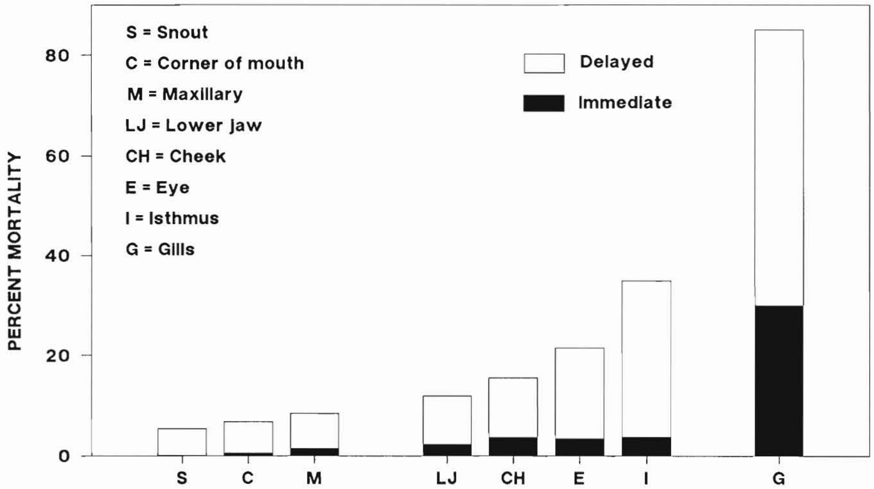

Figure 2.—Immediate and delayed mortality according to location of hooking injury for chinook salmon caught in Whale Bay in August 1987; all sizes combined.

Table 2.—Total catch and subsequent mortality by hooking location and size class of chinook salmon captured at Whale Bay in 1987. Immediate mortality includes all fish that died prior to transfer into the holding nets; delayed mortality is the total number of deaths minus the immediate deaths, divided by the total number captured; it is not weighted for length of time the fish were held.

	Legal-size fish				Sublegal-size fish			
		Mortality (%)				Mortality (%)		
Hooking location	Total catch	Immediate	Delayed	Total	Total catch	Immediate	Delayed	Total
Snout	31	0	9.7	9.7	26	0	0	0
Corner of mouth	117	0.9	6.8	7.7	93	0	5.4	5.4
Maxillary	46	0	10.9	10.9	25	4.0	0	4.0
Cheek	51	3.9	11.8	15.7	33	3.3	12.1	15.4
Lower jaw	85	1.2	7.1	8.3	51	3.9	13.7	17.6
Eye	132	2.3	18.9	21.2	73	5.5	16.4	21.9
Isthmus	68	4.4	33.8	38.2	41	2.4	26.8	29.2
Gills	20	20.0	65.0	85.0	20	40.0	45.0	85.0
Other					1	0	0	0

Table 3.—Effort, catch, catch by wound category, and percent dying for three lure types. Effort is the percent of the total gear-hours each lure type was fished. Catch is the percent of the total landings caught by each lure type. Wound category is the percent of the landings that occurred in a particular wound category; see text for wound locations included in each wound category.

	Lure type		
Item	Hootchie	Spoon	Plug
Effort	30	58	12
Catch	52	14	34
Wound category			
High mortality	5	8	2
Intermediate	62	60	53
Low mortality	33	32	45
Percent dying	20	22	14

graded condition 2 (severe injury), and 0.4 percent (4 fish) were assessed as dead at landing. Mortality of condition 1 fish subsequent to landing was 8.4 percent, significantly lower (χ^2 = 67.823, df = 1, P < 0.001) than the 29.5 percent mortality of condition 2 fish.

Total Hooking Mortality

When the maximum likelihood estimates of immediate and daily mortality rates were summed, the estimated total mortality was 18.3 percent for sublegal-size and 19.0 percent for legal-size fish (Table 4). The pattern of mortality over the 6-day holding period was similar for both size classes: High mortality the day of capture, declining to no mortality on day 6 (Table 4). The 95 percent confidence intervals for total mortality were 14.0–22.6 percent for sublegal-size fish and 15.5–22.5 percent for legal-size fish.

To recalculate the mortality estimates of Butler and Loeffel (1972) for chinook salmon of sublegal size, an estimate of delayed mortality was substituted for their assumption of no delayed mortality for maxillary-hooked fish. Only 25 sublegal-size fish were hooked in the maxillary in our study (Table 2), with no delayed mortality observed; therefore, fish with hooking injuries that resulted in low delayed mortality (maxillary, snout, or corner of the mouth) were pooled to derive a delayed mortality rate to substitute for the assumption of no delayed mortality in maxillary-hooked fish. There were five delayed deaths out of 144 sublegal-size fish in this group (Table 2), or 3.5 percent; weighted for the number of days held, the mortality rate is 4.2 percent. Wertheimer (1988) used the same wound locations, with the addition of cheek-hooked fish, in his assignment of hooking locations with low mortality. Mortality for cheek-hooked sublegal-size fish was in the intermediate range in our study, with a delayed mortality of 12.1 percent. If cheek-hooked fish are included in the pool of injury locations causing low mortality, delayed mortality was 5.1 percent (9 of 177) fish; weighted for the number of days held, the rate is 5.6 percent.

Equations (1) and (2) were used to estimate the numbers of delayed deaths for all injury locations reported in Table 5 of Butler and Loeffel (1972). If the 4.2 percent mortality rate observed for the low mortality category was substituted for the assumption of no delayed mortality, the recalculated delayed mortality was 17.2 percent. Total mortality, including the 8 percent immediate mortality reported for barbed hooks by Butler and Loeffel (1972) for this tag recovery data set, would then be 25.2 percent. If the 5.6 percent mortality rate observed when cheek-hooked fish are included in the low mortality category was used, the recalculated delayed mortality was 18.4 percent, and total mortality would be 26.4 percent.

Recalculation of data on tag recovery by condition for chinook salmon (Wright, 1970) was done similarly. The delayed mortality of 8.4 percent observed in our study for condition 1 fish was used to replace the assumption of zero mortality for "good" fish reported by Wright (1970). This mortality rate was for all sizes combined, because Wright's (1970) data included both legal- and sublegal-size fish. The recalculated estimate with this value was a total delayed mortality of 15.5 percent based on number of fish tagged. If an immediate mortality of 8 percent was assumed, delayed mortality was 14.2 percent based on number of fish landed, and total mortality was 22.2 percent.

Fish Size and Mortality

Mortality was not significantly associated with fish size in the 1987 data, however, Wertheimer (1988) did find a significant relationship in a 1986 study. When the data from both years were combined, there was a significant (P < 0.01) relationship identified by logistic regression between size and mortality (Table 5). If the combined data set was split into legal- and sublegal-size fish, there was a significant (P < 0.01) effect identified over the sublegal size range (27–65 cm), but not over the legal size range (66–106 cm). This indicated that the effects of fish size on mortality occurred in the sublegal size range.

Smoothed curves of mortality rate as a function of fish size pooled for 3 cm increments also indicated differences in mortality with size (Fig. 3). The data for both years pooled indicated a higher mortality rate for smaller fish, and then a rapid decline between 50 and 53 cm. Mortality rates continued to decline for the combined data until 62 cm, and then gradually increased with fish size.

The graphed representation of mortality rate as a function of fish size suggested that the significant inverse relationship between mortality and size identified by logistic regression for sublegal-size fish was due to two

Table 4.—Total numbers of chinook salmon caught and held for various time periods, numbers dying, and the maximum likelihood estimates of mortality. The standard deviation of the summed mortality is the sum of the variances for each time period, corrected for the covariance.

Size of fish and time period	Days in sample	No. of fish: Caught	Died	Maximum Likelihood est.: % mortality	SD
Legal-size fish					
Immediate	9	550	14	2.55	0.67
Day 1	9	550	69	12.55	1.41
Day 2	9	550	5	0.91	0.40
Day 3	9	550	5	0.91	0.40
Day 4	9	550	7	1.27	0.48
Day 5	6	371	3	0.81	0.47
Day 6	3	185	0	0.00	0.00
Total mortality				19.00	1.79
Sublegal-size fish					
Immediate	9	363	17	4.67	1.11
Day 1	9	363	41	11.26	1.66
Day 2	9	363	2	0.55	0.39
Day 3	9	363	1	0.27	0.27
Day 4	9	363	1	0.27	0.27
Day 5	6	249	3	1.24	0.72
Day 6	3	124	0	0.00	0.00
Total mortality				18.26	2.18

Table 5.—Logistic regression of mortality on fish size for chinook salmon hooked on commercial troll gear in 1987 (current study) and 1986 (Wertheimer 1988), for both data sets combined. Asterisks denote significant F values at P < 0.01 or P < 0.001***.**

Fish size (range, cm)	Approximate F to enter model	Regression coefficient
All (27–106)	7.15**	−.017
Legal (66–106)	0.72	
Sublegal (27–65)	12.42***	−.039

levels of mortality: High for fish < 53 cm, and low for fish > 53 cm. If the data were split around this 53 cm inflection point, maximum likelihood estimates of mortality for both 1986 and 1987 data showed that fish < 53 cm had the highest mortality rate, relative to both larger sublegal-size fish and legal-size fish (Table 6). When the data for both years were combined, the maximum likelihood estimate of moratality for fish < 53 cm was 28.3 percent, 1.62 times the 17.5 percent rate estimated for larger sublegal-size fish (Table 6). The mortality estimate for legal-size fish in 1986 and 1987 combined was 18.5 percent, 1.06 times the rate of the larger sublegal size category. Note that the estimates from the combined data were in some cases slightly outside the range of the estimates for each year; this was due to the effects of sample size in the estimation of daily mortality increments, especially where small samples had been heavily weighted in the uncombined data. In the combined data sets, estimated mortality of legal-size fish was 85 percent of the estimated sublegal-size rate.

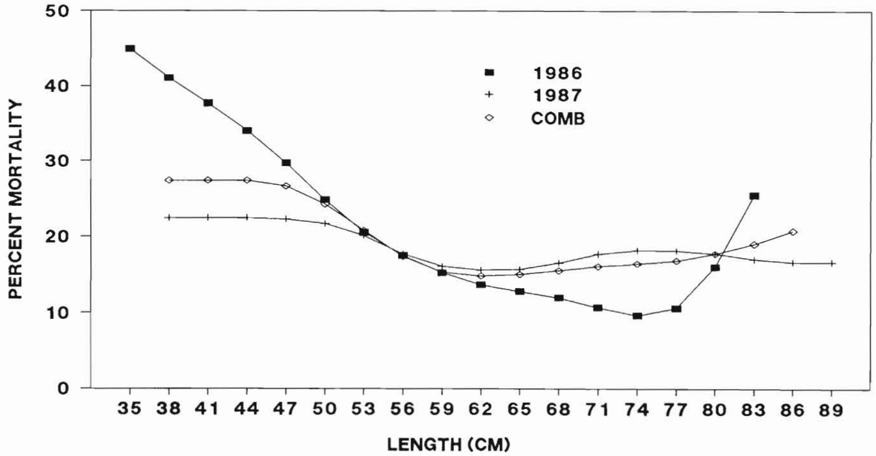

Figure 3.—Hook and release mortality as a function of fork length for chinook salmon caught on commercial troll gear in 1986, 1987, and both years combined. Data were smoothed twice with the 4253H algorithm (Velleman and Hoaglin, 1981). End points of the curves incorporate observations outside the range shown.

Table 6.—Mean size and observed mortality (weighted for time held) of legal- and sublegal-size chinook salmon caught in 1986 and 1987. Sublegal-size fish were partitioned into two groups based on the inflection point of 53 cm observed in Figure 3. Numbers in parentheses are the 95 percent confidence intervals for mortality estimates. Data for 1986 are from Wertheimer (1988).

	Legal (>65 cm)		Sublegal (<66 cm)		Sublegal (<53 cm)		Sublegal (53–65 cm)	
Year	Mean (cm)	Mortality (%)	Mean (cm)	Mortality (%)	N	Mortality (%)	N	Mortality (%)
1986	73.5	20.5 (9.0-31.9)	52.0	24.5 (20.1-29.0)	200	32.4	198	16.8
1987	72.9	19.0 (15.5-22.5)	56.0	18.3 (14.0-22.6)	93	20.4	270	17.4
Combined		18.5 (15.4-21.6)		21.7 (18.6-24.8)	293	28.3	468	17.5

Discussion

Observed mortality rates in this study were lower for both legal- and sublegal-size chinook salmon than those reported in a similar study by Wertheimer (1988). The 95 percent confidence intervals overlapped in both studies for both size classes, indicating the differences may be due to chance. Two other factors that may have contributed to lower mortality rates were size distribution of the catch and lure type.

Size distribution of the sublegal-size fish changed considerably between 1986 and 1987. In 1986, 50 percent of the sublegal-size fish were < 53 cm FL, and in 1987, only 26 percent of the sublegal-size catch was < 53 cm FL (Table 6). However, mortality within this size category was considerably lower in 1987 than 1986, so size distribution alone cannot explain the differences observed between years.

A substantial shift was also observed between 1986 and 1987 in the proportion of fish caught by the three lure types fished. Because there were differences in mortality associated with lure type, this shift may have contributed to the lower mortality rate. The mortality rates of the different lure types were not consistent between years. Although the highest proportion of fish that died in both years had been caught with spoons, this proportion decreased from 31 percent in 1986 (Wertheimer, 1988) to 22 percent in 1987 (Table 3).

The proportion of fish that died changed between years for those caught with hootchies and plugs, increasing from 13 percent in 1986 to 20 percent in 1987 for hootchies, and decreasing from 26 percent in 1986 to 13 percent in 1987 for plugs. The fish may attack the lure types disproportionately and with different levels of aggression depending on the lure depth, water clarity, and prey species composition and density. This variability in the mortality caused by a specific lure type probably contributed to the differences in total mortality observed between years. One conclusion from this interannual variability in mortality by lure type is that none of the three lure types could be conclusively identified as minimizing mortality.

Do the observed mortality rates adequately represent the rates that actually occur in a commercial troll fishery, or are the results biased by the experimental techniques? Wertheimer (1988) examined potential sources of bias in a similar enclosure study, and argued that the close agreement of the observed rates and mortality estimates recalculated from previous tagging studies validated the experimental estimates. In our study, the observed rates over the 6-day holding period were considerably lower than the recalculated rates. The two most important potential sources of bias identified by Wertheimer (1988) were: 1) The stress of handling and holding the fish increased mortality and resulted in an overestimate of the true rate, and 2) mortality due to hooking injuries continued after the duration of the holding period and resulted in an underestimate of the true rate.

The stress of electric shock, tagging, transfer to live tanks, and holding in net pens could have increased mortality. Fry and Hughes (1951) found that holding troll-caught chinook salmon in small live tanks decreased tag recovery rates and Wertheimer (1988) found that longer holding time was associated with increased mortality. Ellis (1964) concluded that holding fish for extended periods in live tanks contributed to the high mortality rates reported for troll-caught chinook salmon by Parker and Black (1959). In our study, there was no indication that length of holding time was related to mortality. Wertheimer (1988) reviewed evidence that the other handling factors listed above do not directly cause mortality; however, these factors could contribute to higher mortality for fish that are already severely stressed by the hooking injury. In our study, fish that were noted to have suffered severe or extraordinary handling stress did not have higher mortality than the rest of the fish sampled. Because increased stress did not result in increased mortality, we concluded that the hooking injury itself, as indicated by the close association of wound location and mortality, was the primary cause of the mortality we observed.

Another possible bias to the observed mortality rates was that mortality was not complete at the end of the holding period. Most mortality occurred by the end of the day the fish were hooked. However, there were fish alive at the end of the 4–6 day holding period that were observed swimming sluggishly with severe injury, typically with an eye torn out or destroyed by hooking. Forty percent of the fish caught in this study that were hooked in the eye or through the orbit of the eye had the eye punctured or torn out. Not all the fish wounded in this way die prior to being caught in a fishery.

We observed three chinook salmon caught during the course of this study with only one functioning eye; we assumed the other eye had been destroyed by a previous hooking incident as the socket was filled with scar tissue. Even though some of these severely injured fish do survive, the probability of their survival has certainly been reduced relative to uninjured fish; therefore we must assume that hooking mortality for fish in this wound category was not complete at the end of the study period.

The recalculation of the tag recovery data of Butler and Loeffel (1972) and Wright (1970) offered a method of estimating total mortality without some of the biases inherent in the original estimates derived from the tag recovery data or identified in our estimates. The recalculated values were based on observed mortality rates for certain categories of fish observed in our study, which replaced the assumption of no delayed mortality for these groups in the original estimates. The estimates based on tag recovery data have no bias due to the incomplete delayed mortality of some severely wounded fish, because the estimate is based on fish surviving until recapture or escapement. The immediate mortality rate used in the recalculated estimate was conservatively high; the 8.0 percent rate used is at the high end of the range of values reported for fish dead at landing (Wright, 1970; Horton and Wilson-Jacobs, 1985), and considerably higher than our observations.

The recalculated estimates of mortality agreed closely for our study and Wertheimer (1988). Our estimates were 25–26.4 percent and 22.2 percent, based on injury location and condition, respectively. Estimates by Wertheimer (1988) were 25.7 percent based on injury location and 23.5 percent based on condition. We think that the use of injury location to determine relative mortality rates is well founded, because of the consistent significance in association between mortality and anatomical hooking site found for a variety of fish species, including chinook salmon in our study and in Butler and Loeffel (1972); coho salmon in Butler and Loeffel (1972); Atlantic salmon, *Salmo salar*, in Warner (1979); lake trout, *Salvelinus namaycush*, in Loftus et al. (1988); and largemouth bass, *Micropterus salmoides*, in Pelzman (1978). The assessment of condition at landing may be more subjective and prone to variability between observers (Wertheimer, 1988) than assessment of injury location.

To place a range on the estimates based on wound location, we examined how the assumptions regarding observed delayed mortality affected the point estimates of total mortality. The estimates of total hooking mortality of sublegal-size chinook salmon based on the injury location varied from 25.7 percent in 1986 (Wertheimer, 1988) to 25.2–26.4 percent in 1987. The variation in these point estimates depended on which injury locations were used to represent delayed mortality of maxillary-hooked fish, the group with the highest tag recovery rate (Butler and Loeffel, 1972). The observed mortality rates used were conservatively high in that the stress of handling and holding the fish may have increased the observed values to some unquantified degree. If all delayed mortality observed for these groups was due to stress, and no delayed mortality for maxillary-hooked fish was assumed, the correctly calculated estimate of total mortality is 22.1 percent (Wertheimer, 1988), the minimum rate that can be calculated from the tag recovery data. Conversely, the 26.4 percent estimate can be considered a maximum rate. It incorporates any bias due to handling and holding stress, and uses the observed delayed mortality of several injury locations as a conservatively high estimate of the delayed mortality of maxillary-hooked fish. We conclude that the total hooking mortality of sublegal-size chinook salmon is in the range of 22.1–26.4 percent, and that a point estimate of about 26 percent is a realistic and conservatively high estimate of the actual rate.

Based on the lower incidence of dead and seriously injured legal-size chinook salmon relative to that for sublegal-size fish, several authors have concluded that larger chinook salmon suffer lower mortality when hooked and released from commercial troll gear (Parker and Kirkness, 1956; Loeffel, 1961; Davis et al., 1986). In a study using the same methodology as in our study, Wertheimer (1988) observed lower hooking mortality for legal-size chinook salmon and found a significant inverse relationship between fish size and mortality. In contrast, Fry and Hughes (1951) found no difference in tag recovery rates relative to size of chinook salmon tagged, and there was no relationship between size and mortality in our study. When we combined our results with those of Wertheimer (1988), however, there was a significant inverse relationship between size and mortality. This relationship was primarily due to higher mortality of small sublegal-size fish (< 53 cm); there was no significant relationship between size and mortality for chinook salmon larger than the legal size limit. Although there was not uniform consistency among the studies cited, these combined data do indicate that sublegal-size chinook salmon suffer higher hooking mortality than legal-size fish.

We assigned a range of values for the total mortality of legal-size chinook salmon by examining our results in perspective to the biases affecting them. Based on the conclusion that sublegal-size fish have a higher mortality rate, mortality of legal-size chinook salmon should not exceed 26.4 percent, the upper end of the range assigned to the sublegal-size fish. A minimum estimate was the 18.5 percent total hooking mortality we calculated by combining the 1986 and 1987 data for legal-size fish held in net pens (Table 6). This minimum estimate does not account for additional delayed mortality occurring after the holding period, the principal source of bias we identified in such estimates. The mortality for legal-size chinook salmon held in the net pens was 85 percent of the estimate calculated for sublegal-size fish from the combined 1986 and 1987 data. By applying this factor to the 26 percent rate that we presented as a realistic, conservative estimate of total hooking mortality for sublegal-size chinook salmon, we derived a rate of 22.1 percent.

We think this rate is a realistic point estimation of total hooking mortality for legal-size chinook salmon because 1) it is consistent with the conclusion that mortality for legal-size fish is lower than that of sublegal-size fish, 2) it is consistent with the conclusion that there is some degree of additional delayed mortality above the 18.5 percent total mortality estimated from the pen studies, 3) it is based on an observed relationship between the hooking mortality of legal- and sublegal-size chinook salmon, and 4) it falls at the mid-point of the 18.5–26.4 percent minimum-maximum range we derived. We conclude that the hooking mortality of legal-size chinook salmon caught and released from commercial troll gear falls within the range of 18.5–26.4 percent, and that a reasonable point estimate is 22.1 percent.

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