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Hooking Mortality by Anatomical Location and Its Use in Estimating Mortality of Spring Chinook Salmon Caught and Released in a River Sport Fishery

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Abstract.—We estimated the hooking mortality of spring Chinook salmon *Oncorhynchus tshawytscha* that were caught and released to determine whether selective fishing on hatchery Chinook salmon would reduce harvest mortality of wild fish in a sport fishery in the lower Willamette River, Oregon. Hooking mortality in the fishery was estimated from hooking mortality rates for each of five anatomical locations (jaw, 2.3%; tongue, 17.8%; eye, 0.0%; gills, 81.6%; and esophagus–stomach, 67.3%) and from the frequency of these anatomical locations in the sport fishery (jaw, 81.5%; tongue, 5.1%; eye, 0.4%; gills, 5.1%; and esophagus–stomach, 7.8%). Mortality rates by anatomical location were estimated from recaptures of 869 tagged fish that were experimentally angled and of 825 tagged controls that were trapped in a nearby fishway. Anatomical hook locations in the lower Willamette River sport fishery were determined with creel surveys. We estimated hooking mortality rates of 12.2% for wild Chinook salmon caught and released in the sport fishery and 3.2% for the entire run of wild Chinook salmon based on a mean encounter rate of 26%. Hook location was the primary factor affecting recapture of hooked fish, but fish length, gear type, bleeding, and the elapsed time to unhook fish were also significant factors. A selective sport fishery in the lower Willamette River can be used to reduce harvest mortality on runs of wild Chinook salmon while maintaining fishing opportunity on hatchery Chinook salmon. The effect of selective fisheries for Chinook salmon in other rivers would depend on the frequency distribution of anatomical hook locations and on river-specific encounter rates.

Selective fisheries for anadromous salmonids are rapidly becoming a standard management tool to reduce harvest mortality of wild fish while maintaining angling opportunity. Regulating agencies often mandate selective fisheries to target abundant hatchery fish while reducing effects on wild fish. Anglers also voluntarily catch and release fish to select for an attribute, such as large size, where creel limits are low (Bendock and Alexandersdottir 1993). Selective fisheries are currently being used in Oregon to target hatchery Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, and steelhead *O. mykiss*. Because many wild populations of these species in Oregon are in low abundance and are listed under the Endangered Species Act, angling opportunity is being maintained by requiring anglers to release wild fish, but allowing them to keep marked hatchery fish—usually identified by an excised adipose fin. This strategy assumes that mortality from the catch and release of fish is low.

Few studies have been published on hooking mortality of anadromous Pacific salmon in selective sport fisheries in freshwater (Bendock and Alexandersdottir 1993). Studies of hooking mortality in hook-and-line salmon fisheries in saltwater are more common (Wertheimer 1988; Gjernes et al. 1993; Lawson and Sampson 1996; Grover et al. 2002) and have found that mortality is largely dependent on fishing technique and anatomical hook location. In general, hooking mortality in commercial troll fisheries is higher than that in saltwater sport fisheries (CTC 1997), except in ocean sport fisheries off California where a drift-mooching technique was used (Grover et al. 2002). Sev-

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eral studies have examined catch-and-release fishing for steelhead in freshwater (Pettit 1977; Hooton 1987) and for trout species (Mongillo 1984; Muoneke and Childress 1994). Most of these studies estimate hooking mortality over short periods and lack controls.

We began a study in 1998 to estimate the hooking mortality that would occur on wild spring Chinook salmon if they were caught and released in a selective sport fishery for hatchery salmon (marked with an adipose fin clip) in the Willamette River, Oregon. The study focused on the large, main-stem fishery below Willamette Falls at river kilometer (rkm) 43, which provided 171,000 angler-days and accounted for about 70% of the Willamette basin catch of spring Chinook salmon annually from 1981 to 1995 (calculated from Foster and Boatner 2002). Smaller fisheries occur in tributaries and in the main stem above the falls. Fisheries for spring Chinook salmon are supported by annual releases of about 5 million hatchery juveniles, which mitigate for dams that block access to or inundate natural production areas in the Willamette basin. Natural spawning still occurs in most large tributaries and in a few smaller ones that drain the Cascade Mountains. Subsequent to the initiation of our study, wild spring Chinook salmon in the Willamette River were listed as a threatened species under the Endangered Species Act (NMFS 1999), in part because of concern about excessive harvest.

Study Site

The Willamette River is the largest interior river in Oregon and flows north through the Willamette River valley, the most populated region in the state, entering the Columbia River near Portland, Oregon (Figure 1). The river drains a basin 31,080 km^2, bounded on the west by the Coast Range and on the east by the Cascade Mountains. Annual flows in the Willamette River (measured at Salem, Oregon, 92 rkm above Willamette Falls) range from 200 m^3/s in summer to 3,640 m^3/s during floods. Flows ranged from 306 to 1,215 m^3/s during our study in late April and May, but we could not sample at Willamette Falls when flows exceeded about 850 m^3/s. Water temperatures ranged from 9°C to 18°C during our study, the highest temperatures occurring in 1998. Spring Chinook salmon spawn in September and October in most of the large, east-side tributaries to the Willamette River. All of the hatcheries in the Willamette River basin are located on these tributaries (Figure 1).

The Willamette River is divided into upper and lower reaches by Willamette Falls. The height (12.5 m) and horseshoe shape of the falls concentrate adult Chinook salmon before they negotiate a fishway to continue their upstream migration. A counting chamber equipped with a video camera at the head of the fishway provides complete counts of fish runs above Willamette Falls. Most of our experimental fish migrated above the falls and were recaptured at hatcheries 212–290 rkm upstream. Others were recaptured above the falls in tributary fisheries, in traps operated at diversion dams on two large tributaries (114–296 rkm upstream of the falls), and on spawning grounds. A few were recaptured in the Clackamas River, a tributary that enters the Willamette River about 3 rkm below the falls. The creel survey of the sport fishery below the falls is divided into three sections: lower (rkm 0–10), middle (rkm 10–32) and upper (rkm 32–43; Figure 1). The lower survey section includes a heavily fished side channel (Multnomah Channel, 35 rkm long).

Methods

Our study was composed of two parts. First, we estimated hooking mortality rates of adult spring Chinook salmon caught and released in an experimental fishery at Willamette Falls for each of five hook locations: jaw, tongue, eye, gills, and esophagus–stomach. Hook location is a significant factor affecting hooking mortality of salmon that are caught and released (Wertheimer 1988; Wertheimer et al. 1989; Bendock and Alexandersdottir 1993; CTC 1997; Grover et al. 2002). Secondly, we surveyed the sport fishery in the lower Willamette River and estimated the frequency that harvested fish were hooked in each of the five hook locations. We applied these frequencies to the hooking mortality rates by hook location to calculate hooking mortality for fish caught and released in the sport fishery. The effect of catch-and-release fishing on the wild run was determined by multiplying the hooking mortality rate by the mean encounter rate of wild and hatchery fish in 1981–1995 in the lower Willamette River sport fishery. We assumed this encounter rate was applicable to wild fish in a selective fishery, although wild and hatchery fish could not be separated in 1981–1995 because most hatchery fish were not marked.

Mortality in the Experimental Fishery

Tagging and recapture.—The Willamette River offered a unique opportunity to estimate hooking mortality of spring Chinook salmon caught and released. Virtually all fish migrate through the fish-

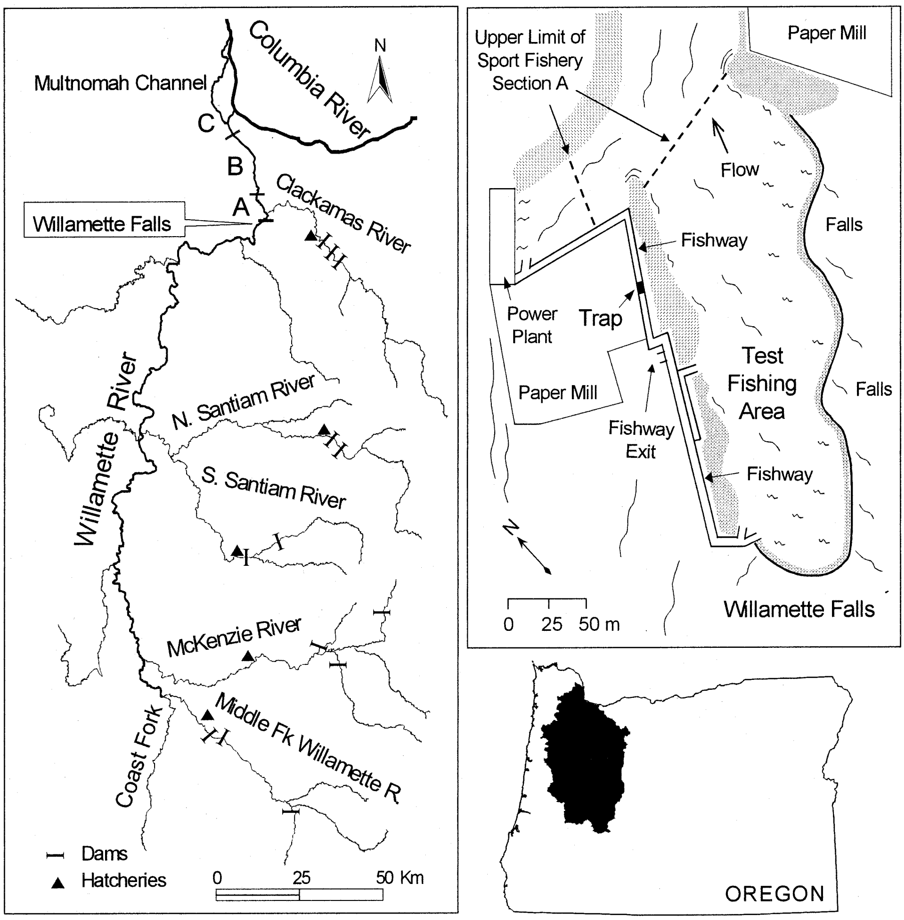

FIGURE 1.—Map of the Willamette River basin, Oregon, showing spring Chinook salmon hatcheries; Willamette Falls test fishing and trapping areas; and the upper (A), middle (B), and lower (C) creel survey sections of the lower Willamette River sport fishery.

way at Willamette Falls, and most enter upriver hatcheries weeks later. The concentration of Chinook salmon at the falls allowed us to tag a large number of fish that we caught with sportfishing gear. Concurrently, we captured and tagged a control group of salmon in the nearby fishway. We adjusted the recapture rate of tags from hooked groups by the recapture rate of tags from control groups to estimate hooking mortality by hook location. We tagged adult spring Chinook salmon at the falls from late April to late May during their upstream migration.

During the 3 years of the study we angled 869 Chinook salmon with a variety of terminal gear—prawn, salmon eggs, spinner, plug, wobbler—each including a variety of hooks (Table 1). We generally fished near the apex of the falls, an area closed to public boating and fishing (Figure 1). A fishing guide provided the boat, sport fishing tackle, and the expertise for catching fish. Two members of the public fished on the boat each day. Two biologists on the boat handled the fish caught, recorded data, and fished when there was opportunity.

Fish were played and netted in a normal manner. Netted fish were lifted into the boat and placed into a 190-L tank partially filled with water. One biologist removed hooks with needle-nosed pliers and removed the fish from the net. We cut the line and left hooks in place when a fish was hooked on bait in the gills or in the esophagus–stomach, assuming that leaving hooks in place would cause less damage than removal (Muoneke and Childress 1994; Schill 1996; Schisler and Bergersen 1996). Most anglers would accept cutting off an inexpensive hook if it improved the chance that a re-

TABLE 1.—Numbers of spring Chinook salmon caught on various types of gear, tagged, and released in an experimental fishery at Willamette Falls, Oregon, to evaluate hooking mortality, 1998–2000.

Terminal gear type	Hook type (all barbed)	Number of hooks	Hook size	Number of fish caught
Prawn[a]	Single	1	4/0, 5/0	82
		2	4/0-4/0, 3/0–5/0	110
Salmon eggs	Single	1	4/0, 5/0	203
Spinner	Single	1	3/0, 6/0	12
	Treble	1	2, 1/0, 2/0	140
Plug	Single	1	2/0, 3/0	17
		2	2/0-2/0	1
	Treble	1	3, 2, 1/0	34
		2	5-5, 4-4, 3-3, 2-2, 1-1, 5-3, 4-3, 1/0-1/0	165
Wobbler	Single	1	3/0	62
	Treble	1	1, 2	43

[a] Vernacular of Oregon anglers for northern shrimp.

leased fish would survive. Lures were always removed regardless of where a fish was hooked. We did not tag fish that were foul hooked or had a severe injury unrelated to hooking. We placed the unanesthetized fish headfirst into a round, plastic cylinder mounted in the bottom of the tank. To calm the fish, the cylinder was darkened with a rubber covering. Fish were then tagged, swabbed with iodine at the tag insertion point to reduce the risk of infection, and released. Fish were tagged at the base of the dorsal fin with a heavy-duty, T-anchor tag (Floy FD-94) that was individually numbered and included an Oregon Department of Fish and Wildlife (ODFW) telephone number. The time to tag, measure, and release a hooked fish (process time) averaged 40 s (range 11–126 s).

We recorded the tag number, hook location, bleeding, fork length (cm; Figure 2), bait type (spinner, salmon eggs, etc.), and hook type (single or treble, number of hooks, and size). For the few fish simultaneously hooked in more than one hook location on gear with two hooks, we recorded the hook location that would most likely cause the greatest reduction in survival (e.g., gills more likely than tongue). Fish hooked in the maxillary bone or the roof of the mouth were included with those hooked in the jaw. We recorded the elapsed time to unhook and remove the fish from the net once the fish was in the tank (unhook time) for a subsample of fish in 1999 and 2000. Sex of fish was not recorded because it could not be externally determined.

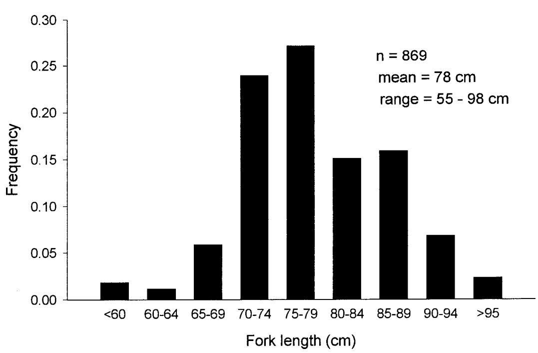

FIGURE 2.—Length-frequency histogram of spring Chinook salmon caught, tagged, and released in the experimental fishery for spring Chinook salmon at Willamette Falls, Willamette River, Oregon, 1998–2000.

We tagged a control group of 825 Chinook salmon captured in the fishway at Willamette Falls during the same time that hooked groups were caught. One control group of 395 fish were trapped in the fishway and returned to the river (river control) in the same area that hooked groups were caught. Because we were uncertain how returning these fish to the river might affect their behavior, a second control group of 430 was released directly into the fishway (fishway control). The fishway trap had a small viewing window and pneumatically operated gates, which allowed us to shunt Chinook salmon into a cage or to pass them up the fishway if they were severely injured or already tagged. Trapped salmon ascended an aluminum steep pass (Clay 1995) into a water-filled, wooden trough 3.7 m long × 0.6 m deep. We gently herded individual fish into the narrow end of the trough (0.3 m wide) and into a V-shaped metal insert fitted with handles and a rubber hood. We processed the fish without anesthetic and in the same manner as the hooked group. We lifted the fish with the metal insert and slid them through a plastic tube back into the fishway above the trap (fishway control) or into an aluminum tube partially filled with water for transport to the river (river control). Fish in the fishway control group slid into a tank suspended in the

TABLE 2.—Recapture of adult spring Chinook salmon (N) tagged at Willamette Falls, Oregon, and the number of days from tagging to recapture, 1998–2000.

Recapture		Proportion recaptured by site		Days from tagging to recapture	
Sites	N	Control	Hooked	Median	Range
Hatcheries	508	0.74	0.78	64	13–152
Traps	61	0.11	0.07	57	10–168
Fisheries	88	0.13	0.13	30	1–95
Spawning grounds	13	0.02	0.02	146	118–168
Combined	670[a]				

[a] Of the 670 recaptures, 22 were recaptured below Willamette Falls, of which 14 were in the Clackamas River.

fishway. Fish in the river control group were transported by hand truck about 40 m along the top of the fishway and lowered into a tank suspended in the river. Fish in both groups volitionally swam out of the tanks after recuperating.

Length measurements of control fish may have been underestimated during the study because the V-shaped insert (with measuring scale attached) could easily slide away from the end of the trough while processing fish. The end of the trough formed the stop for the snout of the fish, and any movement of the insert would underestimate length. The magnitude of the measurement error could not be determined and precluded estimating lengths of control groups.

Three biologists tagged all fish and each tagged a similar number of hooked and control fish during sampling periods. We assessed tag loss in 1998 by tagging each fish with an additional filament tag (Floy FD-67F). Of 220 tagged fish examined in 1998, 1% had lost the numbered tag and 6% had lost the filament tag. Consequently, only a single, numbered tag was used to tag Chinook salmon after 1998.

A tagged Chinook salmon was considered a survivor if it was recaptured, regardless of the number of days after tagging. Fish from hooked and control groups were recaptured primarily at hatcheries (Table 2) because hatchery spring Chinook salmon compose a high percentage of Chinook salmon in the Willamette River. Tags were also collected from fish caught by anglers in the main stem and in tributaries, at traps on two tributaries, and on spawning grounds. The proportions of hooked and control fish recaptured were not significantly different among recapture sites ($\chi^2 = 2.55$, df = 3, $P = 0.47$).

Statistical analyses.—Hooking mortality by hook location was estimated from combined 1998–2000 data. We used a chi-square test to compare recapture rates of river control fish with those of fishway controls and found no significant difference within years ($P = 0.07$, 0.20, and 0.93 for 1998–2000, respectively) or among years ($P = 0.82$). Recapture rates of the combined control groups were also not different among years ($P = 0.19$). Based on the homogeneity of recapture rates of control fish, we pooled hooked fish over years, assuming that any differences in recapture rates were the result of factors associated with their catch and release.

We estimated a hooking mortality rate for each hook location ($\hat{m}_l$) with the equation

$$\hat{m}_l = 1 - (a_l/b), \qquad (1)$$

where a_l is the proportion of hooked fish recaptured for hook location l, and b is the proportion of control fish recaptured. The variance of ($\hat{m}_l$) was estimated by methods described by Grover et al. (2002). If the 95% confidence interval (CI) calculated from this variance included zero, we concluded that mortality was not significantly different than zero.

We applied point estimates of hooking mortality by hook location in equation (1) to the frequency of those hook locations in the sport fishery by making two assumptions. First, we assumed that anatomical hook location is the primary factor affecting mortality of fish caught and released. Second, we assumed that fish hooked in the same hook location would suffer similar mortality regardless of the terminal gear used to hook the fish. This assumption was necessary because the terminal gear used in the experimental fishery did not cover the range of gear used by anglers in the sport fishery. To test these assumptions we used logistic regression models and the likelihood-ratio chi-square statistic (Agresti 1990; SAS Institute 2000) to identify factors that affected recapture rates. For factors with complete data sets (hook location, bleeding, gear type, fish length, and river flow;

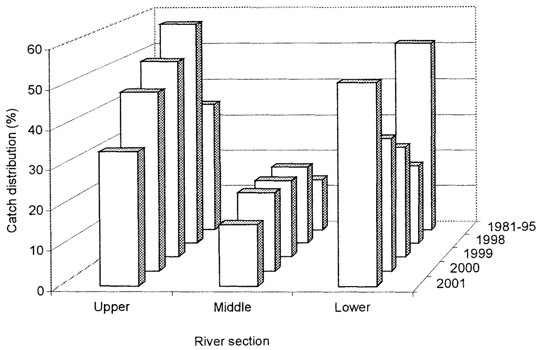

FIGURE 3.—Distribution of the angler catch of spring Chinook salmon in three creel survey sections of the Willamette River below Willamette Falls, 1998–2001, and the mean distribution in 1981–1995 (calculated from Foster and Boatner 2002). Additional angling regulations were enacted in 1998–2000 because of low run sizes.

$N = 869$) we used forward stepwise regression. For partial data sets (unhook time $N = 465$, processing time $N = 252$, and river temperature $N = 643$) we used individual logistic regressions. We also used logistic regressions to determine if river flow and river temperature affected recapture rates of the control group.

Hooking Mortality in the Sport Fishery

Anatomical hook locations of spring Chinook salmon caught in the general sport fishery were determined for 1998–2001 via creel surveys of anglers conducted by ODFW in three sections of the lower Willamette River (Foster and Boatner 2002). Creel clerks recorded the hook location of caught salmon, the type of gear used by anglers, and the number of hours different types of gear were used.

The distribution of sport catch among the three survey sections has historically differed (Foster and Boatner 2002), but was atypical in 1998–2000, 3 of the 4 years we monitored hook locations in the sport fishery (Figure 3). Additional regulations were enacted in these 3 years because of low run sizes of wild fish. Mean frequency distributions of hook locations in 1998–2001 also differed among the three survey sections because anglers used different types of gear. Consequently, to obtain a single frequency distribution of hook locations that would represent a typical fishing season in the lower river, we calculated a mean frequency weighted by catch ($\hat{w}_l$) for each hook location l with the equation

$$\hat{w}_l = \sum_{k=1}^{3} \left[\left(\frac{1}{4} \sum_{t=1998}^{2001} f_{tkl} \right) \left(\frac{1}{15} \sum_{t=1981}^{1995} c_{tk} \right) \right], \qquad (2)$$

where f_{tkl} is the frequency that Chinook salmon in the sport fishery were hooked in anatomical location l in survey section k in year t, and c_{tk} is the proportion of sport catch in survey section k in year t (1981–1995 data from Foster and Boatner 2002).

Equations (1) and (2) were used to estimate a hooking mortality rate for Chinook salmon caught and released ($\hat{s}$) in the lower Willamette River sport fishery as

$$\hat{s} = \sum_{l=1}^{5} \hat{w}_l \hat{m}_l. \qquad (3)$$

Hooking mortality relative to the run of wild fish ($\hat{q}$) was then estimated as

$$\hat{q} = \hat{s} \left(\frac{1}{15} \sum_{t=1981}^{1995} h_t \right), \qquad (4)$$

where h_t is the encounter rate in the sport fishery in year t (data from Foster and Boatner 2002). Encounter rates do not include sport fisheries in tributaries or in the main stem above Willamette Falls or account for multiple angler encounters with fish caught and released. The hooking mortality estimates of equations (3) and (4) also assume that wild Chinook salmon caught and released in a selective fishery would have the same distribution of hook locations as hatchery and wild Chinook salmon caught and kept in 1998–2001.

Confidence intervals for hooking mortality estimates ($\hat{s}$) and ($\hat{q}$) were calculated from bootstrap estimates of standard errors (Efron and Tibshirani 1993). Estimates of $\hat{s}_{\text{boot}}$ and $\hat{q}_{\text{boot}}$ were generated (1,000 repetitions) by resampling binomial distributions defined by $\{N, p\}$ for each of a_l and b in equation (1), where N is the number of fish tagged, and p is the proportion of tagged fish recaptured; and by resampling from original data sets of f, c, and h in equation (2) and equation (4). Confidence intervals (95%) were estimated as $\hat{s}$ and $\hat{q} \pm 2$ SE_{boot}. Bootstrap estimates were normally distributed and bias between bootstrap means and original estimates of $\hat{s}$ and $\hat{q}$ were negligible (-0.02 and -0.01, respectively).

We compared the effects on hooking mortality of additional regulation of fishing seasons in 1998–2000 with those in a typical season represented by 1981–1995 data. Additional regulations in 1998–2000 included early closures when catch quotas were reached, restricted days of the week, and reduced daily and annual creel limits. Regulations returned to normal in 2001, except that regulations

TABLE 3.—Mortality rates by hook location of spring Chinook salmon that were caught in the experimental sport fishery, tagged, and released at Willamette Falls, Oregon, 1998–2000. Recapture of control groups, 1998–2000, is shown for reference.

Group	Number tagged	Number recaptured	Mortality rate (95% confidence interval)
Hooked			
Jaw	633	270	0.023 (−0.068–0.113)
Tongue	39	14	0.177 (−0.103–0.458)
Eye	15	7	0.000[a] (−0.564–0.425)
Gills	112	9	0.816 (0.725–0.907)
Esophagus–stomach	70	10	0.673 (0.523–0.822)
Control	825	360	

[a] Mortality estimates less than zero were assumed to be zero.

required the release of unmarked Chinook salmon. We calculated a single frequency distribution of hook locations for 1998–2000 by weighting the mean frequency distributions of hook locations for each of the three survey sections by the mean proportion of catch in each section over the 3 years. Hooking mortality and bootstrap confidence intervals were calculated in the same manner as that for a typical fishing season described above.

Results

Mortality in the Experimental Fishery

Because of confounding effects and small sample size, hooking mortality rates in the experimental fishery at Willamette Falls could not be isolated by the hook characteristics (i.e., hook type, number, size; Table 1) or by the five gear types. Therefore, terminal gear was grouped into only two gear types, bait (prawn, salmon eggs) and lure (spinner, plug, wobbler), and their significance in the stepwise model was examined.

Hooking mortality rates were lowest for Chinook salmon hooked in the jaw and highest for those hooked in the gills and in the esophagus–stomach (Table 3). Estimated mortality rates of fish hooked in the jaw, tongue, and eye were not significantly different from zero ($P = 0.71$, 0.34, 0.81, respectively), although sample size for fish hooked in the eye was small (Table 3). Mortality rates of fish hooked in the gills and in the esophagus–stomach were significantly greater than zero ($P < 0.001$).

Anatomical hook location was the primary factor affecting recapture of fish in the stepwise regression model (Table 4). Hook location accounted for 79% of the variation explained by the model, which validated one of the underlying assumptions of the study. Fish length, gear type, and bleeding were also significant factors in the model, but not river flow (Table 4). For partial data sets, processing time ($P = 0.42$) and river temperature ($P = 0.53$) were unrelated to recapture rates, but unhook time was significantly related ($\chi^2 = 4.8$, df $= 1$, $P = 0.0339$). The mean time to unhook fish was lower for fish recaptured (34 s, SE = 2) than for those not recaptured (39 s, SE = 1). River flow ($P = 0.68$) and river temperature ($P = 0.64$) were not significant factors in the recapture of the control group.

The significance of gear type in the stepwise regression model invalidated our assumption of similar mortality within hook locations regardless of the gear used. To determine the potential effect on estimates of hooking mortality, we examined each hook location separately (logistic regression) to identify hook locations where recapture rates were significantly affected by gear. We found that gear type was not related to recapture of fish hooked in the eye ($P = 0.20$), in the tongue ($P = 0.48$) or in the gills ($P = 0.42$), but was related to recapture of fish hooked in the jaw ($P = 0.004$). Fish hooked in the jaw on lures were recaptured at a lower rate than those caught on bait, although fish hooked in the jaw had low mortality (2.3%) overall. Fish hooked on lures took longer to un-

TABLE 4.—Summary of the stepwise logistic regression analysis of explanatory factors on recapture rates of spring Chinook salmon caught and released in the experimental fishery at Willamette Falls, 1998–2000.

Factor	−2 Log likelihood	df	Chi-square value	*P*
Intercept	1,132.332			
Hook location	1,055.515	4	76.817	<0.0001
Length	1,046.670	1	8.845	0.0029
Gear	1,040.588	1	6.082	0.0137
Bleeding	1,034.742	1	5.846	0.0156
River flow	1,034.387	1	0.355	0.5513

TABLE 5.—Mean (SE) frequency distributions of hook locations by creel survey section for spring Chinook salmon caught in the lower Willamette River, Oregon, sport fishery, 1998–2001. The frequency distribution for combined sections was calculated by weighting each section distribution by 0.348 (SE = 0.020), 0.138 (SE = 0.009), and 0.514 (SE = 0.026), the mean proportions of total catch estimated annually in the upper, middle, and lower sections, respectively, in 1981–1995 (calculated from Foster and Boatner 2002).

Hook location	Creel survey section			
	Upper	Middle	Lower	Combined[a]
Jaw	0.782 (0.051)	0.725 (0.048)	0.862 (0.002)	0.815 (0.021)
Tongue	0.046 (0.015)	0.074 (0.006)	0.049 (0.025)	0.051 (0.014)
Eye	0.007 (0.005)	0.007 (0.004)	0.002 (0.002)	0.004 (0.003)
Gills	0.071 (0.024)	0.057 (0.015)	0.036 (0.016)	0.051 (0.005)
Esophagus–stomach	0.095 (0.033)	0.138 (0.038)	0.051 (0.014)	0.078 (0.011)
Sample size	790	508	732	2030

[a] Bootstrap estimate of standard error.

hook (mean = 42 s, SE = 2) than did fish hooked on bait (mean = 30 s, SE = 2; t-test, $P < 0.001$), which may have contributed to the lower recapture of fish hooked on lures. No fish were hooked in the esophagus–stomach on lures.

Hooking Mortality in the Sport Fishery

We examined the anatomical hook locations of 2,030 spring Chinook salmon caught by sport anglers in the lower Willamette River in 1998–2001. Most of these fish (81.5%) were hooked in the jaw (Table 5). Fish hooked in locations producing high mortality (gills or esophagus–stomach), composed 12.9% of the catch. Based on hook location frequencies in the sport fishery and the corresponding hooking mortality rates for each hook location in the experimental fishery, we estimated a hooking mortality rate of 12.2% (95% CI = 1.8–22.6%) for wild spring Chinook salmon that would be caught and released in a selective sport fishery in the lower Willamette River. Hooking mortality relative to the run of wild Chinook salmon in the Willamette River was 3.2% (CI = 0.5–5.9%) based on a mean encounter rate of 26% (SE = 1%) in 1981–1995 (calculated from Foster and Boatner 2002).

The frequency distribution of hook locations varied among survey sections (Table 5) and was generally associated with differences in the type of gear anglers used to catch Chinook salmon (Table 6). Bait predominated in all survey sections, but Pacific herring *Clupea pallasi* was most commonly used in the lower section and prawns (vernacular of Oregon anglers for northern shrimp *Pandalus borealis*) or ghost shrimp *Callianassa* sp. were most commonly used in the upper section. Anglers who used prawns or ghost shrimp generally hooked more fish in the gills and esophagus–stomach and fewer in the jaw than did anglers who used Pacific herring or lures (Table 7).

When additional regulations were enacted in 1998–2000, the catch distribution of Chinook salmon shifted from the lower survey section to upper survey sections compared with 1981–1995 and with 2001 (Figure 3). Because anglers in upper sections used a higher proportion of gear that

TABLE 6.—The mean (SE) frequency distribution of hours that anglers used different types of gear to fish for spring Chinook salmon in each of three creel survey sections of the lower Willamette River, Oregon, 1998–2001. Frequencies may not add to 1.00 due to rounding.

Gear type	Mean (SE) frequency of gear usage by survey section		
	Upper	Middle	Lower
Pacific herring[a]	0.06 (0.01)	0.52 (0.06)	0.74 (0.05)
Prawn or ghost shrimp	0.53 (0.04)	0.38 (0.05)	0.06 (0.01)
Salmon eggs[b]	0.06 (0.02)	<0.01 (0.00)	<0.01 (0.00)
Spinner	0.13 (0.00)	0.05 (0.01)	0.10 (0.02)
Plug	0.07 (0.02)	0.04 (0.01)	0.08 (0.02)
Wobbler	0.05 (0.02)	0.01 (0.00)	0.01 (0.00)
Winged attractor	0.10 (0.05)	<0.01 (0.00)	<0.01 (0.00)
Miscellaneous	0.01 (0.00)	<0.01 (0.00)	0.01 (0.00)

[a] Includes a few northern anchovies *Engraulis mordax*, Pacific sardines *Sardinops sagax*, and eulachons *Thaleichthys pacificus*.
[b] Includes salmon eggs used in combination with prawns or ghost shrimp.

TABLE 7.—Frequency distributions of hook locations for the three most common types of gear used to catch spring Chinook salmon in the lower Willamette River, Oregon, sport fishery, 1998–2001.

	Location					
Year	Jaw	Tongue	Eye	Gills	Esophagus–stomach	Sample size
Pacific herring						
1998[a]	0.84	0.15	0.00	0.00	0.02	117
1999	0.83	0.04	0.00	0.06	0.06	309
2000	0.85	0.03	0.01	0.03	0.08	349
2001	0.82	0.06	0.01	0.05	0.06	86
Prawn or ghost shrimp						
1998	0.58	0.05	0.00	0.15	0.22	81
1999	0.84	0.03	0.00	0.03	0.10	213
2000	0.71	0.07	0.01	0.07	0.14	364
2001	0.72	0.11	0.01	0.11	0.05	117
Spinner						
1998	0.96	0.04	0.00	0.00	0.00	23
1999	0.89	0.03	0.00	0.03	0.05	37
2000	0.83	0.08	0.04	0.04	0.02	52
2001	0.85	0.03	0.00	0.09	0.03	59

[a] Includes one fish caught on a northern anchovy.

hooked fish in the gills and esophagus–stomach (Tables 6, 7), hooking mortality estimates increased from 12.2% for typical years (1981–1995) to 14.3% (CI = 3.5–25.0%) in 1998–2000. However, the increased hooking mortality in 1998–2000 was offset by a reduction in mean encounter rate from 26% in 1981–1995 to 11% (SE = 3%) in 1998–2000 (calculated from Foster and Boatner 2002). The addition of catch-and-release regulations for Chinook salmon in 2001 did not change the catch distribution among survey sections compared with the distribution in 1981–1995 (Figure 3).

Discussion

We found that hooking mortality of spring Chinook salmon caught and released in the lower Willamette River sport fishery is largely dependent on anatomical hook location, which is consistent with other hooking mortality studies on salmon (Wertheimer 1988; Bendock and Alexandersdottir 1993; Gjernes et al. 1993; Grover et al. 2002). Length, gear type, bleeding, and unhook time were also significantly related to recapture of hooked fish. Other studies have shown that bleeding is a significant factor in survival of fish caught and released (Wertheimer 1988; Bendock and Alexandersdottir 1993). The significance of length in our study was difficult to interpret because of the absence of length data for the control group. Size effects could be a function of natural mortality above Willamette Falls or of being caught and released. Natural differences in size-related mortality are unknown but could have affected estimates of hooking mortality if lengths differed between hooked and control groups. The significance of gear type invalidated our assumption that fish hooked in the same anatomical location would suffer similar mortality regardless of the gear used because fish hooked in the jaw with lures had lower recapture rates than those hooked in the jaw on bait. Fish hooked on lures took longer to unhook than fish hooked on bait, and unhook time was inversely related to recapture rates.

Because about 60% of the jaw-hooked fish caught in our experimental fishery were hooked on lures compared with about 20% in the sport fishery, we may have overestimated hooking mortality for the jaw. Had we used the same ratio of lures and bait as in the sport fishery, hooking mortality would have been reduced from 12.2% to 10.3% for fish caught and released and from 3.2% to 2.7% relative to the run. However, bait (prawns and salmon eggs) and lures (spinners and plugs) were broad categories within which components (hook types, hook sizes and body styles, etc.) could not be isolated in our study. In addition, the range and intensity of use of specific types of terminal gear differed between the sport fishery and the experimental fishery. For example, Pacific herring was not used in the experimental fishery but was common in the sport fishery and had a hook location profile more similar to lures than to bait. Therefore, the adjustments in hooking mortality estimates because of differences between bait and lures should be viewed with caution.

Our estimate of 3.2% hooking mortality for wild spring Chinook salmon in the lower Willamette River sport fishery does not include fisheries in the main stem above Willamette Falls or in tributaries, which accounted for about 30% of the total annual harvest in 1981–1995 (calculated from Foster and Boatner 2002). Combining all fisheries, we estimate that sport anglers would encounter 37% of the wild spring Chinook salmon in the Willamette Basin. Assuming the hooking mortality rate of 12.2% estimated in the lower river fishery is applicable to other fisheries in the basin and by using a 6.4% multiple encounter rate for fish previously caught and released (ODFW 2001), we estimate the basinwide mortality for the run of wild spring Chinook salmon would be 4.8% in a catch-and-release fishery. This estimate assumes that the frequency distribution of hook locations in the main stem above the falls and in tributaries is the same as that in the lower Willamette River sport fishery. However, we found that the distribution of hook locations depends on the types of gear anglers use and that gear types varied among survey sections below Willamette Falls. Predominate gear types and the resulting hook location distributions are unlikely to be the same in upper and lower river fisheries. Hooking mortality in other rivers would depend on the type of gear anglers use, the hook location distribution, and river-specific encounter rates.

Our hooking mortality rate of 12.2% for Chinook salmon that are caught and released is higher than the 7.6% mortality rate reported for a Chinook salmon fishery in the Kenai River, Alaska (Bendock and Alexandersdottir 1993). Anglers in the Willamette River hooked a higher percentage of fish in the esophagus–stomach (7.8%), a high mortality location, than in the Kenai River (0%). In addition, water temperatures in the Willamette River during tagging averaged 12.8°C compared with mean water temperatures of 10.7°C in the Kenai River during tagging (calculated from Bendock and Alexandersdottir 1990, 1991, 1992). Studies have consistently demonstrated that hooking mortality increases with water temperature (reviewed in Muoneke and Childress 1994).

Our estimate of hooking mortality for Chinook salmon caught and released in the Willamette River is essentially the same as the 12.3% estimated for sport fisheries in saltwater targeting Chinook salmon 33 cm or larger (CTC 1997). The hooking mortality rate of 32.2% estimated for Chinook salmon less than 33 cm (CTC 1997) is considerably higher than our estimate, but most Chinook salmon in our study were much larger than 33 cm and none were smaller. Estimates of hooking mortality in commercial troll fisheries for legal and sublegal Chinook salmon are nearly double those in sport fisheries (Wertheimer 1988; CTC 1997).

Several studies have considered the tongue, eyes, gills, and esophagus–stomach to be ''critical'' or ''vital'' hooking locations that result in high mortality of released fish (Mongillo 1984; Muoneke and Childress 1994). The tongue, gills, and eyes were considered vital hooking locations of Chinook salmon in the Kenai River (Bendock and Alexandersdottir 1993). None of their study fish were listed as being hooked in the esophagus–stomach, although about 50% of the fish tagged had been caught on bait by sport anglers. We found that mortality rates of fish hooked in the eye and the tongue were not significantly different from zero, but sample sizes for the eye were small. In contrast, fish hooked in the gills and the esophagus–stomach had high mortality rates. In a study of the California ocean sport fishery (Grover et al. 2002), mortality from hook injury of the eyes was 46%, but the incidence of that injury in the fishery was low (6%). Circle hooks used in that study were reported to be difficult to remove from the eye. The mortality rate for fish hooked in the esophagus–stomach in the California fishery was 85%, higher than the 67% we observed in the Willamette River. However, their estimate for this location was partially based on projected mortality of fish killed and necropsied after they had survived a 4-d holding period. Our estimate of mortality for Chinook salmon hooked in the gills was 81%, similar to the 73% observed in the Kenai River (calculated from Bendock and Alexandersdottir 1992) and the 83–85% for Chinook salmon taken in the Alaskan troll fishery (Wertheimer 1988; Wertheimer et al. 1989).

Our estimates of hooking mortality could be low if we removed hooks more gently from fish than would anglers. However, we also assessed bleeding, measured length, and tagged the fish before it was released, time anglers would not spend before releasing fish. In addition, we hoisted fish into the processing tank inside the boat exposing them briefly to air. Air exposure has been shown to increase mortality (Ferguson and Tufts 1992). The lower Willamette River fishery is primarily a boat fishery, so it is unnecessary for anglers to expose fish to the air before removing hooks. With education, we expect that most anglers would use more care in releasing unmarked spring Chinook salmon.

Hooked fish were recaptured at various sites at about the same frequency as control fish, indicating catch-and-release angling did not influence the migratory behavior of fish that survived. Most of these fish were recaptured at hatcheries where they were used as part of the broodstock, although the reproductive success of experimental fish was not determined. Two studies found that catch and release of steelhead did not affect their return to spawning streams (Pettit 1977; Hooton 1987). Catch-and-release angling also did not influence the reproductive success of steelhead (Pettit 1977) or of Atlantic salmon *Salmo salar* (Booth et al. 1995).

Our study showed that a selective sport fishery requiring the release of wild spring Chinook salmon can decrease harvest mortality while maintaining sport catch of hatchery Chinook salmon. Managers can reduce hooking mortality of wild fish by regulating terminal gear to decrease the incidence of hooking fish in the gills and the esophagus or stomach in fisheries where these hook locations are common. For example, eliminating the use of bait may reduce the incidence of deeply hooked fish and reduce mortality, although in the Willamette River sport fishery the distribution of hook locations for some baits was similar to that of lures. However, eliminating the use of bait may also reduce the catch of hatchery fish. Educating anglers in proper release techniques would also reduce hooking mortality. For example, cutting the line has been shown to reduce postrelease mortality of deeply hooked fish (Muoneke and Childress 1994; Schill 1996; Schisler and Bergersen 1996). Cutting the line should be encouraged but may not be acceptable to anglers when fish are deeply hooked with expensive lures. Fish should be kept in the water and unhooked quickly because we found that mortality was higher for fish that took longer to unhook. Managers should be aware that changes in angling regulations can shift effort among river sections, which could affect hooking mortality provided fishing techniques also vary among sections.

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RELATION OF HOOKING MORTALITY AND SUBLETHAL HOOKING STRESS TO QUALITY FISHERY MANAGEMENT

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ABSTRACT

The demand for "quality" angling experiences has been increasing in concert with the increase in the number of anglers in the United States. "Catch-and-release" fishing has been one tool used by fishery managers to produce "quality" angling with the logic that fish will be available to be caught several times and will reach larger sizes since they are allowed to live longer. Under light to moderate angling pressure, this concept works well in managing for quality fishing. However, the factors of hooking mortality or sublethal hooking stress may become important considerations for the manager in catch-and-release fishing programs when pressure is high.

Initial hooking mortality is often linked with the type of terminal gear used by anglers and hook damage to vital organs such as the heart or a gill. Since bait is often taken deeply by fish, this terminal gear has caused the highest mortality in fish (mean 25.0 percent, range 3.3 to 61.5 percent, n = 2,859). The average mortality to fish from barbed hooks on lures was 6.1 percent (range 1.7 to 42.6 percent, n = 3,625) while barbed hooks on artificial flies caused an average mortality of 4.02 percent (range 0.0 to 11.3 percent, n = 2,713). These hooking mortalities were determined in experiments that differed due to variables such as species of fish, size of fish, sample size, type of bait used, hook size, anatomical site of hooking, angling technique, and different water temperatures. Single hooks have usually caused higher mortality than treble hooks when used with bait or lures as the terminal gear. Also, the use of barbless hooks did not significantly reduce mortality when compared to barbed hooks but the use of such hooks reduces handling time of fish that could add to their survival after release.

Stress in fish can disrupt normal metabolic and osmo-regulatory functions in fish and various stresses are cumulative in their affect on fish. Hooking stress does not cause mortality in fish that are in good physiological condition. However, hooking stress added to fish that are already under stress from adverse environmental conditions or pollutants may cause mortality of fish either directly or indirectly by allowing them to become more susceptible to predators, diseases, or parasites. The delayed mortality that results from stress can be more important than the initial hooking mortality that is observed and must be taken into account by fishery managers in quality fisheries if the angling pressure is high or the fish are under adverse or stressful conditions.

The losses of fish to hooking mortality or hooking stress is probably not very important in the productive waters of the United States. However, such losses could be very important to management of quality fisheries in less productive waters such as found in northern United States. In such waters, the most important factors to consider in the overall loss of fish from hooking mortality are species differences in voracity of feeding, type of terminal gear being used by anglers, the anatomical site of hooking, and water temperature.

Fishery biologists may sometimes have the biological facts to solve a particular problem but may not be able to implement the solution because of economical, political, or sociological constraints. Fishery managers should be certain to adequately inform the public about their policies or programs and employ effective public relations to help influence politicians and the public in the proper direction for the best management of U.S. waters for recreational fishing opportunities.

INTRODUCTION

Fishery management is a complex, dynamic activity that involves many biological, economical, political, and sociological factors that are continuously interacting. It has also been defined as the purposeful surveillance, regulation, and manipulation of (1) the fish habitat, (2) the

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fish populations, (3) their food supply, and (4) the fisheries (Northcote 1970). Everhart, Eipper, and Youngs (1975) have further stated that: "Fishery biologists must be prepared to accept variation, dynamic populations, and environment largely uncontrollable, the need for compromise, optimum rather than maximum results in the resolution of many harvest problems, and the conflicting desires of the people we work for." Sport fisheries are, therefore, systems consisting of aquatic biota, aquatic habitat, and man, interacting through time and space (Clark and Lackey 1974). Clark and Lackey also stated that angler consumption of fisheries resources is one of the major interactions of man with aquatic biota and habitat and, that management policies have been designed to respond to consumptive trends, but rarely to shape them.

All of these statements contain the human element in them and intelligent management of recreational fisheries will be concerned with a number of growing problems to meet the future demand for fishing, including: (1) space for anglers, (2) improving water quality and quantity, (3) adjusting to competing uses, (4) providing access to public and private waters, (5) adequate funding to do the job, and (6) preferences and opinions of anglers (Bureau of Sport Fisheries and Wildlife 1962).

Because of increased angling pressure on U.S. waters as well as increased pressure from concerned sportsmen (Cartier 1975; Wulff 1975), regulatory agencies have experimented with various regulations toward sustaining fisheries. Many regulations in fisheries management are directed at creel limits, minimum size, and restrictions on terminal gear. If fishing pressure is intense enough, however, creel limits may not protect the fishery since the fish population can be over exploited. In addition, minimum size limits may be of no use if most of the undersized fish are killed from repeated hooking (Shetter and Allison 1955); Shetter and Allison 1958; Mason and Hunt 1967). Nonetheless, restrictions on terminal gear or angling methods should be imposed only if there is justification for such regulations (Wydoski 1976).

This paper will attempt to concisely synthesize the published literature on the demand and desire for quality angling experiences, hooking mortality from different types of terminal gear, the effects of sublethal hooking stress on fish, and the relation of these factors to quality fishery management.

DEMAND FOR QUALITY ANGLING EXPERIENCES

The demand for sport fishing has been increasing rapidly and the trend is expected to continue in the future (Bureau of Sport Fisheries and Wildlife 1972; McFadden 1969; Stroud 1977). The U.S. Fish and Wildlife Service has conducted surveys at five-year intervals since 1955 that have shown an increase of 37 percent in the number of freshwater anglers (12 years old and older) in the U.S. between 1955 and 1970 (Bureau of Sport Fisheries and Wildlife 1972). The increase in the number of anglers for the same period was 37 percent for the Mountain States (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico) and 44 percent for the Pacific States (Washington, Oregon and California). The most recent survey, that cannot be directly compared with the others because of a change in design, estimated that over 53.9 million anglers (nine years old or older) fished in the United States during 1975 (U.S. Fish and Wildlife Service 1977). This survey indicated that Americans participated more in fishing (1.3 billion days) than in any other wildlife-associated recreation in 1975. Fishing will continue to rank high in outdoor recreation because more people of all ages and ethnic backgrounds participate in this sport than in most other types of outdoor recreation.

Three types of anglers have been identified by Clawson (1965): (1) purists, (2) active anglers, and (3) incidental anglers. He stated that purists are individuals who are highly informed about their sport, the fish species they are seeking, the waters that they fish, and the methods of fishing. They are willing to travel long distances and spend considerable amounts of money for their sport. Active anglers are interested, able, and skillful in fishing, but usually will not travel as far as the purists and probably spend less for this sport since they weigh alternative uses of their money. Incidental anglers are those individuals who fish while engaged in other outdoor activities such as picnicking, hiking, or camping with their families or friends. These anglers are not very successful since they lack the knowledge about fish and fishing methods and/or the proper tackle or other equipment.

The angling experience is similar to other forms of outdoor recreation in having five components: (1) preparation for the trip, (2) travel to the site, (3) on-site experience, (4) travel back home, and (5) recollection of the trip (Clawson and Knetsch 1972). It differs from other forms of outdoor recreation in that the on-site experience must include: (1) catching fish, and (2) keeping at least a part of the catch (Stroud and Martin 1968). Furthermore, the "recollection of the trip" is most likely to occur if the angler had a memorable (i.e., quality) experience. For these reasons, the incidental anglers identified by Clawson (1965) would probably not continue to fish if they were not engaged in other activities or with friends. On the other hand, the purists and active anglers continue to fish for different reasons and the psychological principle of reinforcement could be an important factor for them (Ley 1967). However, it is difficult to generalize for all types of anglers since motives differ considerably among individuals (Driver and Knopf 1976; Knopf, Driver, and Bassett 1973; Gordon 1970; Moeller and Engelken 1972; Stroud 1974). In addition, motives, preferences, and opinions differ widely among anglers from different parts of the United States (Addis and Erickson 1966; Bevins *et al.* 1968; Brown 1968; Burrows 1975; Calhoun 1964; Calhoun 1965; Gordon 1970; McFadden, Ryckman, and Cooper 1964; Moeller and Engelken 1972; Montgomery 1971; Stevens 1966; Wallis 1971).

While the number of fish caught, the rate of catching these fish, and the size of the fish are important factors in fishing (Stevens 1966), other factors are also important such as being outdoors (Stroud 1974), aesthetic surroundings (Andrews, *et al.* 1972), fresh, good tasting fish (Burrows 1975), size of stream (Talhelm 1973), social interaction with family and friends (Andrews, *et al.* 1972), and perhaps most importantly, a means to escape from the fast pace of a complex society (Blasingame 1967; Driver and Knopf 1976; Duttweiler 1976; Hoover 1964; Stainbrook 1973). Blasingame (1967) provided the following thought: "The Creator does not subtract from your allotted time the hours you spend fishing," and further stated that: "In short, fishermen are free to relax mentally, emotionally, and physically. And, this is good medicine for any man." Therefore, the satisfaction that is derived from fishing is dependent upon the existence of fish, but goes considerably beyond the actual taking of fish (Driver and Knopf 1976). Driver and Knopf also pointed out that many factors influence angler satisfaction and that these factors differ widely among individual anglers.

The productivity of any water is limited by numerous biological, chemical, and physical factors that interact continuously within the ecosystem. If fishing pressure is great enough, the age composition, numbers and size of the fish in a population can be changed. Much fishing in the Intermountain West is done in reservoirs where the catch is dependent on stocking. Gebhards (1975) documented that only a small percentage (4.7 percent) of the fluctuating reservoirs in this area produce enough wild trout to comprise as much as 20 percent of the total catch.

Fishery management agencies have been limited by budgets and manpower to provide unlimited fishing opportunities for the public. At the same time, managers in these agencies are facing increasing numbers of anglers to satisfy as well as the loss, destruction, or alteration of aquatic habitats that are necessary for fish production (Wydoski 1978).

Historically fishery managers devoted much of their effort toward the production of more fish (Benson 1970). Although this is still an important objective today, Stroud (1977) has proposed that fish conservation in the future must feature the concept of optimum yield rather than the traditional concept of maximum sustainable yield. The optimum yield concept takes into account the elusive element of "quality" in recreational fishing and is directed toward broader socio-ecological objectives, thereby differing from the concept of maximum sustainable yield.

Although quality reflects the person who is doing the fishing, it is related to personal experiences, personal education or training, and personal development. In an earlier paper (Wydoski 1976), I stated that there is a generalized evolution in anglers where catching fish is most important in the novice angler that changes to a point where the challenge of catching larger fish or actual art of fishing becomes more important. The time when this change takes place is highly variable among anglers – very much like the onset of maturity in human judgment – and, there are probably some anglers who never reach this stage.

The concern for improving angling quality or maintaining satisfactory angling experiences has increased in recent years among outdoor writers who are communicating with the public (Cartier 1975; Travis 1971; Wulff 1973; Zern 1978). Brown (1968) defined a quality or trophy trout fishery as one in which the trout are harvested at a significantly larger size than in comparable fisheries in the same geographic region. Rupp (1961) stated that, "The quality of sport that an angler experiences involves more than the number of fish caught and the rate of catch to provide a description of fishing quality that can be compared more logically from water and from time to time, it seems essential that both catch rate and average size of fish be included." In addition, crowding can have an adverse affect on angling quality (Wagar 1964).

All fishery managers have heard the statement that a few anglers catch the majority of the fish. Cooper (1970) documented that four percent of the individual anglers who fished the Pigeon River, Michigan, caught slightly over 50 percent of the wild trout, 27 percent of the anglers caught slightly under 50 percent, and 69 percent of the anglers caught no fish at all. Rupp (1961) also stated that the percentage of completely unsuccessful angling trips often exceeds 60 percent, and at particularly unfavorable times, even expert anglers are unsuccessful. However, few anglers, whether expert or novice, would fish waters if they knew no fish existed there (Clawson 1965). Zern (1971) stated that quality angling could not exist without some element of mystery or the possibility of catching a fish that was large for a particular water. Angling quality as well as angler satisfaction and preference means different things to different people. Brown (1968) listed size, number, fighting ability, eating quality, and particular species characteristics in descending order of importance for a quality trout fishery in western United States. Angling was viewed by Clawson (1965) as primarily a recreational experience in which fish provided food, trophies, challenge, excitement, and status.

For the reasons stated above, fishery managers will always be faced with satisfying different kinds of anglers. Cooper (1970) concluded his chapter on the management of trout streams by stating:

> Many fishermen are gregarious and can enjoy pitting their skills against a conditioned hatchery fish in a confusion of crowds of people and tangled lines. Others are solitary souls longing for the opportunity of catching an occasional wild trout from a stream where man has deliberately not interfered with the natural course of events. Fish managers have a responsibility to provide these varied fishing opportunities where it is possible to do so, and to offer the public different options in their search for angling satisfaction. In fish management, as in animal evolution, versatility is likely to lead to success.

This conclusion concisely states the future challenge for all fishery managers.

McNall (1975) further emphasized that fishery managers must prepare now for future anglers' freedom of choice that he defined "to mean regulatory constraints concerning anglers' consumptive, nonconsumptive, and recreational benefits." At the present time, managers in most agencies do not know what the various segments of the angling public prefer for their angling satisfaction. However, this information can be obtained through such techniques as questionnaires in which the design, construction, use, and validity have been established and will improve (Potter, Sharpe, Hendee, and Clark 1972). Continuous changes will likely occur in the patterns of use, desires, opinions, and satisfaction of anglers (Potter, Sharpe, and Hendee 1973) and managers must periodically evaluate the changes in these factors so that they can maximize the total angling benefits from the state's recreational fisheries within the limits of their budgets.

The demand for "quality" angling experiences will increase in concert with the expanding angling clientele in the United States. One technique that fishery managers can employ to meet this demand for quality is "catch-and-release" fishing. The renowned angler and outdoor writer Lee Wulff has advocated this technique by stating that a good (i.e., large or trophy) fish is too valuable to be caught but one time. The logic of catch-and-release fishing as a tool to produce quality fishing is that fish will be available to be caught several times and will reach a larger size since it will be allowed to live longer. This concept is particularly applicable to the management of quality fishing if the angling pressure is light to moderate. As the angling pressure becomes more intense, however, the factors of hooking mortality or sublethal stress (i.e., fatigue, or physiological disruptions) imposed by playing the fish may become important considerations to the manager in catch-and-release fishing programs.

HOOKING MORTALITY

The catching and releasing of fish instead of creeling them was proposed in the early 1800's (Wydoski 1976) or perhaps even earlier. However, estimates of hooking mortality were first made about 45 years ago (Westerman 1932) but did not result in serious concern until the 1950's (Shetter and Allison 1955, 1958; Parker and Black 1959; Parker *et al.* 1959; Webster and Little 1947). Hooking mortality became an even greater concern to fishery managers after the mid-1960's (Bouck and Ball 1967; Horak and Klein 1967; Klein 1965, 1966; Mason and Hunt 1967; and Stringer 1967). During the 1970's, a still greater research effort was made to estimate the extent of such mortality (e.g., Bjornn 1975a; Falk and Gillman 1975; Gresswell 1976; Gustaveson 1977; Holbrook 1975; Marnell and Hunsaker 1970; Peltzman 1978; Warner, 1976, 1978, 1979; Warner and Johnson 1978; Weithman and Anderson 1976; Wydoski 1976; Wydoski *et al.* 1976).

Because of the increased interest and importance of hooking mortality in "quality" or "catch-and-release" angling, it was desirable and timely to synthesize the "state-of-the-art" on hooking mortality so that the information could be used for establishing regulations by managers and to guide future research by biologists. This section of the manuscript provides a complete synthesis of hooking mortality that was found in the published literature through April, 1979.

A comparison of hooking mortality should logically begin by reviewing the types of terminal gear used by anglers. Because of the high percentage of active and incidental anglers (Clawson 1965) who comprise the American angling clientele, the preferences for terminal gear among anglers who fished for trout in waters without restrictions provide insight into the types of terminal gear that would normally be used by such anglers (Figure 1; Klein 1963). Although the percentages may vary somewhat between studies, other studies also suggest similar preferences for terminal gear. Bait was used by most anglers followed by flies and lures (Klein 1963). Bass anglers would probably use lures more than flies but bait would probably still be the most commonly used terminal gear by active and incidental anglers.

Trout anglers who fished in waters restricted to artificial lures indicated a preference toward flies over hardware (Table 1, Klein 1966; Wydoski 1976). These anglers would probably be considered in the "purist" category of Clawson (1965). Changes will no doubt occur in the types of anglers who fish a particular water similar to the example of a quality water in Washington (Table 1, Wydoski 1976). There was a steady decrease in the percentage of anglers who used flies as terminal gear on this lake that was correlated with the type of anglers who fished the lake. The increased pressure at the lake was composed of anglers that would be classified as "active" by Clawson (1965). These anglers were willing to drive a fairly long distance (~ 160 miles one way) to catch and retain three fish over 12 inches long. As the average size of the fish that were creeled declined, the percentages of anglers who used flies also declined. The higher percentage of anglers using flies in the fall fishery was correlated with the Clawson "purist" category. These anglers chose to fish in quality trout waters when the incidental or active anglers were fishing for Pacific salmon in Puget Sound or its tributaries, or were engaged in small and big game hunting. The average size of rainbow trout that were harvested in the fall was larger than those harvested in the spring (Wydoski 1976). Although the difference in size of harvested fish was due to growth gained by the fish during the summer, it was also due, at least in part if not wholly, to the type of angler (i.e., Clawson's "purist") who used the lake at that season.

Another interesting statistic is that the average angler day is about four hours long in waters with different restrictions (Figure 2, Fatora 1970). I observed a similar result during three years of creel checks on Lenice Lake – a quality water in Washington. If the manager knows the average

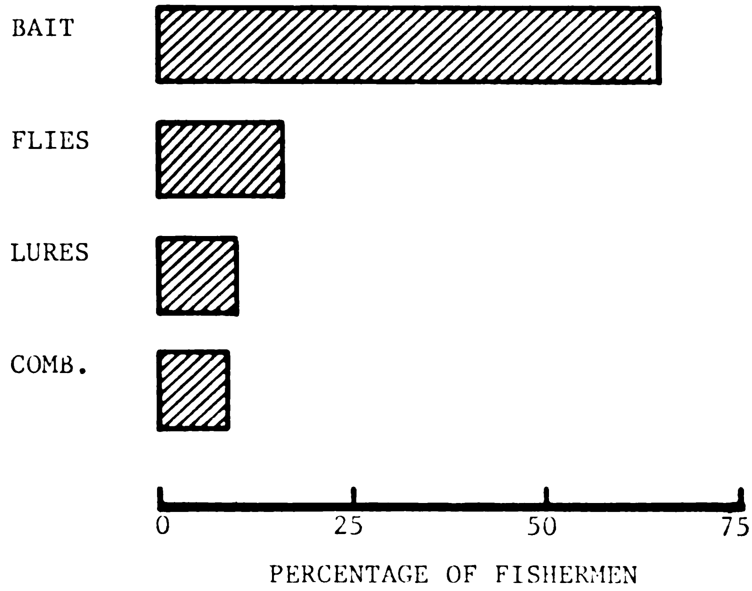

Figure 1. Preference for terminal gear by anglers who fished waters with no restrictions - Poudre River, Colorado. (Adapted from Klein 1963).

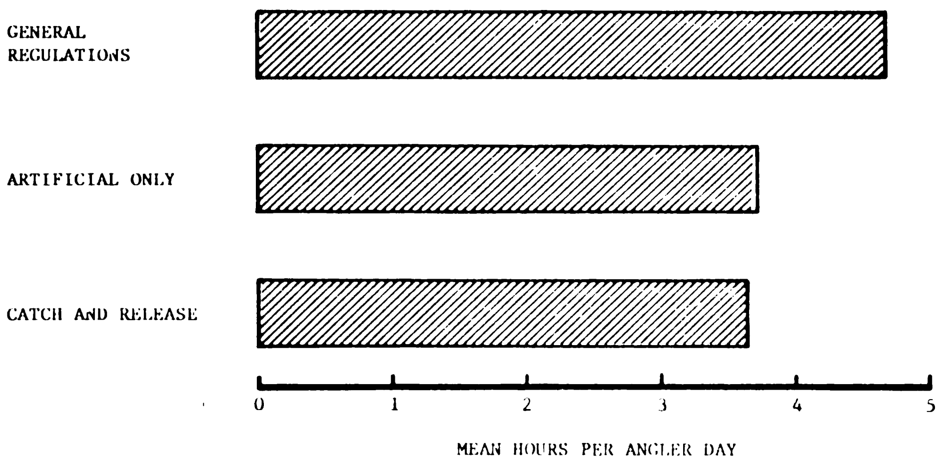

Figure 2. Comparison of the mean number of hours fished per day by anglers on a southern Appalachian trout stream - Noontootla Creek, Georgia. (Adapted from Fatora 1970).

Table 1. Preference for terminal gear by anglers who fish waters restricted to artificial lures.

Terminal Gear	Washington[1]						Colorado[2]	
	Spring			Fall				
	1970	1971	1972	1970	1971	1972	1961	1962
Flies	66.8	55.9	48.8	72.8	71.3	65.1	61	67
Lures	25.1	17.9	27.2	15.1	14.7	21.3	22	10
Both	8.1	26.1	24.1	12.0	14.0	13.6	17	23

[1] From Wydoski (1976).
[2] From Klein (1966).

length of the angler day, the average number of angler days of pressure, the catch rate (fish/angler hour), and the percentage lost to hooking, the magnitude of hooking mortality can be estimated.

Type of Terminal Gear

The earliest concerns of biologists about hooking mortality were centered on the use of bait as a terminal gear (Westerman 1932; Thompson 1946; Shetter and Allison 1955). Indeed, the mortality of salmonids was rather high from this gear (Table 2). The average loss of fish (n = 2,859) caught on baited hooks was 25.0 percent with a range between 3.3 and 61.5 percent. This range was due to a number of variables including the species of fish, size of fish, sample size, type of bait used, hook size, anatomical site of hooking, angling technique, and different water temperatures. Despite the variability under which the data were collected, this comparison demonstrated the loss of fish captured on baited hooks is substantial – an average of one out of four fish that were caught on bait were lost. In fact, the loss of fish caught on baited hooks was usually higher than if they were caught on flies or lures (e.g., Figure 3; Warner 1978; Warner and Johnson 1978). The procedure for handling the fish after capture is particularly important since a baited hook is usually taken well inside the mouth where it could penetrate a vital organ such as the heart or a gill. In one study where sample sizes were larger than 100, most of the rainbow trout that were deeply hooked died regardless of the procedure used to remove the hook (Figure 4; Mason and Hunt 1967). In contrast, only about one-third of these fish died if the leader was cut and the hook left in place. In another recent study, about twice as many Atlantic salmon died if the baited hook was removed (90 percent of 50 fish) than if the hook was left in the fish (57 percent of 56 fish) after 14 days of holding (Warner 1979).

In general, artificial lures caused a larger mortality to fish than artificial flies. For example, Shetter and Allison (1955) demonstrated that lures caused a higher mortality than flies in three species of trout under similar conditions (Figure 5). Although the highest mortality was just over six percent, Shetter and Allison reported that the small, single hook in the flies usually hooked the maxillary and consequently did not damage a vital organ. The average mortality to fish (n = 3,625) from barbed hooks on lures was 6.1 percent with a range of 1.7 to 42.6 percent (Table 3). In comparison, the average mortality to fish (n = 2,713) from barbed hooks on artificial flies was 4.02 percent with a range of 0.0 to 11.3 percent (Table 4). The experiments summarized in Tables 3 and 4 were done under the same variables that were discussed under the section on baited hooks (Table 2) – namely the species of fish, size of fish, sample size, anatomical site of hooking, angling technique, and different water temperatures.

Single Versus Treble Hooks

The mortality of fish due to the type of hook (single versus treble) is dependent upon factors such as the size of the hook used and the voracity of the fish in taking the bait, artificial fly, or lure. For example, Klein (1965) demonstrated that the difference in mortality of rainbow trout was small and about the same (Figure 6) for trout caught on lures with single or treble hooks when the water temperatures were cool (6.5 C) but lures with a single hook caused about double the mortality of trout (Figure 6) than treble hooks when the water temperatures were warmer (14.5C). In another study (Klein 1974a), nearly one-fourth (20-23 percent) of the rainbow trout that were caught while ice-fishing in Parvin Lake, Colorado, were lost to hooking mortality. Klein reported that 97 percent of the trout were caught on bait, mostly salmon eggs (74 percent). He assumed that some type of single hook was used by the anglers. The management implications of this information would depend upon the voracity of the fish species during feeding and its vulnerability to angling as well as its physiological state. Many of these factors would be greatly influenced by water temperatures. For example, Klein (1974a) stated that the average mortality of released rainbow trout by bait fishermen in the summer was 46.7 percent (range 32.1 to 52.3 percent) in contrast to the 20-23 percent mortality in winter at Parvin Lake, Colorado. Lures with a single hook also caused a higher but not significant mortality in Atlantic salmon than lures with a treble hook but the reverse was true for flies (Figure 7; Warner 1978). Warner stated that the

Table 2 . Summary of research on hooking mortality for fish caught and played on bait with barbed hooks.

Species[1/] Common Name	Species[1/] Scientific Name	Hooking Mortality (%)	Number of fish	Water Temperature (°C)	Location	Reference
Cutthroat trout	*Salmo clarki*	48.5	161	4.5-17	Wyoming	Hunsaker, Marnell and Sharpe (1970)
Rainbow trout	*Salmo gairdneri*	35.4	79	-	Michigan	Shetter and Allison (1955)
"	" "	23.0	565	4	Colorado	Klein (1974)
"	" "	29.4	136	15	British Columbia	Stringer (1967)
"	" "	38.8	103	17	" "	" "
"	" "	61.5	400	-	Wisconsin	Mason and Hunt (1967)
Trout	- -	3.3	61	10-14.4	New Mexico	Thompson (1946)
Atlantic salmon	*Salmo salar*	5.7	298	-	Maine	Warner (1976)
"	" "	5.7	300	13.9-18.6	"	Warner (1979)
"	" "	35.0	100	14-19	"	Warner and Johnson (1978)
Brown trout	*Salmo trutta*	20.3	59	-	Michigan	Shetter and Allison (1955)
Brook trout	*Salvelinus fontinalus*	42.4	177	-	"	" " " "
"	" "	8.75	400	-	"	Westerman (1932)
Combined	- -	25.0 (3.3-61.5)[2/]	2,859	-	-	-

[1/] Fish species are listed alphabetically by scientific name.

[2/] Range of hooking mortalities reported by various investigators.

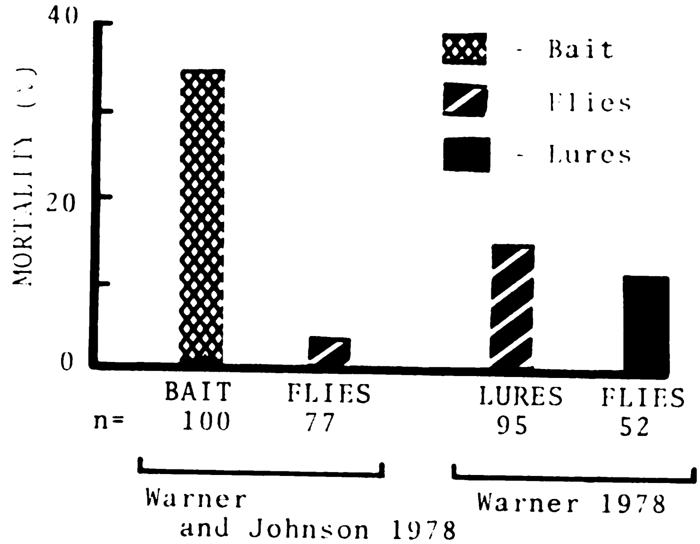

Figure 3. Comparison of hooking mortality in Atlantic salmon from single hooks on three types of terminal tackle. (Adapted from Warner 1978, and Warner and Johnson 1978).

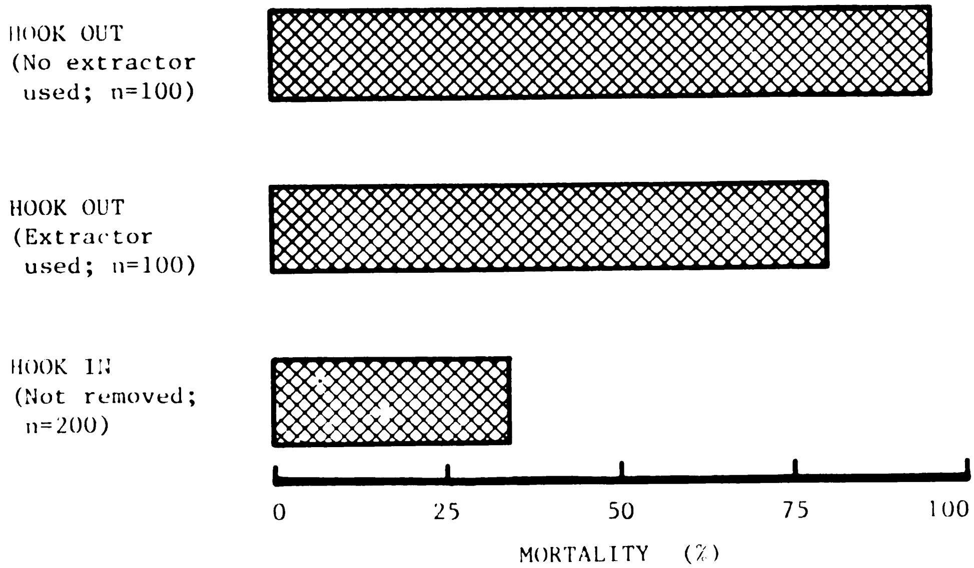

Figure 4. Differential mortality of deeply hooked rainbow trout related to handling procedures. (All fish were caught on baited No. 8 hooks. Adapted from Mason and Hunt 1967).

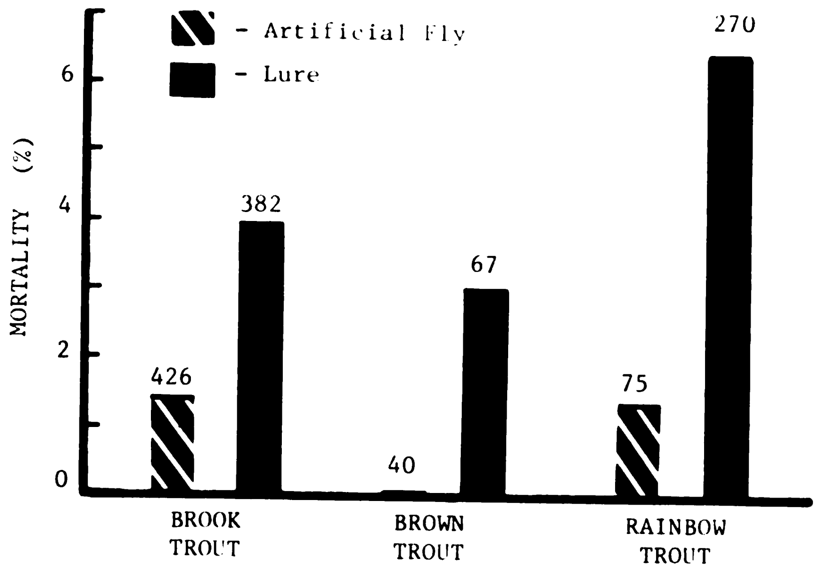

Figure 5. Comparison of hooking mortality from two kinds of terminal gear in three species of trout from Michigan waters. (The number of trout captured by each method is given above each bar. Adapted from Shetter and Allison 1958).

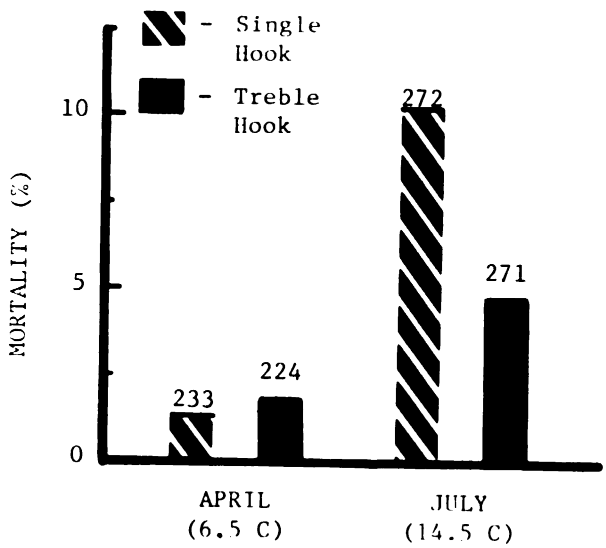

Figure 6. Comparison of hooking mortality in rainbow trout from two types of hooks on wobbling lures at two water temperatures. (The number of trout captured by method and time period is given above each bar. Adapted from Klein 1965).

Table 3 . Summary of research on hooking mortality for fish caught and played on artificial lures with barbed, treble hooks.

Species[1/] Common Name	Scientific Name	Hooking Mortality (%)	Number of fish	Water Temperature (°C)	Location	Reference
Esocids	(*Esox* sp.)	1.7[2/]	59	15-23	Missouri	Weithman and Anderson (1978)
Northern pike	*Esox lucius*	5.3	75	11-13.5	Manitoba	Falk and Gillman (1975)
Coho salmon	*Oncorhynchus kisutch*	42.6	115	13-15(7-10)[3/]	Pacific Ocean	Parker, Black and Larkin (1959)
Chinook salmon	*Oncorhynchus tshawytscha*	33.3	66	14-15(7-10)[3/]	" "	Parker and Black (1959)
Cutthroat salmon	*Salmo clarki*	2.9	102	3-9.5	Wyoming	Marnell and Hunsaker (1970)
" "	" "	6.5	200	7.5-13	"	" " " "
" "	" "	4.0	50	14.5-16.5	"	" " " "
" "	" "	2.7	113	4.5-16.75	"	Hunsaker, Marnell, and Sharpe (1970)
" "	" "	0.7[4/]	-	10	"	Benson and Bulkley (1963)
" "	" "	21.3[4/]	-	17	"	" " " "
" "	" "	2.4	209	7	Idaho	Bjornn (1975a)
Rainbow trout	*Salmo gairdneri*	2.8	145	15-17	British Columbia	Stringer (1967)
" "	" "	6.3	270	-	Michigan	Shetter and Allison (1958)
" "	" "	1.8	224	6.5	Colorado	Klein (1965)
" "	" "	4.8	271	14.5	"	" "
Atlantic salmon	*Salmo salar*	0.3	333	10-14.4	Maine	Warner (1976)
" "	" "	2.7[5/]	296	10-14.4	"	" "
" "	" "	15.0[5/]	42	-	"	Warner (1978)
" "	" "	8.0	55	-	"	" "
" "	" "	6.0	300	13.9-18.6	"	Warner (1979)
" "	" "	4.6[5/]	302	13.9-18.6	"	Warner (1979)
Brown trout	*Salmo trutta*	3.0	67	-	Michigan	Shetter and Allison (1955)
Brook trout	*Salvelinus fontinalis*	3.9	382	-	"	Shetter and Allison (1958)
Lake trout	*Salvelinus namaycush*	6.9	72	-	Manitoba	Falk, Gillman and Dahlke (1974)
Arctic grayling	*Thymallus arcticus*	11.7	77	11-13.5	"	Falk and Gillman (1975)
Combined	- -	6.1 (1.7-42.6)[6/]	3,625	-	-	-

1/ Fish species are listed alphabetically by scientific name.
2/ Data refers to total hooking mortality of 38 northern pike (*Esox lucius*), 9 muskellunge (*Esox masquinongy*), and 12 hybrids.
3/ The temperature range in parentheses occurred at the depth where the fish were caught.
4/ These studies were not included in the combined data since the number of fish was not known.
5/ Lures used in this experiment contained a single, barbed hook.
6/ Range of hooking mortality reported by various investigators.

Table 4 . Summary of research on hooking mortality for fish caught and played on artificial flies with barbed hooks.

Species[1/] Common Name	Species[1/] Scientific Name	Hooking Mortality (%)	Number of fish	Water Temperature (°C)	Location	Reference
Cutthroat trout	*Salmo clarki*	4.0	75	4.5-16.75	Wyoming	Hunsaker, Marnell, and Sharpe (1970)
" "	" "	0.4	256	7	Idaho	Bjornn (1975 a)
Rainbow trout	*Salmo gairdneri*	1.3	75	-	Michigan	Shetter and Allison (1958)
" "	" "	8.7	190	15-17	British Columbia	Stringer (1967)
" "	" "	11.3	80	-	Michigan	Shetter and Allison (1955)
Trout	- -	5.9	51	-	New Mexico	Thompson (1946)
Atlantic salmon	*Salmo salar*	4.6	304	10-14.4	Maine	Warner (1976)
" "	" "	12.0	52	-	"	Warner (1978)
" "	" "	2.6[2/]	39	-	"	" "
" "	" "	4.1	319	13.9-18.6	"	Warner (1979)
" "	" "	3.9	77	14-19	"	Warner and Johnson (1978)
Brown trout	*Salmo trutta*	0	40	-	Michigan	Shetter and Allison (1958)
" "	" "	0	69	-	"	Shetter and Allison (1955)
Brook trout	*Salvelinus fontinalis*	1.4	424	-	"	Shetter and Allison (1958)
" "	" "	3.3	181	-	"	Shetter and Allison (1955)
" "	" "	2.75	400	-	"	Westerman (1932)
Arctic grayling	*Thymallus arcticus*	8.6	81	11-13.5	Manitoba	Falk and Gillman (1975)
Combined	- -	4.05 (0.0-11.3)[3/]	2,713	-	-	-

1/ Fish species are listed alphabetically by scientific name.
2/ Flies in this experiment contained treble barbed hooks.
3/ Range of hooking mortalities reported by various investigators.

smaller treble hooks (No. 10) used in streamers were ingested more deeply than single hooked flies and, therefore, caused a significantly higher mortality.

A higher percentage of northern pike were deeply hooked by single hooks baited with live fish (63.5 percent of 63 fish) than on treble hooks (42.5 percent of 87 fish) in Holland (Reimens 1978). The overwinter mortality (December–May) of these deeply hooked fish was 13 percent while natural mortality was considered to be zero percent and two percent for pike caught in the mouth. The mortality of these fish may have been greater if the fish were caught during the warmer summer months similar to that reported by Hunsaker *et al.* (1970). About ten months after hooking, approximately one-half of the deeply embedded hooks had disappeared from the pike (62 percent of the single hooks and 54 percent of the treble hooks) as revealed by dissection of the fish (Reimens 1978). Since more fish were deeply hooked on single hooks than on treble hooks, one can assume that a higher percentage of these fish were also lost to hooking mortality.

In an indirect estimate of hooking mortality of coho salmon from single and treble hooks, Lasater and Haw (1961) concluded that there was no significant difference in mortality between the two types of hooks. About one-fifth of the salmon caught on either type of hook were later recovered (24.3 percent of 70 fish caught on treble hooks and 20.2 percent of 110 fish caught on single hooks). Lasater and Haw suggested that single hooks hooked more fish and held as well or better than treble hooks, although the differences were not statistically different.

One possible explanation of the higher mortality with single hooks versus treble hooks on lures is that lures resemble or mimic forage fish and are fished rather quickly through the water and, therefore, are engulfed by the game fish. Another possibility is that lures with treble hooks cannot be taken into the mouth as deeply without hooking the fish.

Variability of Hooking Mortality

The range of estimates in hooking mortality in Tables 2, 3, and 4 were made by different investigators under different conditions and do not indicate the variation in hooking mortality if the conditions of the experiments were similar. The factors that could affect estimates of hooking mortality include the species of fish, size of fish, sample size, hook size, anatomical site of hooking, angling technique, and different water temperatures. The intensive work of Warner (1979), however, provided an indication of the variability in estimating hooking mortality since it was (1) supervised by Warner, (2) on a single species (Age II *Salmo salar*) (3) with large sample sizes, (4) using four types of terminal gear, and (5) conducted under comparable conditions – spring (Figure 8). Note that a wide variation occurred in estimating the hooking mortality in this species although conditions were fairly similar and the main variable was different experiments (also different years, 1976-78). Obviously, the mean value would be the best estimate to use for determining the extent of fish loss from hooking mortality since it includes all of the variables inherent to such experiments. Using similar logic, the mean values that are represented in Figure 9 would be the best estimates to use for purposes of comparing the mortality of salmonids caused by angling using bait, lures, or flies under variable conditions. Only salmonids are considered in this graph since most studies of hooking mortality pertain to this group of fish. The range of estimates in hooking mortality in this graph indicates that the difference is greatest between bait (mean, 25 percent) when compared to lures (mean, 6.1 percent) and flies (mean, 4.1 percent). Although the percentages are low for lures and flies, lures caused about one-third (32 percent) more mortalities than flies. In contrast, hooking mortalities caused by bait fishing were 4.1 times greater than for lures and 6.2 times greater than for flies. These values, of course, are relative but allow comparison of the differences that were observed in estimates of hooking mortality involving 9,062 fish.

Barbed Versus Barbless Hooks

Fly fishermen have used barbless hooks to reduce the damage to fish from hooking or removing hooks and "purists" would use only barbless hooks. The variation in hooking mortality caused by using barbless hooks on lures or flies ranged from 0.8 to 10.5 percent with a mean of 3.04 percent in eight studies (Table 5). The mortalities to 513 fish using flies with barbless hooks

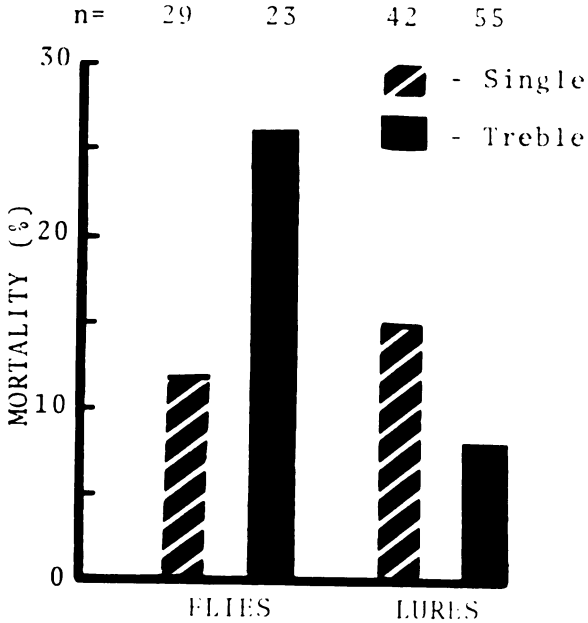

Figure 7. Comparison of hooking mortality in Atlantic salmon from two types of hooks on flies and lures. (Adapted from Warner 1978).

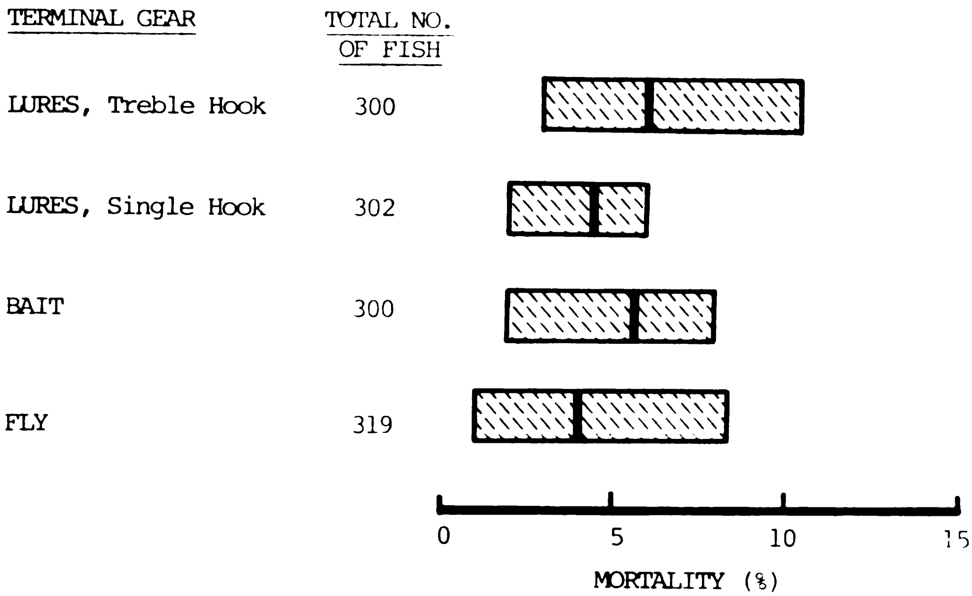

Figure 8. Mean (thick vertical line) and range of hooking mortalities from four types of terminal gear during three years. (The sample sizes (≥ 100) were about equal for each year. Adapted from Warner 1979).

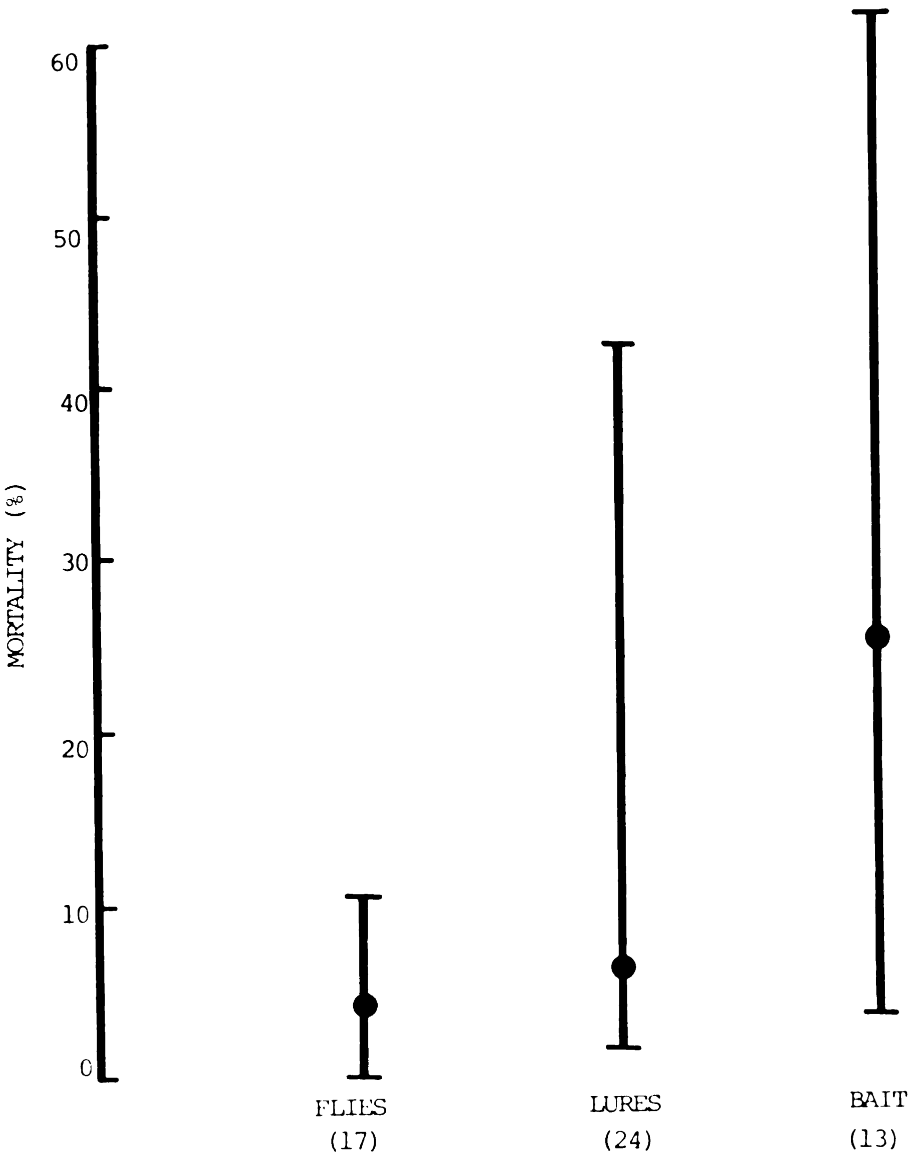

Figure 9. Summary of hooking mortality in salmonids from three types of terminal tackle with barbed hooks under different environmental and physiological conditions. (The dots represent the means and the vertical lines represent the range of values for individual studies. The number in parenthesis under each type of terminal tackle represents the number of studies involved. Data from Tables 2, 3, and 4.).

Table 5. Summary of research on hooking mortality for fish caught and played on artificial flies or lures with barbless hooks.

Species 1/ Common Name	Scientific Name	Type of gear	Hooking Mortality (%)	Number of fish	Water Temperature (°C)	Location	References
Northern pike	Esox lucius	Lure	10.5	19	11-13.5	Manitoba	Falk and Gillman (1975)
Cutthroat trout	Salmo clarki	Fly	3.3	60	4.5-16.75	Wyoming	Hunsaker, Marnell, and Sharpe (1970)
" "	" "	Lure	6.0	100	4.5-16.75	"	" " " " "
" "	" "	Fly	0.8	264	7	Idaho	Bjornn (1975a)
" "	" "	Lure	1.2	166	7	"	" "
Rainbow trout	Salmo gairdneri	Fly	3.9	129	15.5	Washington	Wydoski (1970)
Trout	- -	Fly	5.0	60	-	New Mexico	Thompson (1946)
Lake trout	Salvelinus namaycush	Lure	7.0	57	-	Manitoba	Falk, Gillman, and Dahlke (1974)
Combined			3.04 (0.8-10.5) 2/	855	-	-	-

1/ Fish species are listed alphabetically by scientific name.

2/ Range of hooking mortalities reported by various investigators.

was 2.34 percent which was 41 percent less than the mean value of 4.05 percent in Table 4. Similarly, the mortality to 342 fish using lures with barbless hooks was 4.05 percent which was 32.4 percent less than the mean value of 6.1 percent in Table 3. These values are relative since the sample sizes in Tables 3 and 4 are 5.3 and 10.5 times as large as those for studies using barbless hooks. A more realistic comparison is made in Figure 10 where seven studies compared the two types of hooks on flies and lures for several fish species. In these studies, the use of barbless hooks did not significantly reduce hooking mortality and in two studies (Hunsaker *et al.* 1970; Falk and Gillman 1975) barbless hooks on lures caused higher mortalities than lures with barbed hooks but the results were not significant.

These results indicate that the use of barbless hooks does not significantly reduce losses of fish from hooking mortalities and that restrictions requiring the use of barbless hooks are not biologically justified on that basis alone. These comments are contrary to what is believed by many purist fly fishermen and the fish manager will, no doubt, continue to be challenged about these findings in the future. However, one benefit that could result from the use of barbless hooks is that handling time is reduced because the hook can be more easily removed from the fish or a landing net (Falk *et al* 1974). Since handling (see next section of this paper) can be more important than hooking in overall mortality, this factor could be an important consideration to quality angling.

Importance of Handling or Injury

Fish have been known to be affected by handling (Hattingh and van Pletzen 1974; Miles *et al.* 1974; Wardle 1974; Wedemeyer 1972). Therefore, the effect of handling during capture by angling should be discussed in a coverage of hooking mortality. The effect of handling fish that swallowed bait deeply was already shown to be extremely important and a substantial reduction in mortality can be realized if the hook is left in place (Figure 4) rather than removing the hook (Mason and Hunt 1967; Warner 1979). Warner (1976) recognized that playing time of fish caught during angling could be an important factor in mortality and he minimized the time for playing the fish used in his studies. Marnell and Hunsaker (1970) performed an experiment to determine the effect of fatigue as a function of playing time on mortality (Figure 11). The sample sizes for each group of fish was 100; the control fish were captured by electrofishing. The estimates of mortality between the three groups ranged between four and six percent but were not significantly different. However, the majority of rainbow trout (87 percent of 16 fish) that were caught by angling in another study (Bouck and Ball 1966) died after being played to exhaustion. Horak and Klein (1967) reported that 7.9 percent of 101 fish caught on flies and played until exhaustion died. However, Horak and Klein did not find a significant difference in the performance index (arithmetic mean of time until exhaustion in a stamina tunnel) of fish captured by fly fishing and the controls. In studies designed to determine the effects of capturing steelhead by angling, Reingold (1975) reported that no apparent effect of angling was found in the ability of fish to return to a hatchery facility and Pettit (1977) found that steelhead caught by angling had similar reproductive success to fish that were not caught by angling. The handling techniques used in tournaments for largemouth bass *(Micropterus salmoides)* have been more important in lowering survival than capture and playing of these fish by angling (Gustaveson 1977; Holbrook 1975). Although the results are variable, the method of handling has been shown to be important in the survival of fish caught by angling. The adverse affects of handling fish during capture by angling can be reduced by (1) minimizing the handling time and (2) taking care not to damage vital organs by squeezing a fish or holding the fish by the gills. Mortality of fish caught in tournaments can be further reduced by using aerated live wells and holding such contests when water temperatures are cooler. The use of bait has already been demonstrated to cause the highest mortality among fish captured by various types of terminal gear. Although other studies have also shown or suggested that swallowing bait and high water temperature can increase the mortality of angler-caught fish, the results of Hunsaker *et al.* (1970) clearly illustrate both concepts in Figure 12. In general, the anatomical site of hooking is the most important aspect related to initial mortality of angler-caught fish since it reflects the possibility of injury to a vital organ. This concept is best

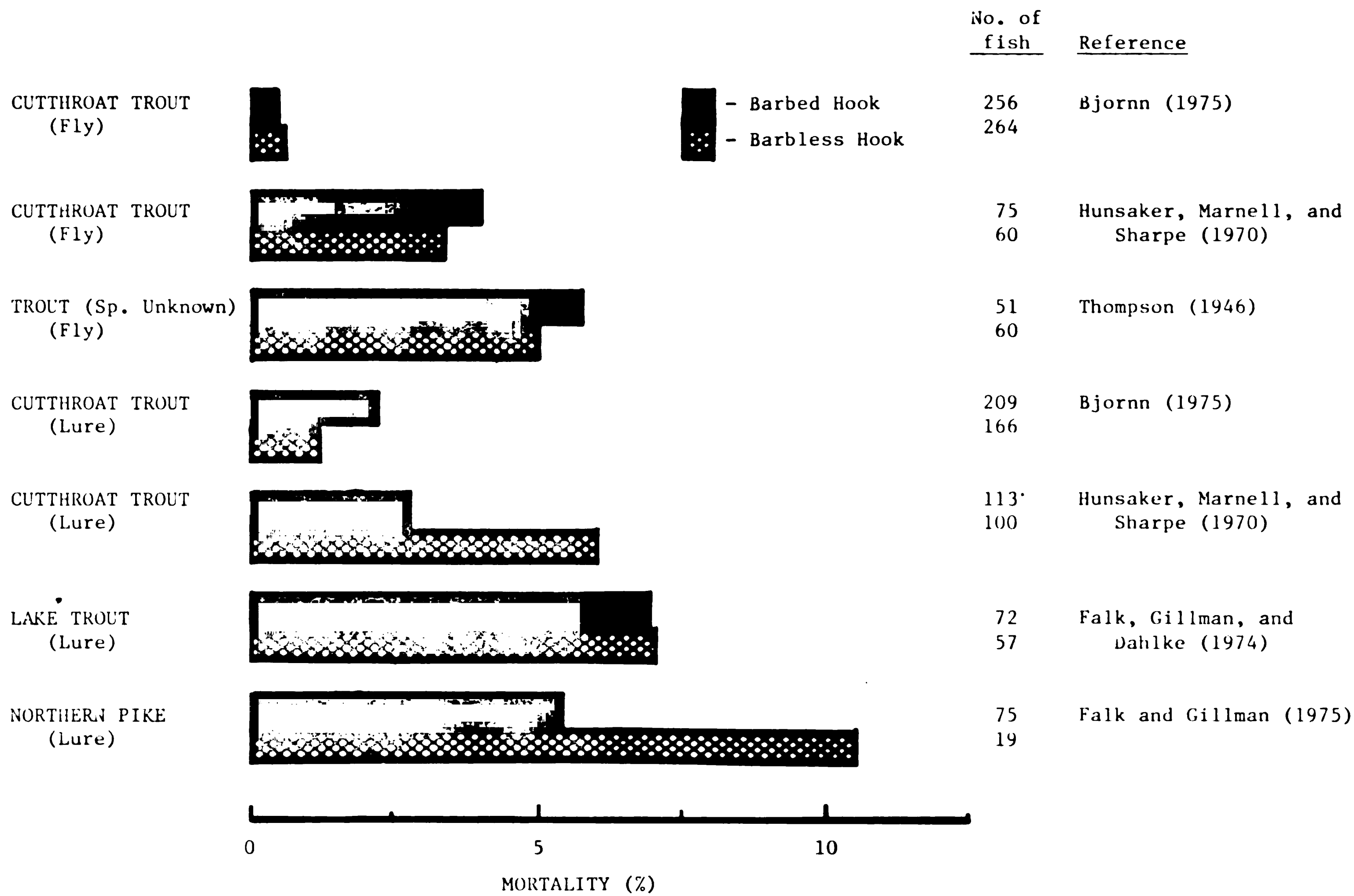

Figure 10. Comparison of hooking mortality caused by barbed or barbless hooks used on flies or lures.

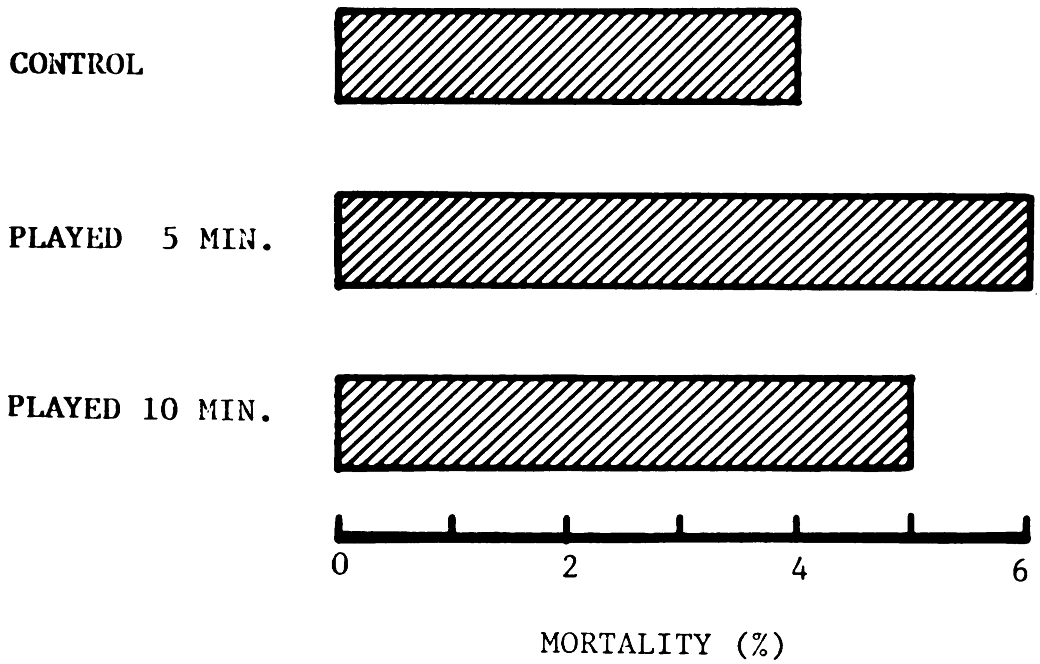

Figure 11. Hooking mortality of cutthroat trout from Yellowstone Lake that were caught on lures for 5 or 10 minutes. (Data from Marnell and Hunsaker 1970).

illustrated by the data of Warner (1979) since he had a large sample of 1,221 fish (Figure 13). Note that the mortality was highest when the fish were hooked in the esophagus or gill region. In either case, the vital organs such as the heart or the gills are damaged and result in bleeding. Warner (1978) reported that Atlantic salmon that bled after hooking had a 37 percent mortality which was significantly higher than the ten percent loss of fish that did not bleed. In another study, Atlantic salmon that bled following hooking exhibited an 86 percent mortality that was significantly greater than the 15 percent mortality of fish that did not bleed (Warner and Johnson 1978). In a hatchery experiment, over half (56 percent) of the largemcuth bass that were hooked in the esophagus died whereas the mortality from damage to other sites ranged from zero to four percent (Pelzman 1978).

Initial Versus Delayed Mortality

Most fish that have a vital organ damaged from a hook have an initial mortality that may be immediate or occur within the first 24 hours. For example, Klein (1965) demonstrated that the majority of the rainbow trout (> 50%) were dead within 24 hours (Figure 14). However, Klein emphasized that lures with a single hook were taken farther into the fish's mouth and resulted in a more serious wound than treble hooks. As a result, almost all fish caught on single hooks died within two days while those caught on treble hooks died more gradually because their wounds were not as serious (Figure 14). Similar results were obtained by Stringer (1967) for rainbow trout that were caught on various types of terminal gear (Figure 15). In another study (Bouck and Ball 1966), however, rainbow trout that were caught on lures and played to exhaustion did not exhibit mortality initially but died from progressive shock – about 20 percent of the fish died three days after being hooked, slightly less than 60 percent by day four, nearly 80 percent by day five, and 87 percent by day nine (Figure 16). The cumulative mortality of rainbow trout that were deeply hooked using bait is illustrated in Figure 17 (Mason and Hunt 1967). Nearly 50 percent of these fish died on the first day and about 75 percent of the fish died by day five. The last fish, however, died during the second month after being hooked.

Falk *et al.* (1974) suggested that a four day period is adequate to obtain an estimate of hooking mortality. If hooking causes damage to the vital organs such as the gills or the heart, the immediate mortality (within 24 hours) will provide a reliable estimate of fish losses from hooking. If the angling technique causes fatigue in the fish, delayed mortality may be more important and should be considered in estimating total mortality from hooking. Fish that are deeply hooked using bait may not be able to feed or the hook may eventually penetrate a vital organ and such mortality may not be detected for some time (e.g., Mason and Hunt 1967). In some species (e.g., northern pike), even deeply swallowed hooks did not affect growth which indicated that the fish may continue to feed even with a hook in its esophagus or stomach (Reimens 1978). The average mortality of largemouth bass that were caught in fishing tournaments was about 21 percent initially in 25 tournaments but an additional 12.5 percent delayed mortality was reported in eight tournaments (Holbrook 1975). In the eight tournaments where initial and delayed mortalities were estimated, the total mortality was 33.5 percent. Peltzman (1975) reported about two-thirds (62.5 percent) of the largemouth bass were lost during the first day after hooking in a hatchery experiment and that slightly over one-third (37.5 percent) accounted for the delayed mortality. Delayed mortality should be considered in estimating losses of fish from hooking, particularly if angling pressure is high, since not all released fish will survive. In some instances, delayed mortality may be significant in the effective management of quality fisheries.

SUBLETHAL HOOKING STRESS

Fish must continually adjust to changing biological, chemical, and physical factors in aquatic environments (Brett 1958). They differ from other vertebrates in a number of ways but probably the major difference is that they must maintain homeostasis of their internal body fluids through their physiological processes affecting osmosis (Wydoski and Wedemeyer 1976, provide a concise review). Although "stress" has been frequently mentioned in fisheries literature, Brett (1958) proposed a working definition for stress as "a state produced by any environmental factor which

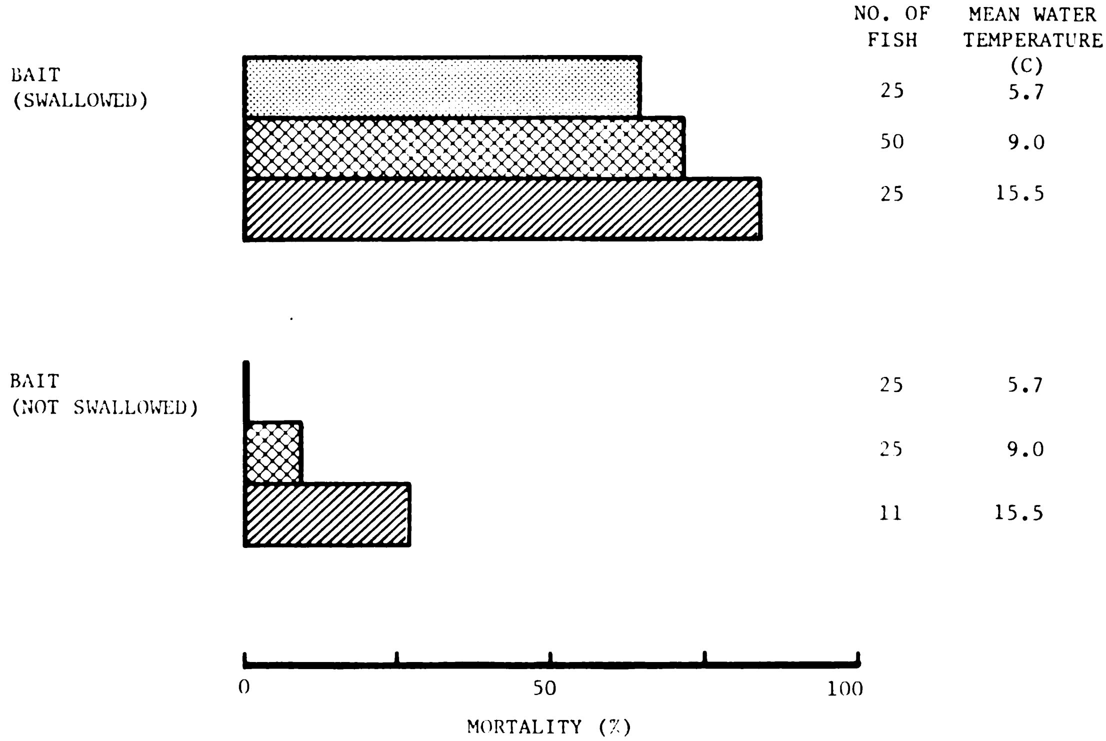

Figure 12. The effect of water temperature on hooking mortality of cutthroat trout. (Adapted from Hunsaker, Marnell, and Sharpe 1970).

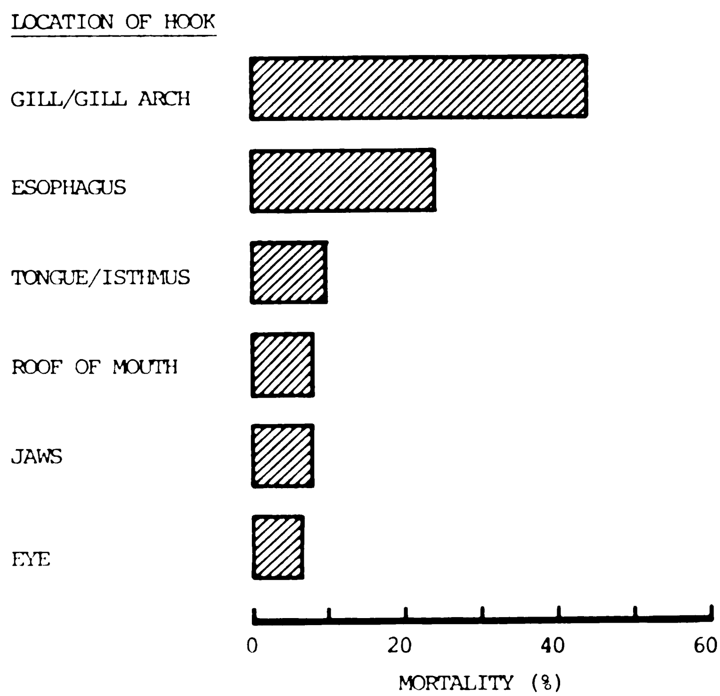

Figure 13. Mortality of Atlantic salmon related to the anatomical site of hooking on four types of terminal gear. (The sample size was 1,221 fish. Adapted from Warner 1979).

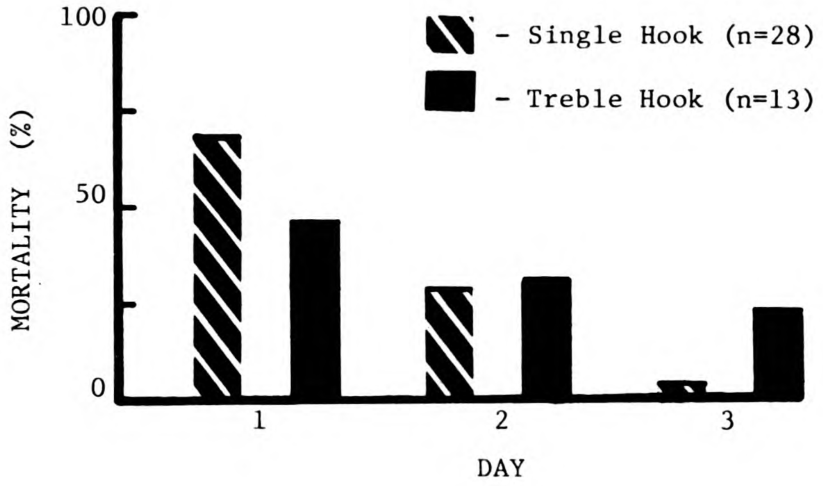

Figure 14. Effect of delayed hooking mortality in rainbow trout from two types of hooks on wobbling lures. (Water temperature was 14.5 C (58 F). Adapted from Klein 1965).

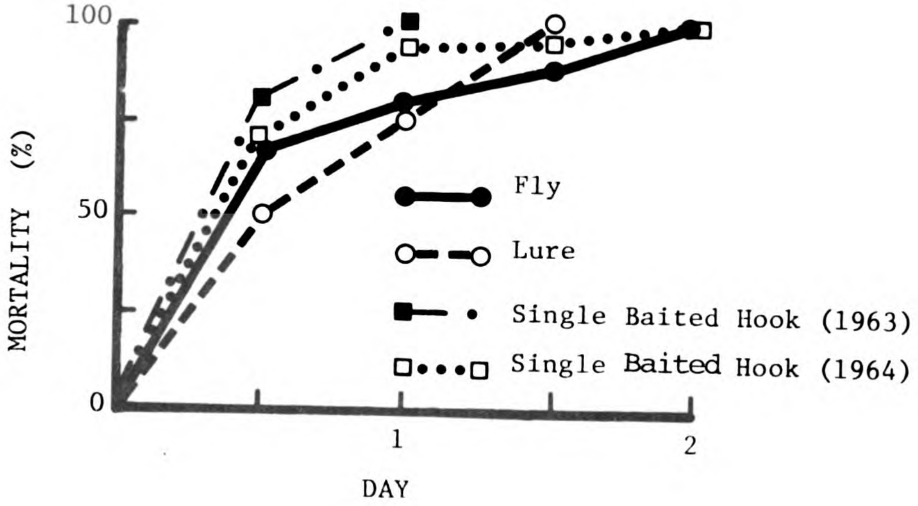

Figure 15. Cumulative mortality of rainbow trout caught on three types of terminal gear. (Water temperature was 15-17 C. Adapted from Stringer 1967).

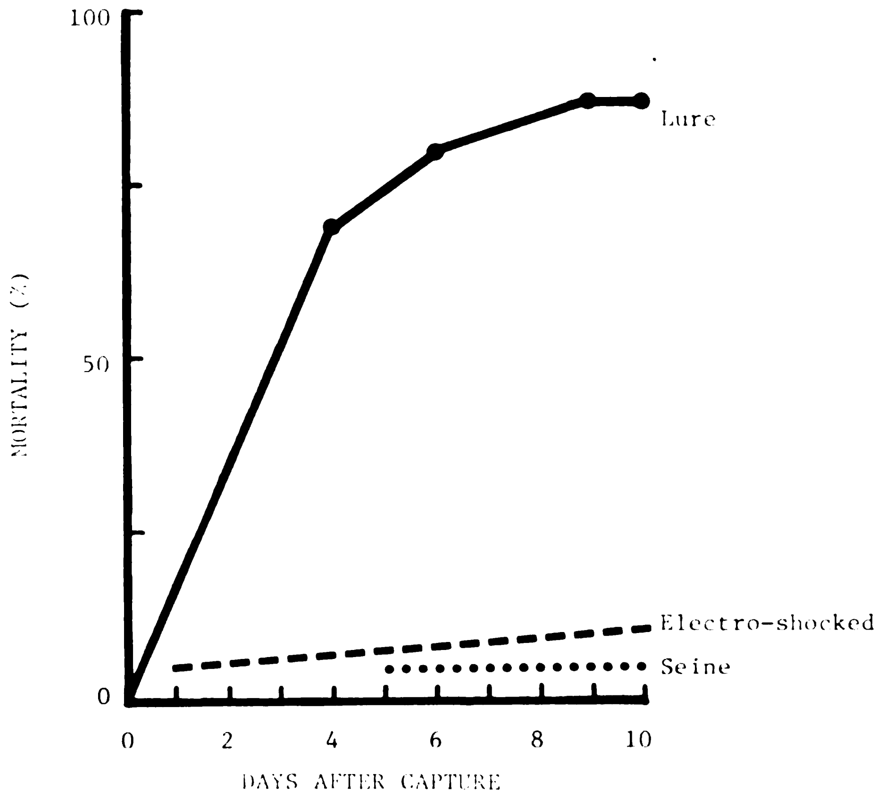

Figure 16. Cumulative mortality of rainbow trout after capture by three different methods. (Sixteen trout were captured by each method. Water temperature ranged from 6-10 C. From Figure 2 of Bouck and Ball 1966).

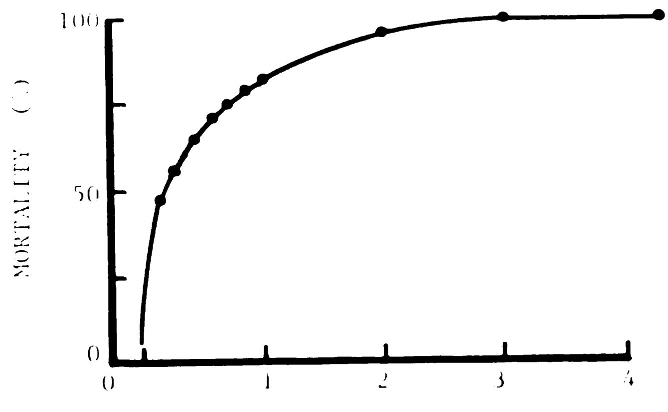

Figure 17. Cumulative mortality of 69 deeply hooked rainbow trout in which a No. 8 hook was not removed. (The last fish died during the second month after being hooked. Adapted from Mason and Hunt 1967).

extends the normal adaptive responses of an animal, or which disturbs the normal functioning to such an extent that the chances of survival are significantly reduced." The primary effects of stress are mediated by neuroendocrine responses that, in turn, elicit secondary effects as changes in metabolism and osmoregulation (Mazeaud *et al.* 1977, provide a review of the stress concept). When fish are stressed, the General Adaptation Syndrome (GAS) of Seyle indicates the reaction that is elicited (Schreck 1976). This response is categorized by: (1) an "alarm" phase where the immediate reaction of the fish is manifested in changes in the primary (neuroendocrine) effects and secondary (metabolic and osmoregulatory) effects (Mazeaud *et al.* 1977), (2) a "resistance" phase that is characterized by changes in metabolism of the organism as it attempts to maintain homeostasis, and finally (3) a phase where the organism can adapt to the stress or it becomes exhausted and dies. Although a fish may not die immediately from a stress such as that imposed on it from being caught and played by an angler, it may die later particularly if it has already been subjected to other stresses since the metabolic disruptions are cumulative.

Problems in Measuring Stress

Many pathological or physiological conditions can be identified by routine, clinical tests of blood chemistry in human and veterinary medicine Changes in the blood chemistry of fish can also be used effectively as an indicator of stress (Mazeaud *et al.* 1977). Various problems exist for thorough physiological monitoring of fish, especially wild populations, in (1) standardization of analytical methodology, (2) establishment of normal values of blood chemistry, (3) responses of fish to capture or handling, and (4) physiological changes due to other environmental factors such as water quality and condition of the fish that may be affected by nutrition, parasitism, or disease (Wydoski and Wedemeyer 1976).

Some of these problems are now being solved. For example, Wedemeyer and Yasutake (1977) provided an excellent reference of clinical methods to be used to determine the blood chemistry of fish and they also provided an outline to help interpret the results of blood chemistry values. Also the reliability of blood chemistry indicators of stress such as changes in blood glucose values has been supported by research (e.g., Hattingh 1976; Narasimhan and Sundararaj 1971).

Physiological Responses

The physiological processes of fish are continuously changing to maintain homeostasis from various stresses. Most of these stresses produce changes in the blood chemistry of fish that are reflected in metabolism or osmoregulation. Although one would expect the primary (neuroendocrine) effects of stress to occur rather quickly (i.e., immediately) in a fish, one might expect the secondary (metabolic) effects to occur much later (e.g., hours). While this concept is somewhat true, some secondary effects of stress can occur much more quickly than was realized (Figure 18, Wydoski *et al.* 1976). Note that the plasma osmolality of hatchery rainbow trout showed an immediate decrease that could be detected within one minute of playing time. This change was due to changes in the ionic components of the plasma that reflected disturbances in osmoregulation of these fish. This change was significantly different ($p < 0.05$) from the control (zero minute) value by three minutes of playing time. The wild fish did not exhibit any marked changes regardless of how long they were played on a hook. The secondary effect on plasma glucose was similar for these rainbow trout. Significant differences occurred in the glucose values after three minutes of playing time in the hatchery fish and after five minutes in the wild fish. Wydoski *et al.* (1976) also demonstrated that hooking stress caused greater differences in the blood chemistry of larger than smaller hatchery rainbow trout and that higher water temperatures aggravated the delayed hyperglycemia and hyperchloremia of both wild and hatchery fish. No mortality was observed from the physiological disturbances and the fish recovered from the hooking stress in about three days at 4, 10, and 12 C. It is noteworthy that only fish that were not deeply hooked and were not bleeding from a hook injury were used in the experiments (i.e., no vital organs were damaged by a hook). In another study, I measured blood lactate to determine metabolic fatigue as affected by different lengths of playing time in cutthroat trout. The trout were planted as 7.5 cm fingerlings and fed on natural foods in a northern Utah reservoir. The

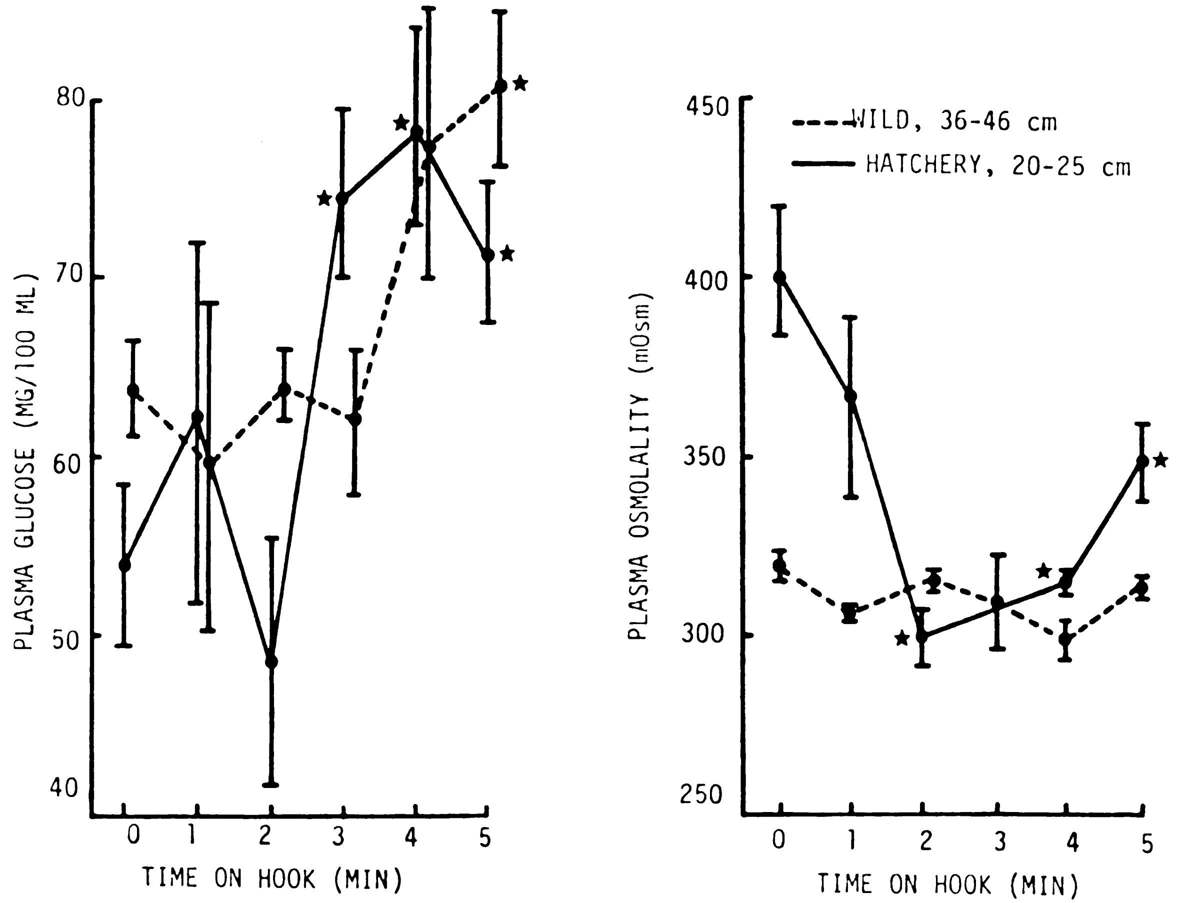

Figure 18. Comparison of disturbances in plasma glucose and osmolality of hatchery and wild rainbow trout following 0-5 min of hooking stress at 10-12 C. (Dots show the means and vertical lines the standard errors for groups of 5 to 10 fish. A star indicates significant difference from the initial level, p $<$.05. From Wydoski, Wedemeyer, and Nelson 1976.).

blood lactate had increased from about 48 mg/100 ml of blood to about 65 mg in one minute of playing time – a significant ($p < 0.05$) difference (Figure 19). The blood lactate increased to about 75 mg/100 ml of blood in five minutes of playing time, continued to increase (to nearly 120 mg/100 ml) after one hour of recovery time, and returned to nearly normal values by 24 hours of recovery. Increases in blood lactate with exercise were also reported for other species (Black 1955; Callouet 1971; Driedzie and Klieniuk 1976).

The effect of water temperature on the blood lactate level with playing time on a hook was best demonstrated for largemouth bass by A.W. Gustaveson and myself (Gustaveson 1978). At 11-13 C, the blood lactate of largemouth bass increased from the zero-minute playing time (control value) of about 30 mg/100 ml of blood to about 50 mg/100 ml after five minutes of playing time. However, at 28-30 C, the blood lactate level at zero-minute playing time was about 55 mg/100 ml of blood that increased steadily to about 115 mg/100 ml. The blood lactate value had decreased to approximately the control value in 24 hours in experiments at 11-13 C and 16-20C. This study demonstrated that internal metabolic or osmoregulatory disturbances caused by playing largemouth bass were sublethal if a vital organ is not penetrated by a hook.

Overexertion or hyperactivity of fish has been suggested as a cause of death in fish (Huntsman 1938; Black 1958; Callouet 1971). Although the exact mechanism is not fully understood, acidosis of the blood from the buildup of lactic acid appears to be a contributing factor. During short bursts of activity such as when a fish is being played during angling, the poorly vascularized white muscle is commonly used and energy is supplied by anaerobic glycolysis. The increase in the concentration of lactic acid produces an oxygen debt since the oxygen-carrying capacity of the blood is lowered through the Root effect. Some investigators (e.g , Black 1958; Parker and Black 1959; Parker *et al.* 1959) suggested that if lactic acid levels increased above a certain "critical" level, then the fish would die from blood acidosis since it was no longer able to maintain homeostasis of its body fluids. This hypothesis produced some confusion since all fish that reached or exceeded this "critical" limit of lactic acid did not die (Parker and Black 1959; Parker *et al.* 1959). In the past decade. research on various forms of cellular enzymes has increased and perhaps allows a refinement of the hypothesis on "lactic acidosis." Various isozymes, which are different molecular forms of an enzyme that can catalyze the same chemical reaction but under different conditions, have been determined through the technique of electrophoresis. One such enzyme, lactate dehydrogenase (LDH) has been found to be genetically influenced by simple Mendelian inheritance (Stillings 1974). The kinetics of the three forms of LDH were studied in detail by Kao (1977). Rainbow trout (Beity strain) with the three different LDH phenotypes were tested under low levels of dissolved oxygen (2 mg/l) at 1.5 body lengths per second in an active respirometer by Klar (1978). The blood lactate for the homozygote dominant LDH phenotype increased about four-fold in about 15 minutes but then became stable and did not increase any further for another hour when the experiment was terminated. The blood lactate level in the homozygote recessive LDH phenotype continued to increase throughout the 75 minutes of testing in the active respirometer and nearly a third ($n = 13$) of the fish died within 24 hours. The blood lactate level of the heterozygote LDH phenotype (hybrid) was intermediate between the other phenotypes. No fish from the homozygote dominant LDH phenotype or the heterozygote (hybrid) phenotype died even after fatigue.

Perhaps the loss of fish after a certain "critical" blood lactate level is reached could be explained by the LDH isozyme; those fish possessing the homozygote dominant LDH phenotype could control the blood lactate physiologically while the other phenotypes could not. Studies of population genetics such as Kao (1977), Klar (1978), and Northcote *et al.* (1970) will provide more complete answers to the physiological adaptations of fish.

Bouck and Ball (1966) suggested that delayed mortality of rainbow trout stressed by angling could have been due to progressive shock. They suggested the cause of this shock could be due to excessive blood lactate levels in conjunction with shortened clotting time of blood in stressed fish that could produce *in vivo* clotting ensuing in delayed mortality. Their explanation is supported by Casillas and Smith (1977) who also found that the blood clotting time in rainbow trout decreased

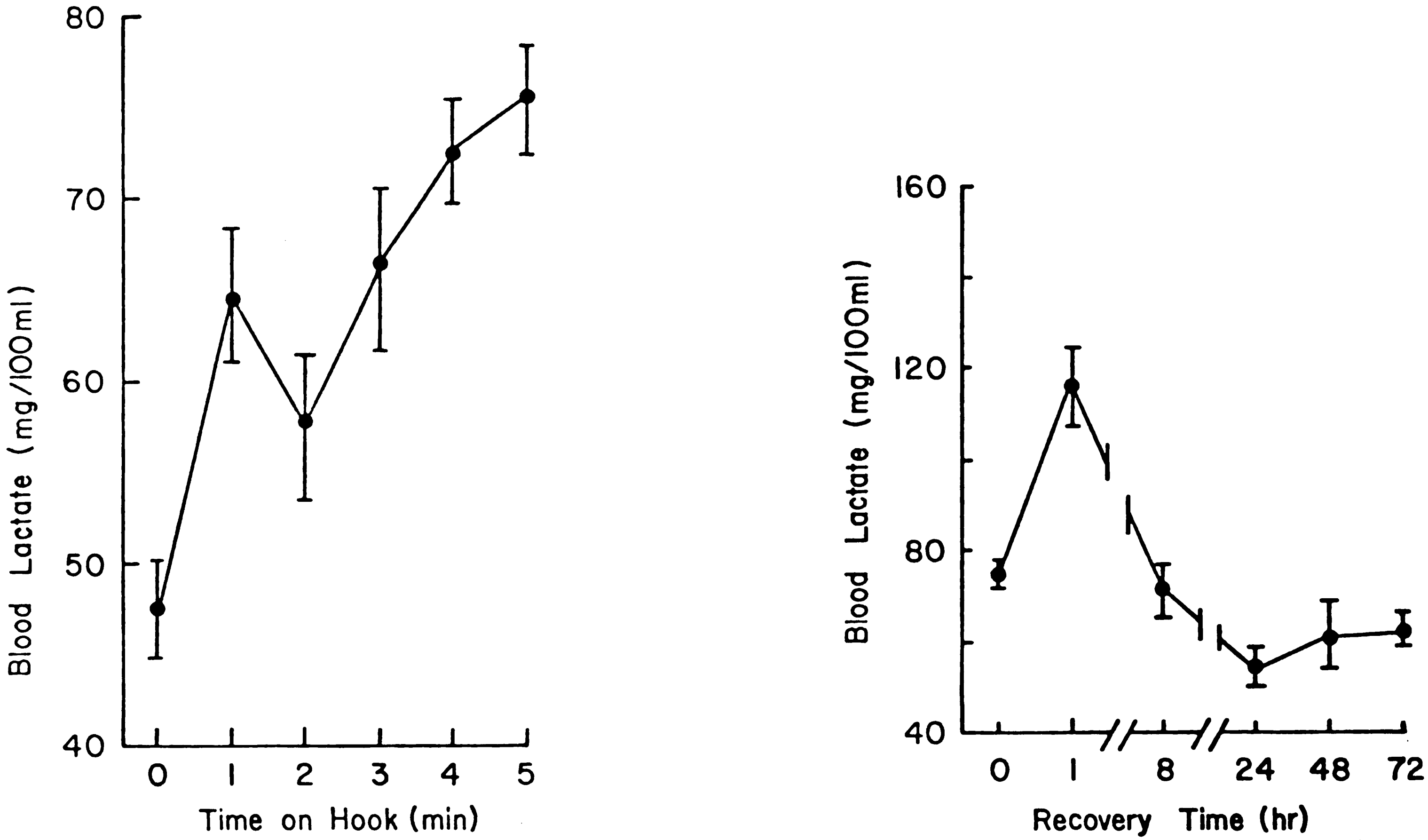

Figure 19. Changes in the blood lactate levels of cutthroat trout after being played 0-5 min. and during recovery from 0 through 72 hr. at 15.5 C. (Unpublished data).

significantly with stress and that wild fish recovered more quickly than hatchery trout. Casillas and Smith pointed out that intravascular coagulation of blood has been neglected as a possible cause of delayed mortality in the past but that such clotting may, in fact, be an extremely important factor.

APPLICATIONS OF FINDINGS TO QUALITY FISHERY MANAGEMENT

Regulations will continue to be an important tool in fishery management, especially as they will relate to establishing or maintaining quality fisheries (e.g., Hunt 1970, 1975; Klein 1974b; Latta 1973; Martin 1979; Shetter and Alexander 1965; Snow and Beard 1972). The following statement by Everhart *et al.* (1975) concisely summarizes reasons for various regulations: "Fisheries have been regulated on the basis of politics, social pressure, gear competition, prejudice, whim, and sometimes for biological reasons." Although the biological ramifications of regulations should always be an important factor, the economical, political, and sociological constraints that are placed upon a manager must also be considered (Wydoski 1976). Obviously, certain kinds of regulations may be accepted by certain anglers but be opposed by other types of anglers. For example, some anglers (Clawson's incidental or active anglers) may wish to participate in snagging of salmon that are excess to hatchery needs while this practice may be vigorously opposed by other types of anglers such as Clawson's "purist" category (Haw and Mathews 1969; East 1975). Anglers in many states oppose spearfishing as an angling technique but some studies have shown that their catch-per-effort is about the same as for anglers using conventional tackle (Kempinger 1968). Conversely, the "purist" angler may favor fishing-for-fun programs (Christensen 1965; Lennon and Parker 1960; Ortman 1976; Patterson 1974; Stroud 1964). However, Stroud (1976) has emphasized that all anglers want to catch fish.

Future programs in fishery management will need to be concerned with the opinions, preferences, and satisfaction of various types of anglers. Even economics can be used as a basis for managing a fishery since fishing is a commodity that can be a good, e.g., a fish that is wanted by the consumptive angler or a service, e.g., catch-and-release fishing that is wanted by a different less consumptive clientele (Gordonn *et al.* 1973). For quality fishery programs such as catch-and-release angling the factor of catchability of the fish will become even more important (Anderson and Heman 1969; Beukema 1969, 1970; McLaren 1970; McLaren and Butler 1970; Rieger *et al.* 1978).

Significance of Hooking Mortality

The type of terminal gear was clearly shown to be extremely important in angling mortality. Bait caused the highest average mortality of 25 percent (range 3.3-61.5 percent) followed by lures (mean 6.1 percent, range 1.7-42.6 percent), and flies (mean 4.05 percent, range 0.0-11.3 percent). In waters that are fished by "incidental" or "active" anglers, bait will continue to be used extensively and the increase in the U.S. angling clientele will be composed of similar anglers. In waters where regulations govern the type of terminal gear that is used, the "active" angler and "purist" will use lures and flies. Although an evolution from incidental to active to purist will occur among anglers, most of the anglers in the future will be novice anglers who will use bait as a terminal gear where it is legal to do so. Therefore, the importance of hooking mortality will increase as anglers demand more quality as reflected in numbers and sizes of fish that are available to the angler (Anderson 1975; Clady *et al.* 1975; Encland and Fatora 1974). Although most states have been altering policy to include special gear restrictions or special fisheries in some waters, Frome (1975) has proposed that even broader policy be established by conservation agencies to meet the needs of all of the American public and Seaman (1969) suggested that management agencies should strive for quality.

This summary of research on hooking mortality has provided other insights into management implications. Single hooks have generally been found to cause higher mortality than treble hooks when used with bait or lures as the terminal gear. Flies often are tied with small single hooks that usually are not taken deeply by fish and consequently do not cause high hooking mortalities. In specialized fisheries, however, single hooks with a large bite (distance from shank to barb) and long shank (Wydoski 1970) or on treble hooks to resemble a bait fish (Warner 1978) may be engulfed deeply causing higher mortality. Therefore, the voracity of feeding by the fish that may be a function of species, food habits, or water temperature should also be considered by the manager. The use of barbless hooks did not significantly reduce mortality when compared to barbed hooks in studies where the two types of hooks were compared together (Figure 10) but the use of such hooks reduces handling time of fish that could be an important factor in survival. Average rates of hooking mortality can help guide the fishery manager in determining the importance of such loss in various fishery programs because average rates include numerous variables. The initial mortality that is observed may not reflect the total loss of fish since delayed mortality can also be significant in some instances. Probably the most important factors to consider in the overall loss of fish from hooking mortality are the type of terminal gear, species differences in feeding, water temperature, and the anatomical site of hooking.

Significance of Sublethal Hooking Stress

Metabolic and osmoregulatory disturbances were demonstrated to occur in fish following stress from capture and handling by anglers. These disturbances are not directly lethal if the fish are in good physiological condition when captured. However, stresses are cumulative and sublethal hooking stress may result indirectly in mortality by allowing the fish to be more susceptible to predators, diseases, or parasites (e.g., Esch *et al.* 1975; Snieszko 1974; Wedemeyer 1970; Wedemeyer and Wood 1974). Also, other environmental stresses may already be affecting the fish (Brett 1958). Various pollutants may add to the overall stresses imposed on a fish (Cairns *et al.* 1976; Sprague 1976) and result in altered behavior of aquatic organisms (Kleerekoper 1976). The significance of sublethal hooking stress, therefore, is probably not too important in angling mortality unless other stresses are already acting upon the fish. Further application of population genetics may result in managing fish that possess morphological, behavioral, or physiological traits that are superior in certain fishery programs (Smith *et al.* 1976).

Relation of Quality Angling to Productivity of U.S. Waters

The productivity of any water is influenced by biological, chemical, and physical factors that are continuously interacting in the environment. Man has altered waters in many ways by destroying habitat, pollution, de-watering, and other ways. Such man-made alterations have destroyed aquatic habitats and jeopardized some species so that they have become threatened with extinction. Consideration of ecological stability of ecosystems would help to minimize the impacts on fish and wildlife resources and, in fact, could improve habitat for fish and wildlife (Wydoski 1977). Through understanding of fish ecology and behavior, the quality of a fishery may be greatly enhanced. A unique example is the restoration of the cutthroat trout fishery in the St. Joe River in Idaho where the fishery was essentially catch-and-release because of a 13-inch minimum size limit (Bjornn 1975b). Another example is the Atlantic salmon fishery in Hosmer Lake, Oregon (Montgomery 1971). Behnke and Zarn (1976) have pointed out that the idea of promoting angling for a rare fish species may appear contradictory to the goal of increasing its abundance. However, they also emphasized that if the habitat of the species is restored or if the fish are re-established into waters in their former range, certain subspecies of cutthroat trout could have significant potential management value. By understanding the habitat requirements of fish (Tebo 1975), instream flow needs (Orsborn and Allman 1976) and other factors such as the fundamentals of fish conservation (Eschmeyer 1954), policies and guidelines for effective fishery management can be formulated such as the first attempt by the Colorado Division of Wildlife (1974). Since the productivity of any water is limited, species that are highly vulnerable to angling such as the cutthroat trout in Yellowstone Lake can and do respond quickly to no-kill rules (Varley 1976). Often the faster growing fish in a population are cropped off as soon as they reach the legal minimum length such as the brook trout populations described by Cooper (1949).

Regier (1971) pointed out man's indifference to fishery resources by stating:

> It seems surprising that we, as a society, have never really been concerned about the collapse of stocks, the transformation of communities, and the extinction of fish species. Unlike the bird fanciers, we have very little, if any, subjective concern about the welfare of fish.

That statement could apply to quality fishery management such as catch-and-release fishing programs. Once the problem of overfishing has been identified, managers must provide and implement solutions for the best management of any water based upon its productivity (Massman 1975). In the more productive waters of southern United States, the losses from hooking mortality may be relatively insignificant to the overall angling quality but this factor may be extremely important in the less productive waters where numbers of fish and their growth rates are limited.

Public Education and Biopolitics

Regier (1971) pointed out that fishery managers could probably communicate more easily with the public and politicians if they used concepts that are already understood within the context of medical, economic, political, or mechanical systems. The American public has become increasingly more aware of environmental problems since the 1900's and will continue to become more involved in public policy decisions in the future (McEvoy 1973). Therefore, fishery managers should be certain that the public be "adequately informed" about the alternative consequences of social, economic, or environmental impacts (Cutler 1974). The fishery manager will need to use effective public relations to help influence politicians and the public in the proper direction for the best management of this nation's waters for recreational fishing opportunities (Gilbert 1971). Such public relations may include the art of biopolitics so that the general public can understand and accept policies, programs, or regulations that are proposed by conservation agencies (Kozicky 1969). Trelease (1976) stated that laws are mechanisms for getting things done for society and society can help to promote laws that will help to maintain and enhance sport fishing in the future. Finally, quality angling will be achieved only by effectively educating the public to become "quality" anglers – sportsmen who respect and develop a responsibility toward natural resource management (Zern 1978).

CONCLUSIONS

The management of people has been and will continue to be the most important aspect of sport fishery management, particularly if the quality of angling is to be maintained or improved. Sometimes managers may have the biological facts to solve a particular problem but the implementation of the solution may not be possible for economical, political, or sociological reasons. Despite all hurdles, however, managers must continue to apply the best principles and techniques that will maintain or enhance the quantity and quality of sport fishing. This challenge has been referred to concisely in the former motto of the Sport Fishing Institute – "To help shorten the time between bites" and its current motto: "Quality of angling reflects the quality of life."

The relation of hooking mortality and sublethal hooking stress to quality angling using catch-and-release fishing as a management tool may be extremely important as angling pressure becomes intense on U.S. waters. Creel limits may not produce a quality fishery because fishing mortality (i.e., harvest) can become excessive under high fishing pressure. Also, minimum size limits may be useless in a quality fishery if repeated hooking increases the mortality of undersized or trophy-sized fish. If the fish are already under stress from physiological disturbances (e.g., accumulation of toxic substances such as pesticides) or from habitat alterations (e.g., low dissolved oxygen, supersaturated nitrogen levels, adverse water temperatures, or lack of cover), the stress of disrupted osmoregulation or metabolism caused by angling and/or handling or alterations of fish behavior from the lack of suitable habitat, may increase mortality since stresses on animals are cumulative. Under such circumstances, two important factors that contribute to quality angling are reduced: (1) the size of fish available and (2) the number of fish available since it affects the success of anglers (i.e., catch per unit of effort).

In the future, fishery managers must be versatile but, at the same time, demand necessary changes to meet the increasing demands of anglers. These managers can accommodate the various kinds of anglers by (1) being adaptable to change (e.g., producing a balance between quality and quantity of fish for different anglers), (2) applying innovative techniques (including the art of biopolitics), (3) informing the public of the need for special programs (e.g., catch-and-release fishing), (4) motivating the public to demand changes for effective natural resource management from elected officials, and (5) applying research findings to practical and effective fishery management.

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KEYWORD INDEX

Because of the length of the literature cited section, references were grouped by selected keywords to aid the reader in identifying supplemental readings.

Angler Preference and Satisfaction

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