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Mortality of coho salmon caught and released using sport tackle in the Little Susitna River, Alaska

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ABSTRACT

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Coho salmon (*Oncorhynchus kisutch*) were caught with sport gear in the estuary of the Little Susitna River, southcentral Alaska. Fish were double marked and released. All coho salmon observed migrating through a weir above the estuary and a portion caught in a sport fishery below the weir were examined for marks. A second group of coho salmon were caught using similar sport gear above the estuary. These fish were handled and marked identically as the fish captured in the estuary, except that they were held in a holding pen at the weir with an equal number of coho salmon dip netted at the weir. Coho salmon which were caught and released in the estuary suffered a significantly higher rate of mortality (69%) than did either the coho salmon caught and held above the estuary (12%) or those which were dip netted and held at the weir (1%). Factors that could influence rates of hook-induced mortality were measured at the time of hooking. Hook location, hook removal, and bleeding significantly affected the measured mortality rate.

INTRODUCTION

In many sport fisheries, anglers are asked to release all or a portion of the fish they catch. This management strategy is commonly called 'catch-and-release' (Pettit, 1977). Catch-and-release is a generally accepted and widely applied management tool in sport fisheries across North America (Reingold, 1975; Pettit, 1977; Johnson and Bjorn, 1978; Hunt, 1981; Anderson, 1982; Jones, 1982; Anderson and Nehring, 1984). It is a tool which enables managers to continue maximizing the opportunity to participate in recreational fisheries while reducing mortality to what can be termed 'catch-and-release

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mortality'. In this way, the economic value of recreational fishing is not jeopardized as the opportunity to participate is not reduced (Clawson, 1965; Gordon et al., 1973). The mortality associated with a catch-and-release fishery is a cost that must be considered when developing a management strategy for specific sport fisheries (Cutter, 1974; Anderson, 1975; Wydoski, 1977).

In contrast to resident fish populations (Klein, 1965; Hunsaker et al., 1970; Wydoski et al., 1976; Dotson, 1982; Schill et al., 1986), little quantitative information is available describing catch-and-release mortality in sport fisheries for Pacific salmon (*Oncorhynchus* sp.) (Warner, 1976, 1978; Warner and Johnson, 1978; Warner, 1979). Many salmon sport fisheries are conducted with bait, a practice which has been shown to result in high mortality rates for resident fish (Hunsaker et al., 1970; Wydoski, 1977; Warner and Johnson, 1978).

The Little Susitna River supports the second largest freshwater sport fishery for coho salmon (*Oncorhynchus kisutch*) in Alaska (Mills, 1988). Fishing effort has tripled and harvests of coho salmon have doubled since 1981. Most of the fishing effort and harvest of coho salmon is concentrated in the estuary of the river (Bartlett and Conrad, 1988). Anglers predominantly fish with bait in the estuary (Bentz, 1987) and release about 13% of the coho salmon caught in the estuary (Bentz, 1987; Bartlett and Conrad, 1988). Managers have raised concern that these released fish suffer high mortality rates (Bentz, 1987).

The objectives of this study were to estimate the short-term (5 day) rate of mortality of coho salmon caught and released in and above the estuary of the Little Susitna River and estimate the effects that several hooking factors have on observed rates of hook-induced mortality.

STUDY AREA

The Little Susitna River is a clearwater tributary to Upper Cook Inlet, Alaska (Fig. 1). The river is approximately 180 km in length and has a drainage area of approximately 1000 km^2. The river has an average stream flow of approximately 6 $m^3 s^{-1}$, with winter flows typically less than 2 $m^3 s^{-1}$ and peak summer flows near 30 $m^3 s^{-1}$. During the study, stream flows ranged from 10 to 20 $m^3 s^{-1}$. In the study area, the river has a channel gradient of approximately 1.0 m km^{-1} and channel widths of approximately 25–30 m. Depths in the study area range from less than 1 to 2 m, depending upon stream flow.

METHODS

Three hundred and eighty-four coho salmon were caught in the estuary using sport gear from 20 July through 18 August 1988. All coho salmon were

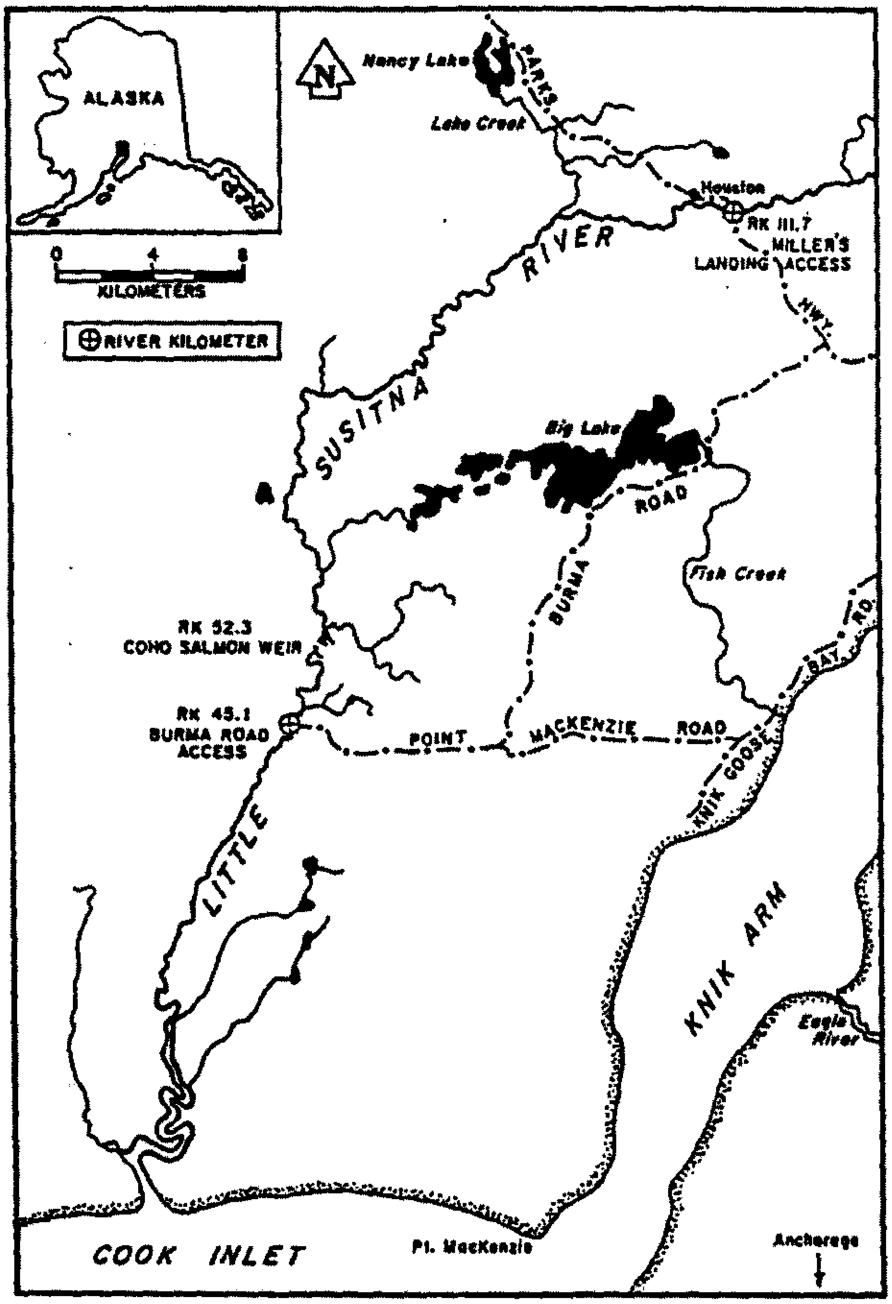

Fig. 1. Study area of the Little Susitna River, Alaska.

captured and released at approximately river kilometer (RK) 32. We were unable to develop a means to capture a control group from this section of the river. Water temperatures during this period ranged from 10 to 13°C. Number 2/0 barbed hooks drifted with clusters of salmon eggs were used to catch fish. This method of fishing was selected over other methods to simulate the typical fishing practices used by anglers fishing the Little Susitna River (Bentz, 1987; Bartlett and Conrad, 1988; Bartlett and Vincent-Lang, 1989). Personnel from the Alaska Department of Fish and Game and volunteers from the public participated in the study.

All coho salmon were hooked, played, and landed in a manner similar to that practiced by most anglers fishing coho salmon in the Little Susitna River, with the exception that all deeply embedded hooks were not removed. An unknown percentage of anglers fishing the Little Susitna River remove deeply embedded hooks. We chose to leave deeply embedded hooks in place as removal has been shown to increase mortality (Mason and Hunt, 1967; Hulbert and Engstrom-Heg, 1980). Each landed fish was marked with an individually numbered Floy FT-4 spaghetti tag. Spaghetti tags were inserted posterior to the dorsal fin using a sharp needle and tied securely using a single overhand knot. In addition, each tagged fish received a punched hole in its caudal fin using a paper punch. After marking, each fish was held in the current, then released.

Several variables that could influence hooking mortality were measured or estimated at the time of capture. The hooking factors or variables recorded for each fish were: time played on hook with two categories (less than 1 min or more than 1 min), time handled out of water with two categories (less than 1 min or more than 1 min), estimated amount of scale loss with three categories (less than 10%, 11–25%, or more than 25%), location of the hook with four categories (mouth, gill, gullet, or head outside of the mouth), whether or not the hook was removed (yes or no), whether or not the fish was bleeding when released (yes or no), and a qualitative assessment of the general condition of the fish when released with two categories (vigorous or lethargic).

All coho salmon observed migrating through a weir upstream of the estuary (at RK 52.3) were examined for tags and punched caudal fins. This weir was a complete barrier to migration of adult salmon and all fish were passed through a trap in the weir where they could be counted and/or examined. The weir was constructed of sealed grey PVC, 2.5 cm schedule 40 electrical conduit pipe (about 3.2 cm o.d.) attached to panels. Spacing between conduits was approximately 3.8 cm. Panels were attached to each other and a 1.0 cm cable secured to a railroad rail substrate. The substrate was attached to the bottom using spikes and sandbags. The buoyancy of the sealed pipes allowed the panels to float. The angle of the panels was adjusted, depending on flow, to vary from 30 to 45°. Over these angles, adult coho salmon were not able to pass through, over, or under the panels.

The number of marked coho salmon removed by the sport fishery below the weir was estimated using a creel survey, with all major access points of the fishery being surveyed. All anglers exiting the fishery at each access point were asked how many coho salmon they had harvested and their harvest of coho salmon was examined during randomly selected time periods for tags and caudal punches. The survey used a stratified (by weekly period), two-stage random sample design with approximately 30% of the total available fishing time being surveyed at each access site. Mean harvest, calculated for the periods sampled, was expanded over all possible periods to estimate total harvest of coho salmon. The harvest and its variance was estimated as described in Sukhatme et al. (1984) and Bartlett and Vincent-Lang (1989), for two-stage designs with unequal numbers of second-stage units (anglers).

The mortality rates for fish caught and released in the estuary were compared with those in a second group of 77 coho salmon which were caught above the estuary, immediately downstream of the weir from 31 July through 11 August 1988. Water temperatures during this period ranged from 10 to 13°C. These fish were caught using identical capture and marking techniques to those described above, except that these fish were held for 5 days in a 12 m^3 live trap located at the weir. The same hooking variables and mortality rate measured for the fish caught in the estuary were measured or estimated for this group of fish at the end of the 5 days.

In order to separate handling-induced mortality from hooking-induced mortality, a control group consisting of an equal number of coho salmon were dip netted at the weir during the same period and held in the same live trap. Fish that were dip netted at the weir site were handled and marked in the same manner as the angled fish, except that the dip netted fish were not subjected to the effect of being hooked and played by rod and reel. The mortality rate was similarly measured for this group of fish after 5 days.

Mortality rates

The rate of hook-induced mortality ($\hat{M}_e$) for the fish captured and released in the estuary and its variance ($V(\hat{M}_e)$) were estimated. Survivors were assumed to include coho salmon passing the weir (N_w) and those removed in the sport fishery ($\hat{N}_r$). All other coho salmon in the experiment were assumed to be hook-and-release mortalities. Therefore, the proportion surviving (p_s) becomes

$$\hat{p}_s = \hat{N}_r/N_t + N_w/N_t$$

where N_t is the total number of coho salmon marked and released in the estuary.

The number removed in the fishery ($\hat{N}_r$) is estimated, but the number passing the weir and the total sample size are constants, so the variance of the proportion surviving is estimated by

$$V(\hat{p}_s) = V(\hat{N}_r)/N_t^2$$

The mortality or proportion dying, $\hat{M}_e$, is estimated by

$$\hat{M}_e = 1 - \hat{p}_s$$

and the variance is equal to the variance of $\hat{p}_s$. Normal confidence intervals (95%) were calculated for the estimated mortality rate, $\hat{M}_e$.

The number of marked coho salmon removed by the sport fishery between the release location and the weir during each strata of the fishery ($\hat{N}_r$) was estimated by expanding the number of marks observed in the creel during each strata to the total estimated harvest during that strata

$$\hat{N}_r = \hat{H} \times \hat{p}_i$$

where $\hat{p}_i$ is the proportion of coho salmon checked in the creel that were observed to have marks during a specific stratum and $\hat{H}$ is the estimated harvest of coho salmon in the sport fishery during that stratum.

The variance of $\hat{N}_r$ in each stratum was estimated using Goodman's (1960) formula for the variance of a product of two independent variates

$$V(\hat{N}_r) = \hat{H}^2 \, \mathrm{var}(\hat{p}_i) + P_i^2 \mathrm{var}(\hat{H})$$

The variance of the proportion, p_i, was calculated using the formula for the variance of a binomial variable (Cochran, 1977). Seasonal totals for $\hat{N}_r$ and its variance were estimated by summing strata estimates as strata estimates were considered to be independent estimates.

The rate of hook-induced mortality ($\hat{M}_{ui}$) for the two groups of fish captured above the estuary and dip netted at the weir (control) was estimated as

$$\hat{M}_{ui} = G_{di} / G_{ti}$$

where G_{di} is the number of fish that died during the holding period in group i and G_{ti} is the number of fish in group i that were placed into the holding pen.

Confidence intervals (95%) for the mortality rate, $\hat{M}_{ui}$, were estimated using the normal approximation to the binomial (Cochran, 1977). This estimate of mortality necessitates the assumption that all hook-induced mortality occurs within the 5 day holding period. The mortality of the control group represents any handling-induced mortality.

Hooking factors

The influence that each of the hooking factors had on observed rates of hook-induced mortality was examined using a series of χ^2 tests. Although all coho salmon that passed through the weir were examined for the presence of tags placed in the estuary, it was not possible to obtain individual numbers for all tags observed during peak migrational periods. Therefore, for fish marked in the estuary, a χ^2 statistic was used to test the null hypothesis that there was no difference ($\alpha = 0.05$) in the distribution of each of the hooking variables for all the fish at the time of tagging and the distribution of these variables for all the fish observed at the weir.

For fish marked and held at the weir, the total sample could be divided into two classes, survivors and mortalities, and a χ^2 statistic was used to test the null hypothesis that the probability of death due to hook-and-release was independent of the hooking variables ($\alpha = 0.05$). In several cases, hooking variable categories had to be grouped owing to small sample sizes.

RESULTS

Hook-induced mortality

Ninety-eight of the 384 coho salmon marked in the estuary were passed through the weir. A total of 5589 fish were examined for marks from the sport fishery below the weir, of which a total of nine marked fish were recovered. These nine marked fish were expanded, based on an estimated harvest of 11 616 (SE=392.8), to an estimated 20 (SE=6.7) marked fish recovered by the sport fishery below the weir over the duration of the fishing season (Table 1). An additional 14 marked fish were recovered by anglers fishing below the weir and were voluntarily returned outside of the creel sampling effort. While these 14 recoveries provide for a slightly greater estimate of contribution to the sport fishery (9+14=23 actual tag recoveries as opposed to an estimated 20 tag recoveries), the number of tags returned is well within the confidence limits of the estimate ($7 < N_r < 33$). For purposes of this anal-

TABLE 1

Data used to estimate the number of marked coho salmon removed by the sport fishery

Strata	Estimated harvest	SE	No. tagged	No. inspected for tags in creel	No. observed with tags in creel	Estimated no. of tags (N_r)	$V(N_r)$
16/7–17/7	88	12.4	0	58	0	0	0.0
18/7–22/7	239	61.9	5	105	0	0	0.0
23/7–24/7	544	52.4	8	390	0	0	0.0
25/7–29/7	2967	273.4	155	1231	1	2	5.8
30/7–31/7	1132	38.2	22	722	2	3	4.9
1/8–5/8	2344	172.4	70	942	4	10	24.7
6/8–7/8	1199	61.5	3	726	1	2	2.7
8/8–12/8	1143	131.2	101	451	0	0	0.0
13/8–14/8	424	29.1	2	294	0	0	0.0
15/8–19/8	787	116.6	18	301	1	3	6.8
20/8–21/8	310	28.0	0	224	0	0	0.0
22/8–26/8	301	61.4	0	76	0	0	0.0
27/8–28/8	106	38.7	0	57	0	0	0.0
29/8–2/9	14	8.4	0	3	0	0	0.0
3/9–5/9	18	7.8	0	9	0	0	0.0
Total	11616	392.8	384	5589	9	20	44.9

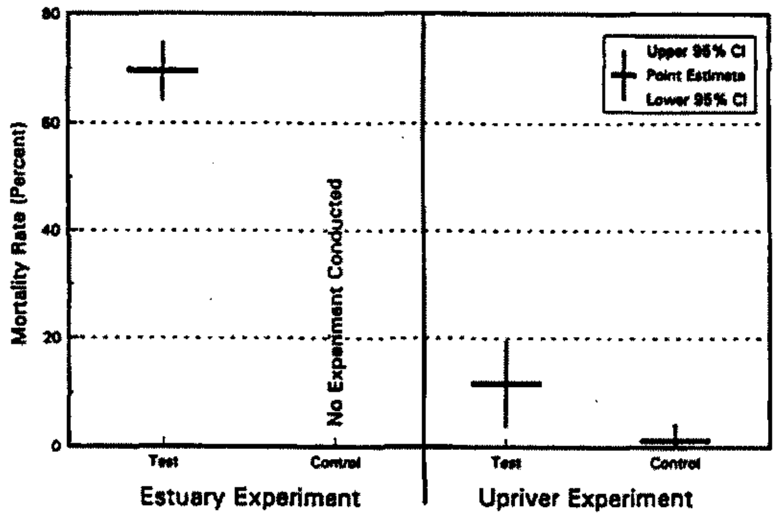

Fig. 2. Estimated rates of mortality for coho salmon in and above the estuary of the Little Susitna River, Alaska.

ysis, we chose to use the unbiased estimate of 20 recoveries in the sport fishery. Therefore, in total, an estimated 118 of the 384 marked coho salmon survived to be recovered either in the sport fishery below the weir (20) or at the weir (98). From this, the estimated rate of hook-induced mortality for the fish captured in the estuary was 69.3±5.3% (Fig. 2).

Of the 77 coho salmon caught above the estuary, nine died during the 5 day holding period, yielding a rate of hook-induced mortality for these fish of 11.7±7.9%. Of the 77 coho salmon dip netted from the weir, only one died during the 5 day holding period, yielding a handling-induced mortality rate of 1.3±3.2%. The mortality rates of the fish captured in and above the estuary significantly ($\alpha=0.05$) differed from each other as well as from the dip netted fish.

Factors influencing hook-induced mortality

Only 47 of the 98 tag numbers of fish marked in the estuary and passed through the weir were identified. Additionally, there were several fish, both at the point of capture in the estuary and at the point of recovery at the weir, for which not all of the variables were recorded. For example, the bleeding criteria was recorded for only 378 of 384 fish in the estuary and 46 of 47 fish examined at the weir. For this reason, the sample sizes for some of the χ^2 tests vary slightly from the total number tagged and examined.

Variables in the estuary experiment that had significantly ($\alpha=0.05$) changed in their distribution from the time of tagging to the time observed at the weir were hook location and hook removal (Table 2). Coho salmon which did not have the hook removed represented 67% (257 fish) of the total tagged sample (384 fish) but only 32% (15 fish) of the fish observed upstream at

TABLE 2

Hook-induced variables measured on angled coho salmon for fish tagged in the estuary and observed passing the weir[1]

	Tagged in estuary		Observed at weir		χ^2 statistic
	N	%	*N*	%	
Bleeding					
Not bleeding	262	68	36	77	2.07
Bleeding	116	30	10	21	
Fish condition					
Vigorous	293	76	42	89	4.18**
Lethargic	80	21	5	11	
Hook removal					
Hook not removed	257	67	15	32	27.38**
Hook removed	123	32	32	68	
Scale loss					
1–10%	330	86	45	96	3.32
11–25%	44	11	1	2	
>25%	7	2	1	2	
Time handled					
Handled ≤1 min	323	84	43	92	1.91
Handled >1 min	56	15	4	8	
Time angled					
Played ≤1 min	157	41	24	51	1.45
Played >1 min	224	58	23	49	
Hook location					
Mouth/head	196	51	40	85	20.84**
Gills	77	20	1	2	
Gullet	105	27	6	13	

[1]A total of 384 fish were tagged and 47 seen at the weir; however, some of the above contingency tables total less owing to missing values.
**Significant at P≤0.05.

the weir (47 total). Of the 182 coho salmon (47%) hooked in the gills or gullet at the time of tagging, only 15% (seven fish) were observed at the weir (Table 2). Hook location and hook removal, however, were not independent variables in the estuary experiment as the hook was not removed from most fish (177 of 184) hooked in the gills or gullet, while of the 197 fish hooked in the head or mouth, 62% (116) had the hook removed (Table 3).

Separate χ^2 tests comparing the observed with the expected frequencies of fish which had the hook removed and with those which did not have the hook removed were carried out for each hook location (Table 3). These tests were only significant ($\alpha=0.05$) for fish hooked in the head or mouth. Of the 39 fish observed at the weir, only 23% (nine fish) were from the group with the hook not removed, while at the time of release in the estuary this group rep-

TABLE 3

Distribution of hook removal group, by hooking location, for coho salmon caught and released in the estuary and observed passing the weir[1]

		Tagged in estuary		Observed at weir		χ^2 statistic
		N	%	*N*	%	
Mouth/head	Hook removed	116	58.9	30	76.9	5.24**
	Not removed	81	41.1	9	23.1	
Gills/gullet	Hook removed	7	3.8	1	12.5	1.65
	Not removed	177	96.2	7	87.5	

[1]Missing values: hook location, two fish; hook removal, one fish.
**Significant at $P \leq 0.05$.

resented 41% of all fish hooked in the head or mouth areas (Table 3). The same test for fish hooked in the gills or gullet was not significant ($\alpha = 0.05$). Few of these fish arrived at the weir and there was not a significant difference in the proportion of these fish at the time of their release and the proportion of these fish that arrived at the weir (Table 3).

In the weir experiment (Table 4), the probability of dying was significantly ($\alpha = 0.05$) related to the location of hooking. Of the 77 coho salmon hooked at the weir for the pen experiments, 81% (62) were hooked in the head or mouth but only 22% of the nine fish that died belonged to this hook location group (Table 4). The χ^2 tests were also significant ($\alpha = 0.05$) for hook removal and bleeding (Table 4), but as for the estuary experiment there appeared to be interaction with hook location. The hook was not removed from 14 of the penned fish in the weir experiment and of these five (36%) died; however, all of these mortalities had been hooked in the gills or the gullet (Table 5). Of the 62 fish hooked in the head or mouth, only two had the hook left in, too small a sample size to test for an effect of hook removal. Fish that were bleeding represented 34% of the sample and were more likely to die, but again most of the mortalities that were bleeding were also gilled fish (Table 5). In effect, although hook removal and bleeding appeared to significantly contribute to the mortality, the sample sizes were too small to separate these effects from hook location.

A comparison of the two experiments show that the number of coho salmon hooked and released in each group of hooking variables differs between the two experiments (Table 6). For example, a higher percentage of coho salmon were hooked in the gill and gullet in the estuary (48%) compared with fish caught at the weir (20%). Also, few of the fish hooked upstream at the weir that were hooked in the head and mouth area had the hook left in. The higher mortality estimated for the estuary experiment appears to be, at least in part,

TABLE 4

Distribution of hooking variables, by fate, for coho salmon captured and tagged above the estuary and held at the weir

	Fate of tagged fish					χ^2 statistic
	Died		Survived		Total	
	N	%	*N*	%		
Hook location						
Mouth/head	2	22	60	88	62	19.48**
Gill	4	45	1	2	5	
Gullet	3	33	7	10	10	
Bleeding						
Bleeding	7	75	19	28	26	8.83**
Not bleeding	2	25	49	72	51	
Condition at release						
Excellent	6	67	49	72	55	0.17
Good	2	22	18	26	20	
Poor	1	11	1	2	2	
Hook removal						
Hook removed	4	44	59	87	63	9.57**
Hook not removed	5	56	9	13	14	
Scale loss						
1–10%	8	89	66	97	74	1.42
11–25%	1	11	2	3	3	
Time handled						
Handled ≤min	–	–	7	13	7	<0.01
Handled > 1 min	9	100	61	89	70	

**Significant at $P \leq 0.05$.

TABLE 5

Distribution of hook removal and bleeding group, by hook location, for coho salmon caught and held at the weir

		Survived	Died
Mouth/head	Hook removed	58	2
	Not removed	2	0
Gills	Hook removed	1	2
	Not removed	0	2
Gullet	Hook removed	–	–
	Not removed	7	3
Mouth/head	Bleeding	15	2
	Not bleeding	43	0
Gills	Bleeding	0	4
	Not bleeding	1	0
Gullet	Bleeding	2	1
	Not bleeding	5	2

TABLE 6

Comparison of the number of coho salmon caught and released, by hooking variable, in the estuary and weir experiments[1]

Combination of categories	Estuary exp.				Weir Exp.	
	Total marked		Handled at weir		Total marked	
	N	%	N	%	N	%
Gilled, hook removed, bleed	4	1.1	0		2	2.6
Gilled, hook not removed, bleed	39	10.3	1	2.2	2	2.6
Gilled, hook not removed, not bleed	33	8.7	0		0	
Gilled, hook removed, not bleed	1	0.3	0		1	1.3
Gullet, hook not removed, bleed	31	8.2	1	2.2	3	3.9
Gullet, hook not removed, not bleed	73	19.3	5	10.9	7	9.1
Gullet, hook removed, not bleed	2	0.5	1	2.2		
Eye/mouth, hook removed, bleed	24	6.3	7	15.2	19	24.7
Eye/mouth, hook not removed, bleed	17	4.5	1	2.2	0	
Eye/mouth, hook not removed, not bleed	64	16.9	8	17.4	2	2.6
Eye/mouth, hook removed, bleed	90	23.8	22	42.8	41	53.2

[1]Missing values in total marked in estuary (384): hook removal = 1, hook location = 2, bleeding = 3. Missing values in salmon observed at the weir (47): bleeding = 1.

due to the high incidence of fish being hooked in the gills or gullet and to the higher frequency of hook non-removal for fish hooked in the head and mouth area. However, even for the group with the lowest mortality in the estuary (fish hooked in the head/eye or mouth with the hook removed), the estimated mortality is higher than that for the upstream pen experiment. Of the 114 fish released in the estuary group, 29 were seen at the weir and two in the creel. Expanding these as was done for the total sample, a total of 62 fish are estimated to survive in this group, which yields a mortality rate of 46%.

DISCUSSION

Assumptions for the mortality estimates

The validity of estimated mortality rate for coho salmon caught and released in the estuary hinge upon the assumption that a marked fish had only one of three fates: (1) it was removed by the sport fishery below the weir; (2) it migrated through the weir; (3) it died due to hook-induced mortality. There are, however, two additional possible fates that need to be considered: migration out of the estuary to other stream systems or migration to tributaries below the weir. Although not rigorously tested, we have no reason to believe that either of these two alternate fates occurred. We found no evidence that coho salmon marked in the estuary of the Little Susitna River migrated out of the river. Extensive commercial set net fisheries which intercept coho salmon of Little Susitna River origin occur in the marine waters near the Little Susitna River. In addition, extensive sport fisheries occur in various freshwater drainages adjacent to the Little Susitna River. This study was well publicized and industry and the fishing public in Alaska are well aware of tagging studies and the desire of Alaska Department of Fish and Game to have tags returned, yet no tags were returned voluntarily. Conversely, 14 tags were voluntarily returned from the Little Susitna River sport fishery. Additionally, approximately 6000 coho salmon were examined during 1988 in Upper Cook Inlet commercial fisheries, sport fisheries, and spawning escapements in the course of sampling for age, sex, and size data (Vincent-Lang and McBride, 1989). No marked fish were found in this sampling. We therefore conclude that there was little movement of marked fish out of the estuary. We also found no evidence that marked fish, or for that matter any coho salmon, spawned in either the Little Susitna River mainstem or its tributaries below the weir. Historically, there has been no spawning in either the mainstem or tributaries below the weir in the Little Susitna River. Aerial and foot surveys conducted from 1977 to 1979 and during 1988, failed to document any spawning downstream of the weir site in either the mainstem or tributaries (L. Engel, Alaska Department of Fish and Game, personal communication, 1989). Based on this information, we conclude that the fate of a marked fish in the estuary was limited to one of the three fates described above.

Several additional assumptions are necessary in assessing the validity of these estimates: (1) there was no handling-induced mortality; (2) there was no tag loss; (3) all hook-induced mortality occurred before marked fish reached the weir and a marked fish which was recaptured in the sport fishery below the weir was considered a survivor. The observed rate of handling mortality after 5 days for dip netted fish at the weir was 1%. Given the magnitude of the mortality rates in this study for sport-caught fish, this level of handling-induced mortality can be considered insignificant. No untagged coho salmon examined in the sport fishery or at the weir had a caudal fin punch. Thus, no tag loss was observed. The last assumption states that all hook-induced mortality occurred before the fish reached the weir or before they could be recaptured in the sport fishery. Previous studies indicate that 90–95% of hook-induced mortalities occur in the first 48 h (Stringer, 1967; Hunsaker et al., 1970; Falk et al., 1974; Warner and Johnson, 1978). The average travelling time of our tagged fish to the weir was 18.8 days, with the first tag observed 5 days after tagging and the last tag observed 32 days after tagging. Short-term mortality occurred within 5 days of tagging, well before any of the fish reached the weir. Of the 23 tagged fish actually recovered from the sport fishery, only 5 (21%) were taken within 5 days of being tagged. Therefore, a small percentage of the fish that were sport-caught might otherwise have died owing to hook-induced mortality. However, if true, then our estimate of hook-induced mortality from the estuary fishery is conservative, as recoveries from the sport fishery are assumed to be survivors in this analysis.

Mortality rates

The measured rate of hook-induced mortality for coho salmon caught by anglers using bait in the estuary of the Little Susitna River (69%) is higher than mortality rates reported in the literature for bait-caught fish while the measured mortality rate for coho salmon caught above the estuary of the Little Susitna River (12%) was lower than rates reported in the literature. Warner and Johnson (1978) found that landlocked Atlantic salmon *Salmo salar* caught with bait suffered a mortality rate of 35%. Wertheimer (1988) estimated hooking mortality for troll-caught chinook salmon *Oncorhynchus tshawytscha* to be 20.5–24.5%. Bendock and Alexandersdoitter (1991) found that the mortality of chinook salmon caught in the estuary of the Kenai River using baited sport tackle was less than 10%. Rates of hook-induced mortality for brown *Salmo trutta* and brook *Salvelinus fontinalis* trout (Shetter and Allision, 1958), cutthroat trout *Salmo clarki* (Hunsaker et al., 1970), and rainbow trout *Oncorhynchus mykiss* (Shetter and Allision, 1958; Stringer, 1967; Klein, unpublished data, 1974) caught with bait ranged from 20 to 48%. In combination, these data suggest that release mortality of coho salmon caught with bait in estuarine waters is higher than for other species of salmon and trout.

Factors influencing hook-induced mortality

The factors which influenced observed rates of hook-induced mortality during this study were hook location, hook removal, and bleeding. Hook location has been reported in the literature to influence hook-induced mortality. Rainbow trout (Stringer, 1967), brook trout (Shetter and Allision, 1958), and landlocked Atlantic salmon (Warner, 1979) hooked in the gullet or gills suffered higher rates of mortality than when hooked in other locations. Wertheimer (1988) reported that wound location was associated with mortality in troll-caught chinook salmon. Wertheimer (1988) also reported that wound severity was related to mortality. Warner and Johnson (1978) observed that 86% percent of the landlocked Atlantic salmon that were bleeding later died, and that there was a probable relationship between hooking location and bleeding. Mason and Hunt (1967) and Hulbert and Engstrom-Heg (1980) showed that removal of hooks from deeply hooked rainbow and brown trout resulted in higher mortality than when the hook was left in place. Nearly 95% of the rainbow trout and 60% of the brown trout died when the hook was removed in comparison with just over 30% and 20%, respectively, when the hook was not removed. Although increased play and handling time (Marnell and Hunsaker, 1970; Wedemeyer, 1972; Hattingh and van Pletzen, 1974); and scale loss (Black, 1957, 1958) have all resulted in increased rates of mortality, these factors did not significantly influence rates of hook-induced mortality in our study.

The degree of mortality suffered by coho salmon in the Little Susitna River appeared to be related to the location of catch in the river. Fish that were caught and released in the estuary suffered significantly higher rates of mortality (69%) than did fish caught and released above the estuary (12%). This appears in part to be due to the higher incidence of gill or gullet hookings in the estuary than above the estuary. Identical gear was used to catch fish in both areas, suggesting that coho salmon are more likely to become hooked in a lethal location in the estuary than above the estuary. We could not find any explanations for this in the literature. One possible explanation, however, may be that coho salmon in the estuary are still actively feeding and as a result, strike more aggressively at the bait, than do fish which are above the estuary and are off the feed. Although not specifically measured in this study, participants reported an increased aggressive behavior of salmon in the estuary compared with those above the estuary.

Other hooking factors also appeared to contribute to the high rate of hook-induced mortality for coho salmon caught in the estuary of the Little Susitna River. For instance, our data showed that estuary-caught fish hooked in a non-lethal location were more likely to survive and reach the weir if their hook was removed. Because we did not remove deeply embedded hooks from the coho salmon we caught in the estuary, this practice likely contributed to the high measured mortality for estuary-caught fish. We also observed that a large number of coho salmon handled in the estuary easily lost their scales, while those at the weir did not lose their scales as readily when handled. In the estuarine experiment, scale loss was not significant, but high scale loss has been observed to be a contributing factor to increased mortality in other studies. Black (1957, 1958) found that scale loss and abrasion of the mucus coat were major factors contributing to observed rates of mortality.

Various environmental factors can influence rates of hook and release mortality of sport-caught fish, one of which is temperature. Increased temperature at time of hooking and play has been shown to increase the mortality rate of sport-released fish (Dotson, 1982). In this study, water temperatures were relatively constant (only a 3 °C variation) between areas of the river sampled. Given this, we believe that temperature probably did not influence the differences in mortality rates of coho salmon hooked and released in different areas of the river during this study. Also, the observed temperatures recorded during this study were relatively cool (10–13°C) in comparison with other studies, suggesting that the mortality rates observed in this study may be minimum rather than maximum rates.

MANAGEMENT IMPLICATIONS

The rates of hook-induced mortality observed in this study for coho salmon show that the mortality of released coho salmon in intertidal sport fisheries is high. This is especially important in intertidal fisheries which have a large catch-and-release component. In such fisheries, catch-and-release may not be a viable management option.

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