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Hooking Mortality of Chinook Salmon Released by Commercial Trollers

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Abstract.—Immediate and short-term (1–5-d) hooking mortality associated with the incidental catch of chinook salmon *Oncorhynchus tshawytscha* was assessed during periods when troll fishing for that species (only) was prohibited. Two chartered power trollers fished their normal complements of gear directed at coho salmon *O. kisutch* in Hawk Inlet, southeastern Alaska. Wound location, fork length, and lure type were the factors principally associated with mortality of incidentally caught chinook salmon. Severity of the hooking wound was also related to mortality. Maximum-likelihood estimates (with 95% confidence intervals in parentheses) of total mortality were 24.5% (20.1–29.0%) for sublegal-sized (<66 cm fork length) chinook salmon and 20.5% (9.0–31.9%) for legal-sized chinook salmon. The delayed-mortality rates were used to recalculate hooking mortality estimates from previous tagging experiments in which it was assumed that no delayed mortality occurred for certain locations and severities of wounds. The recalculated estimate of total hooking mortality for sublegal fish, based on wound location, was 25.7%. The recalculated estimate of total hooking mortality for legal and sublegal fish, based on wound severity, was 23.5%.

Minimum-size restrictions to protect young age-classes are common for hook-and-line fishing directed at chinook salmon *Oncorhynchus tshawytscha*. In the commercial troll fishery in southeastern Alaska, for example, chinook salmon less than 71 cm long (sublegal fish) must be released. Some mortality is associated with the hooking and release of sublegal fish in these fisheries. Recently, there has been an increase in the number of closures of the chinook salmon (only) troll fishery. During such periods, trolling is directed primarily at coho salmon *O. kisutch*, and incidentally captured chinook salmon must be released. Fisheries managers require mortality estimates for released fish to assess the effectiveness of these closures for protecting chinook salmon.

Estimates of hooking mortality for chinook salmon vary widely. Immediate-mortality estimates range from 2.5% (Van Hyning 1951) to 10.6% (Davis et al. 1986), whereas estimates that include both immediate and delayed mortality range from 11.8% (Butler and Loeffel 1972) to 71% (Parker and Black 1959). Reviewers of published and unpublished data on hooking mortality of chinook salmon have proposed estimates of 30% (Wright 1970), 38% (Horton and Wilson-Jacobs 1985), and 50% (Ricker 1976).

The wide variations in the estimates may be due to biases associated with different experimental approaches, but this cannot be quantified because of the lack of experimental controls. The lowest hooking-mortality estimates (11.8–12.0%) are from tagging studies in which fish with certain superficial injuries were assumed to suffer no delayed mortality; investigators used tag recovery rates of these fish to calculate delayed mortality for all injury categories (Wright 1970; Butler and Loeffel 1972). Estimates like these are negatively biased if fish with superficial injuries suffer delayed mortality.

Mortality estimates based on the investigator's judgement of whether or not a fish has been mortally wounded are higher than those calculated from immediate mortality (12–31%; Wright 1970), but these, too, may be biased. Chinook salmon with severe wounds have been subsequently recovered in tagging experiments (Wright 1970; Butler and Loeffel 1972), and fish with superficially minor injuries may suffer delayed mortality. Mortality rates up to 71% have been reported for fish with apparently minor injuries when the fish were held for several hours in live tanks aboard a fishing vessel (Parker and Black 1959). These deaths were attributed to lactic acid accumulation caused by hyperactivity while the fish fought the troll gear (Parker et al. 1959). Ellis (1964), however, concluded that just holding fish for extended periods may stress the fish, causing lactic acid buildup and high mortality.

Previous estimates of hooking mortality of chinook salmon included sublegal fish only or all fish sizes together. The limited information on mortality rates of chinook salmon relative to size indicates that larger fish are not as severely affected by hooking as smaller fish (Parker and Kirkness 1956; Loeffel 1961; Davis et al. 1986). However, Fry and Hughes (1951) found no size-related differences in recoveries of tagged chinook salmon.

The main objective of this study was to determine immediate and short-term (1–5-d) mortality rates of chinook salmon hooked and released from commercial trolling gear typical of the gear used in coho salmon fishing. Secondary objectives were to examine the association of mortality with wound location and to make a qualitative assessment of wound severity so that observed rates of delayed mortality could be used to refine mortality estimates from previous tagging studies.

Methods

Gear.—Two power trollers were chartered to fish for two 5-d periods, 11–20 August 1986, at Hawk Inlet in southeastern Alaska. This site was chosen because of its accessibility, the availability of mooring sites for a large net-pen, and the high catch rates of chinook salmon during previous trolling research in the area. Vessel 1 was a 13.7-m troller rigged with bow poles to separate the forward and aft trolling lines, and vessel 2 was a 14.3-m troller rigged with float bags to separate the lines. Four wire lines with 8–10 individual lures per line were used. To simulate fishing during chinook salmon closures, the operators fished their normal complement of coho salmon gear, including hootchies (imitation squid) with flashers, spoons, and plugs; the selection of colors and relative proportions of the lures deployed was varied by the operators. Hook size was limited to 6/0 barbed, single hooks. Operators were instructed to operate the gear in their normal manner. Typically, all lines were checked if a strike was detected on one or more lines, or when a complete circuit of the fishing area had been made.

Processing the catch.—Techniques for boating fish differed between vessels because of differences in vessel design. When a chinook salmon was caught, it was placed in an electrically charged basket (Orsi and Short 1987) to stun the fish. On vessel 1, fish were lifted from the water by the leader before being placed in the electric basket. On vessel 2, they were led to the electric basket, which was in the water, and simultaneously lifted and stunned. Operators removed the hook in their normal manner by inserting a gaff into the curve of the lure hook and turning the gaff so that the weight of the fish pulled it free of the lure. An observer noted the lure type, depth fished, and location of the wound, and rated the severity of the wound by the Alaska Department of Fish and Game troll observer criteria (Davis et al. 1986). Condition 1 denotes a minor injury, including hooking injuries near the outer portion of the mouth and little or no bleeding. Condition 2 denotes a serious injury, including hooking injuries in or near the gills or eyes and severe bleeding. Condition 3 denotes a dead fish. Fork lengths of fish were measured to the nearest centimeter. On the basis of conversions given by Van Hyning (1951), a fork length of 66 cm was considered equivalent to a total length of 71 cm, the legal size limit. Fish were marked with numbered Floy anchor tags. Average processing time was less than 45 s.

Each fish was placed in a 175-L covered live tank with flowing seawater until it was transferred with a large dip net (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; this was accomplished by pouring the contents of the live tank into the pen. Transfer time from capture until placement in the net-pen varied from 7 to 60 min and averaged 22 min. Transfer times tended to be longer in poor weather, but this was compensated for by keeping the trollers closer to the net-pen.

The net-pen, constructed of 2.5-cm knotless nylon mesh suspended from a float frame, had a total volume of 1,700 m^3, a depth of 12 m, and an area of 142 m^2 defined by eight sides that were alternately 9.1 and 2.2 m long. This design eliminated the blind tunnels that can form in the corners of square or rectangular net-pens. The pen was checked by divers at the end of each fishing day; dead fish were removed and their tag numbers were recorded. At the end of five fishing days, all fish in the pen were released.

Temperature and salinity profiles in the holding net were determined five times over the course of the experiment with a conductivity–temperature probe. A temperature and salinity profile also was determined on the fishing grounds with a single bathymetric cast of a recording conductivity–temperature instrument.

To test the hypothesis that "stunned" fish are frequently killed by predators, some chinook salmon dead at landing were returned to the water after being tied to a 30-m-long, 6-mm diameter line attached to a buoy. The line used was alternately either yellow polypropylene with slight positive bouyancy or brown nylon with slight negative bouyancy. The buoy was retrieved by a skiff operator, when convenient, after a minimum of 20 min.

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

$$e^u/(1 + e^u); \tag{1}$$

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 ($P < 0.05$). At each step of the regression, the BMDPLR program computed goodness-of-fit tests. Two stepwise regression analyses were performed, based on when mortality occurred. In the first, all deaths were included; in the second, fish dead at landing were excluded from the model. Lure type was not recorded for 45 chinook salmon. Observations with missing values were excluded from the stepwise regression analysis.

The G-test for independence (Sokal and Rohlf 1981) was used to examine the relationship between severity of the hooking wound and subsequent mortality between vessel and number caught by size category, and among vessel, lure type, and mortality.

Mortality rates were determined for each of six time periods: immediate (fish dead at landing or at the time of transfer to the pen) and at the end of fishing days 1–5. The BMDP3R nonlinear regression program (Dixon et al. 1983) was used to generate maximum-likelihood estimates and asymptotic standard deviations for each time period, as well as the correlation matrix for the estimates. The maximum-likelihood estimates usually are distributed about the true value of the parameter, which is close to the mean for large samples (Mood and Graybill 1963). The total mortality is the sum of mortality estimates for individual time periods. The variance of this estimate is the sum of the variances for individual time periods plus the off-diagonal sum of the variance–covariance matrix (Mood and Graybill 1963):

$$V\left(\sum_{i=1}^{6} \hat{P}_i\right) = \sum_{i=1}^{6} V\hat{p}_i + 2 \sum_{i} \sum_{j} \text{cov}(\hat{p}_i; \hat{p}_j);$$

$\hat{p}_i$ is the estimated mortality rate for the ith period and j denotes a period after i. The variance calculations derived from BMDP3R were confirmed by calculating the variance–covariance matrix with a separate program.

To recalibrate the estimates of delayed mortality based on the tag recovery data reported by Wright (1970) and Butler and Loeffel (1972), who assumed there was no delayed mortality for the groups with the highest tag recovery rates, I applied mortality rates from the present study. The earlier investigators calculated a recapture coefficient (r) for fish with the lowest wound severity (Wright 1970) or for fish hooked in the maxillary (Butler and Loeffel 1972):

$$r = n/N'; \tag{2}$$

n is the number of recaptures, and N' is the number of tagged fish released. In using this equation, one assumes delayed mortality is 0. To calculate r when delayed mortality is some other value, the equation is

$$r = n/(N' - D); \tag{3}$$

D is N' times the delayed mortality rate. Once r has been recalculated, the number of deaths due to delayed mortality in a particular category can be determined by

$$D_k = N_k' - (n_k/r); \tag{4}$$

k is a particular condition or wound location. Delayed mortality for category k is then D_k divided by N_k'. (Delayed mortality expressed as the proportion of the fish landed would be D divided by N; $N = N' + I$, and I is the number of immediate deaths.)

Wright's (1970) calculations are equivalent to equations (2) and (4), although his terminology is not identical. However, Butler and Loeffel (1972) calculated the number of delayed deaths by

$$D_k = r(N_k - I_k) - n_k. \tag{5}$$

This equation is incorrect; the number computed was actually the number of fish that would have been expected to be recovered from the fish that died, $r \cdot D_k$. Thus, it was necessary to recalculate the original values for delayed mortality given in Butler and Loeffel (1972).

Results

Altogether, 108 legal and 398 sublegal chinook salmon were caught and landed. The catch of legal chinook salmon was similar between boats: 52 for vessel 1 and 56 for vessel 2. Vessel 2 caught 239 sublegal chinook salmon, 36% more than the 159 caught by vessel 1; however, this difference was not statistically significant (chi-square; $P > 0.10$).

Ninety-six percent of the legal and 93% of the sublegal fish were caught at depths greater than 12 m. Only 6% of the legal and 3% of the sublegal fish were caught at depths greater than 35 m. Once in the holding pen, fish in good condition primarily used the lower half of the pen, whereas severely injured fish swam slowly at the surface or along the pen margins, or lay quiescently on the bottom.

Temperature decreased and salinity increased with depth in both the net-pen and fishing area. Temperatures in the net-pen were 10.3°C at 5 m and 9.0°C at 12 m, the depths where most of the fish remained. Temperatures where most fish were caught in the fishing area decreased from 9.3°C at 12 m to 6.5°C at 35 m. Salinity increased from 29.3‰ at 5 m to 30.7‰ at 12 m in the net, and from 29.8‰ at 12 m to 31.1‰ at 35 m in the fishing area.

Effect of Predation

Of the 506 chinook salmon captured, one had a fresh predator wound, probably received while hooked. Twenty-six dead fish were tethered to a buoy and allowed to drift or sink for an average of 31 min. None of these fish were damaged or removed by predators even though Stellar's sea lions *Eumetopias jubatus*, harbor seals *Phoca vitulina*, bald eagles *Haliaetus leucocephalus*, and glaucous-winged gulls *Larus glaucescens* were frequently observed in the fishing area.

Variables Affecting Mortality

Three variables—length, injury location, and lure type—were significantly associated with mortality both when all observed mortality was included in the analysis and when immediate mortality was excluded (Table 1). These variables were also significantly associated with mortality in both analyses when no other variables were in the logistic regression model (Table 1). Vessel did not enter the regression model in either analysis but was significantly related to delayed mortality if other variables were excluded. Transfer time entered the model when it was considered a variable but was not significant when other variables were excluded (Table 1).

The relationship between fork length and mortality was obvious when the fish were grouped by legal and sublegal categories. Ninety-four (23.6%) of the 398 sublegal fish died over the course of the study, and only 14 (13.0%) of the 108 legal fish died.

TABLE 1.—Summary of stepwise logistic regression analyses of chinook salmon mortality after fish were hooked. Analysis 1 included all observations of mortality in the model; analysis 2 excluded observations of immediate mortality from the regression model and included transfer time as an independent variable. Asterisks denote $P \leq 0.05$* or $P \leq 0.01$**.

Variable	Approximate F, no other variables in model	Improvement chi-square
	Analysis 1	
Fork length	18.30**	18.91**
Injury location	16.55**	106.43**
Lure type	12.01**	31.87**
Vessel	2.21	
Lure depth	1.53	
	Analysis 2	
Fork length	15.53**	18.13**
Injury location	11.92**	82.56**
Lure type	14.26**	26.91**
Time	1.52	4.88*
Vessel	6.47*	
Lure depth	0.95	

In both size categories, fish hooked in the gills had the highest total mortality (Table 2). Further comparisons were not meaningful for legal fish because of the small sample size. Among sublegal fish, the total mortality rates, based on hooking location (exclusive of tongue and "other," for which there were few observations) were lowest for snout, maxillary, corner of the mouth, and cheek; intermediate for lower jaw, isthmus, and eye area; and highest for gills (Table 2). Postmortem examinations of 18 fish (total number dead at landing or removed from the net-pen during 2 d of the study) revealed that these fish incurred some gill injury although not all were so classified by the on-board observer. The original assessments were wounds to gills (8), eye (5), lower jaw (4), and isthmus (1).

The predominant lure types that caught both size-classes of fish were hootchies on vessel 1 and spoons on vessel 2 (Table 3). The numbers of fish captured by lure type were significantly different ($P < 0.05$) between vessels for both legal and sublegal fish. This difference between vessels was probably due to differences in the proportions of lure types fished, which were not measured. Because of the low expected values for fish caught on plugs, differences in mortality between vessels and lure type were tested only for sublegal fish caught on hootchies or spoons. Mortality significantly differed between these lure types ($P < 0.05$) but not between the vessels.

TABLE 2.—Total catch and subsequent mortality by hooking location and size-class of chinook salmon. I = immediate mortality; numbers 1–5 indicate number of days in pen. Delayed mortality shown is total number of deaths minus immediate deaths, divided by total number captured; it is not weighted for smaller sample size associated with longer holding periods. Sublegal fish were smaller than 66 cm fork length.

Hooking location	Total catch	Number of deaths by day in net-pen						Mortality (%)		
		I	1	2	3	4	5	Immediate	Delayed	Total
					Sublegal fish					
Snout	22	1	0	0	0	0	0	4.5	0.0	4.5
Maxillary	34	0	2	0	0	0	0	0.0	5.9	5.9
Corner of mouth	52	2	2	0	0	0	0	3.8	3.8	7.6
Cheek	53	3	3	0	0	0	0	5.7	5.7	11.4
Lower jaw	90	6	12	1	1	1	0	6.7	16.7	23.4
Tongue	4	0	1	0	0	0	0	0.0	25.0	25.0
Isthmus	35	5	4	0	0	0	0	14.3	11.4	25.7
Eye, orbit of eye	73	8	10	1	0	0	0	11.0	15.1	26.1
Gills	33	15	15	0	0	0	0	45.4	45.4	90.8
Other	2	0	1	0	0	0	0	0.0	50.0	50.0
					Legal fish					
Snout	2	0	1	0	0	0	0	0.0	50.0	50.0
Maxillary	10	0	0	0	0	0	0	0.0	0.0	0.0
Corner of mouth	13	0	1	0	0	0	0	0.0	7.7	7.7
Cheek	13	0	0	0	0	0	0	0.0	0.0	0.0
Lower jaw	20	0	1	0	0	0	0	0.0	5.0	5.0
Tongue	0									
Isthmus	3	0	0	0	0	0	0	0.0	0.0	0.0
Eye, orbit of eye	38	1	2	1	0	0	2	2.6	13.2	15.8
Gills	9	3	1	0	0	1	0	33.3	22.2	55.5

Wound Severity and Mortality

For vessels and size-classes, substantially more severely wounded fish died than slightly wounded fish (Table 4). Size-classes had to be combined to statistically compare mortality between wound-severity classifications. For both vessels, severely wounded fish had significantly higher mortality ($P < 0.05$). There also was a significant difference between vessels in the proportion of fish assigned to the wound-severity categories: 66% of the fish were graded slightly wounded on vessel 2 versus 31% on vessel 1 (Table 4). The observer on vessel 1 made a more detailed survey of the fish, noting wound severity as he measured and tagged the fish and taking into consideration the amount of bleeding in the live tank. The observer on vessel 2 made his assessment as each fish was removed from the hook. The observations from vessel 2 were more consistent with the observations of wound severity at release made by troll observers during chinook salmon closures in the Alaska troll fishery (Davis et al. 1986).

TABLE 3.—Chinook salmon catch and mortality by vessel, lure type, and size-class (sublegal fish were smaller than 66 cm fork length).

Vessel	Lure type	Number of fish caught	Landings (%)	Mortality (%)
		Sublegal fish		
1	Hootchie	108	78.3	13.0
	Spoon	25	18.1	36.0
	Plug	5	3.6	20.0
2	Hootchie	97	42.2	13.1
	Spoon	125	54.3	36.8
	Plug	8	3.5	25.0
		Legal fish		
1	Hootchie	30	69.8	13.3
	Spoon	5	11.6	20.0
	Plug	8	18.6	25.0
2	Hootchie	20	40.0	5.0
	Spoon	28	56.0	3.6
	Plug	2	4.0	50.0

TABLE 4.—Total catch and mortality weighted by days held of chinook salmon by size-class, vessel, and condition. Conditions 1 and 2 are minor injuries and serious injuries, respectively. Sublegal fish were smaller than 66 cm fork length.

Condition	Vessel 1		Vessel 2	
	Catch (number)	Mortality (%)	Catch (number)	Mortality (%)
		Sublegal fish		
1	12	0.0	33	3.3
2	38	28.2	23	32.9
		Legal fish		
1	54	0.0	162	15.3
2	94	21.9	69	47.2

If only the observations for vessel 2 were considered, mortality still was significantly different between wound-severity classifications ($P < 0.05$). Again, sample sizes required pooling the size-classes to compare the classifications. These pooled values are 13.3% mortality for slightly wounded and 43.6% mortality for severely wounded fish.

Total Hooking Mortality

When maximum-likelihood estimates of immediate and daily mortality rates were summed, the estimated total mortality was 24.5% for sublegal and 20.5% for legal fish (Table 5). The cumulative mortality over a 5-d period differed distinctly between size-classes. The rate for sublegal fish appeared to be approaching an asymptote, whereas mortality increased on days 4 and 5 for legal fish. This increase in mortality for legal fish was based on the deaths of only three fish that were weighted heavily because of small sample size (Table 5); this weighting also caused the estimate of total mortality to be considerably higher than the 13% of the legal catch that died during the study. The 95% confidence intervals for total mortality were 9.0–31.9% for legal fish and 20.1–29.0% for sublegal fish. The wide confidence interval for legal fish was due to the small sample size and variability of mortality for fish held 4–5 d.

Recalculation of Previous Mortality Estimates

To recalculate the mortality estimates of Butler and Loeffel (1972) for sublegal chinook salmon, a positive estimate of delayed mortality was used instead of the 0% delayed mortality assumed by those authors for maxillary-hooked fish. Few (34) fish were hooked in the maxillary (Table 2); therefore, fish with hooking injuries that resulted in low delayed mortalities (maxillary, snout, corner of the mouth, and cheek wounds) were pooled to derive a delayed-mortality rate applicable to maxillary-hooked fish. Of the 161 fish in these categories, 7 fish died (Table 2); the estimated delayed mortality was 4.3%, and the binomial 95% confidence interval was 1.2–7.5%. Pooling these fish seemed reasonable because (1) in the study by Butler and Loeffel (1972), tagged fish injured in locations other than the maxillary were recovered at lower rates than maxillary-hooked fish; (2) the confidence range of the pooled estimate included the delayed-mortality rate (5.9%) for the 34 fish hooked in the maxillary; and (3) no fish in the low-mortality category died after the day of capture (Table 2), indicating that delayed mortality due to hooking had been completely expressed for this group of fish.

TABLE 5.—Total numbers of chinook salmon caught and held for various time periods, numbers dying, and maximum-likelihood estimates of mortality. Sublegal fish are smaller than 66 cm fork length.

Time period	Number of days in sample	Number of fish: Caught	Number of fish: Died	Maximum-likelihood estimate: Mortality (%)	Maximum-likelihood estimate: SD
		Sublegal fish			
Immediate	10	398	40	10.0	1.51
Day 1	10	398	48	12.0	1.63
Day 2	8	323	4	1.2	0.61
Day 3	6	201	1	0.5	0.49
Day 4	4	131	1	0.8	0.77
Day 5	2	54	0	0.0	0.00
Sum			94	24.5	2.29
		Legal fish			
Immediate	10	108	4	3.7	1.81
Day 1	10	108	5	4.6	2.01
Day 2	8	93	2	2.1	1.50
Day 3	6	65	0	0.0	0.00
Day 4	4	48	1	2.2	2.12
Day 5	2	30	2	7.9	4.82
Sum			14	20.5	5.85

Equation (4) was used to estimate the numbers of delayed deaths for each injury location, based on the tag recovery data reported in Table 5 of Butler and Loeffel (1972). When the correct equation was used, overall delayed mortality, expressed as a percentage of fish landed, increased from Butler and Loeffel's 5.1% to 14.1%, still with an assumed 0% delayed mortality for maxillary-hooked fish (Table 6). With incorporation of 4.3% delayed mortality for these fish, estimated delayed mortality for all groups rose further to 17.7% (Table 6). To complete the recalculation of Butler and Loeffel's (1972) data, their observation of 8.0% immediate mortality for 1,066 sublegal chinook salmon caught on barbed hooks was added to the delayed mortality estimate to arrive at an estimated total mortality of 25.7%.

Recalculation of the data reported by Wright (1970) for tag recovery by condition category for chinook salmon was carried out in a similar manner. In this case, the delayed-mortality rate of 9.9% observed for slightly wounded legal and sublegal fish caught by both vessels (Table 4) was used to replace the zero mortality for "good" fish assumed by Wright (1970). The resulting estimate was a total delayed mortality of 16.8%, based on the number of fish released. When an 8% immediate mortality was assumed, delayed mortality was

TABLE 6.—Total catch and delayed mortality rates of sublegal chinook salmon (<66 cm fork length) by hooking location, based on tag recovery data reported by Butler and Loeffel (1972). Shown are the original rates reported by these researchers with the assumption that delayed mortality for maxillary-hooked fish was 0, the correct calculation of these values, and the recalculated rates incorporating 4.3% delayed mortality of maxillary-hooked fish.

		Delayed mortality					
		Original		Corrected		Recalculated	
Hooking location	Total caught	Number	%	Number	%	Number	%
Snout	234	6	2.6	17	7.3	26	11.1
Corner of mouth	444	27	6.1	75	16.9	90	20.3
Maxillary	280	0		0		12	4.3
Eye	158	33	20.9	91	57.6	94	59.5
Gills	55	7	12.7	21	38.2	22	40.0
Tongue	23	1	4.3	2	8.7	3	13.0
Cheek	442	11	2.5	31	7.0	48	10.6
Lower jaw	324	11	3.4	30	9.3	43	13.3
Isthmus	119	9	7.6	26	21.8	29	24.4
Combined	2,079	105	5.1	293	14.1	367	17.7

15.5%, based on the number of fish landed, and total mortality was 23.5%.

Discussion

Potential Sources of Bias

Are the mortality rates observed in this study representative of the mortality that actually occurs during a commercial troll fishery? Certain factors inherent in the study may have biased the observed rates. As in previous studies on hooking mortality, it was not possible to maintain a control group. Therefore, it is necessary to examine the degree and direction of the potential sources of bias.

During this study, each fish was landed and then stunned in an electronarcosis basket prior to removal of the hook. In an actual troll fishery, the hook is removed while the fish is either partially or completely out of the water. On one study vessel, the fish was lifted out of the water to the boat by the leader; on the other vessel, it was lifted out in the basket. These two techniques represent the extremes in the way a fish is normally handled when it is being released by a commercial fishing operator: some operators remove the hook without lifting the fish from the water, but others must first lift the fish out by the leader. However, there was no difference in mortality between vessels for a given lure type, suggesting that differences in release methodology are not important factors influencing mortality.

If released fish are likely to be attacked by predators before they recover from the shock of hooking, then holding the fish during this study reduced mortality and biased the results. None of our dead fish tethered to simulate stunned fish were damaged or removed by predators, however. A hooked fish is probably more at risk of predator attack than one that is floating or sinking because it is among an array of lures that may attract a predator, and its struggling against the hook and line gives visual and vibrational cues for a potential predator. Only one (0.2%) chinook salmon caught during this study was bitten by a predator. From 1978 to 1981, troll fishermen in southeastern Alaska reported that 0.6–1.9% of their catch of coho salmon and chinook salmon was mutilated by predators (Krygier 1982). Fishermen who encounter high predation, which is typically a localized problem, minimize it by moving to another area (Krygier 1981). These observations do not mean that dying or severely damaged fish are not more susceptible to predation than uninjured fish. They do suggest that fish with minor injuries are not normally exposed to immediate predation mortality that we avoided by holding the fish.

Electronarcosis, tagging, transfer, and holding may stress the fish enough to increase mortality. However, evidence indicates that electronarcosis, tagging, and holding the fish in net-pens do not cause mortality. No deaths occurred among 50 pen-reared chinook salmon that were hooked on sportfishing gear, landed in the electronarcosis basket, tagged, and held for 19 d in a large net-pen (J. A. Orsi, Auke Bay Laboratory, personal communication). Chinook salmon are routinely cultured in net-pens, indicating the pens provide an adequate environment for these animals. Although it is arguable whether comparisons between cultured fish and wild animals are appropriate, no chinook salmon hooked in the snout, maxillary, corner of the mouth, or cheek died after the first day of this study. Milne and Ball (1956) reported 89% survival for coho salmon that were held for 35 d in a pen of an undisclosed size after being caught on troll gear and held in live tanks on a troller for 1–6 h.

There is evidence that holding fish in small live tanks increases mortality for troll-caught chinook salmon. Fry and Hughes (1951) found a tenfold decrease in tag recovery rates when chinook salmon were held in live tanks overnight rather than being tagged and immediately released. Parker and Black (1959) reported 71% mortality for tagged chinook salmon caught on commercial troll gear and held up to 11 h. They included only fish with superficially minor injuries in their study. In contrast, with holding times of up to 5 d, less than 25% mortality was observed in the present study for all fish, including those severely injured and dead at landing. These results support the conclusion of Ellis (1964) that holding fish in live tanks for extended periods caused stress that contributed to the mortality observed by Parker and Black (1959). In the present study, a significant, albeit weak, relationship existed between mortality and time in the live tanks, even though time in the live tanks never exceeded 1 h. Therefore, it must be assumed that holding the fish in the live tanks caused some unquantified, positive bias to the observed mortality.

Another possible bias is that all mortality due to hooking injuries may not have occurred by the end of the holding period. Parker et al. (1959) reviewed experiments in which troll-caught fish were held in live tanks, and concluded that mortality due to hooking occurred within 6 h. Their findings were based primarily on fish with superficially minor injuries. In the present study, 10–12 fish, all of which had an eye torn out or destroyed by hooking, were observed swimming sluggishly at the surface at the end of both 5-d holding periods. It is unlikely that a high proportion of immature fish with this type of injury would survive. From 1984 to 1986, 2,954 adult chinook salmon returning to the National Marine Fisheries Service experimental hatchery at Little Port Walter were examined for hooking scars; 170 scars were attributed to hooking, but no fish were observed with only one functioning eye (F. P. Thrower, Auke Bay Laboratory, personal communication). The eye is not necessarily destroyed on all fish hooked through the orbit. In the present study, an observer on one of the trollers examined a small sample (17) of eye-hooked fish and noted that the eye in 65% of these fish had been destroyed (burst or torn out). The observed mortality rates for eye-hooked fish in this study were 26% for sublegal fish and 16% for legal fish (Table 3); weighted for days held, these rates were 26.5% and 25.4%, respectively. Additional mortality of fish in this wound category would likely occur subsequent to the end of the study.

Comparison with Recalculated Estimates

The general agreement between the estimates generated in this study and the recalculated estimates from previous studies is strong evidence that the estimates are good representations of the actual mortality rate, and that the biases previously identified for the current estimates are either small or compensatory. The mortality rates for sublegal chinook salmon are similar to those recalculated from tagging data from Butler and Loeffel (1972). As would also be expected if the rates were representative, the estimated rates for the two size-classes of fish in the present study were intermediate between these recalculated from tagging data of Wright (1970). This consistency between the two types of studies supports the conclusions of Wright (1970) that estimates of hooking mortality above 30% are probably excessive because they are based on experiments in which seriously injured fish were included among total mortalities or based on experiments in which stress caused by holding fish in tanks may have contributed to observed losses.

The recalculated tagging data of Butler and Loeffel (1972) may represent the best estimate of hooking mortality of sublegal fish. Tag recovery data are not biased by continued delayed mortality after an experiment ends, because they represent fish that survived to be caught or recovered during spawning runs. To estimate hooking-related mortality from such data, it need only be assumed that the effects of handling are similar across all wound categories. Substitution of observed mortality rates for fish with minor injuries in this study for the zero delayed mortality of maxillary-hooked fish assumed by Butler and Loeffel (1972) eliminated a source of bias in the original estimates derived from the tagging data. The recalculations give conservative estimates of mortality, because they incorporate any positive bias due to experimental handling of the fish. The gear used by Butler and Loeffel (1972) included a wider range of hook sizes (5/0 to 7/0) than used in this study (6/0), so the 26% rate calculated from the tagging data may apply to the incidental catch of sublegal chinook salmon during directed commercial trolling for chinook salmon, as well as to fish caught incidentally during chinook salmon closures.

The observed mortality of legal fish was lower than that of sublegal fish. Previous studies (e.g., Parker and Kirkness 1956; Loeffel 1961; Davis et al. 1986) concluded that large fish were less severely affected by hooking than smaller fish, based on the lower incidence of dead and seriously injured legal fish. In contrast, the incidence of dead and seriously injured fish in this study was actually higher for legal than sublegal fish. However, the relationship between size and mortality and the lower estimate of total mortality do indicate a lower mortality for larger fish. The mortality rate for legal fish observed in this study has a wide (9–31%) confidence interval because of the small sample size, and the mean size of the legal fish was only 73 cm fork length (77 cm total length). More research is needed on the relative mortality of legal and sublegal chinook salmon to accurately define the differences. At this time, the 20% mortality estimate from this study is a reasonable figure to use for legal chinook salmon incidentally hooked during closures because (1) mortality of legal chinook salmon appears to be lower than that of sublegal chinook salmon, and (2) the estimate of mortality for sublegal chinook salmon from this study is similar to the estimate calculated from tag recovery data.

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