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Evidence of Handling Mortality of Adult Chum Salmon Caused by Fish Wheel Capture in the Yukon River, Alaska

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Abstract.—From 1996 to 1998, marked fish from a mark–recapture experiment were used to examine potential effects of fish wheel capture, handling, and tagging on adult chum salmon *Oncorhynchus keta* in the Yukon River, Alaska. Four fish wheels equipped with live holding boxes were used to capture fish, two at the marking site and two at the recapture site. During the 3 years of the study we annually marked 8,513–18,632 fish with individually numbered spaghetti tags; annual tag returns external to the mark–recapture experiment (not by project fish wheels) ranged from 594 to 1,007. Individual salmon were captured from one to four times in the four project fish wheels used in the mark–recapture experiment. Tag returns, interviews, carcass surveys, and data from other management projects indicated that the proportion of fish with marks decreased as distance from the marking site increased. Nine possible explanations for these observations were considered, but fish mortality associated with capture and handling appeared to be the most likely cause. Tags returned outside of the mark–recapture experiment were used to investigate the relationship between the capture history within the experiment and upriver recapture. Recapture probabilities declined significantly as the number of times a fish was captured increased. Our results raise concern over the relatively common use of fish wheels for gathering in-season management data and for other research purposes. We recommend more definitive investigation of these phenomena, a review of fish wheel construction and operation to minimize potential effects to salmon populations, reexamination of the efficacy of live box capture as a management tool, and development of alternatives to current live box capture practices.

First developed in North Carolina, fish wheels were used there and in the Columbia River of Oregon and Washington for commercial harvest of migrating fish before 1900 (Donaldson and Cramer 1971). Fish wheels were suggested as a sampling tool in 1951 (Meehan 1961) and since have been commonly used for research and management studies of Pacific salmon *Oncorhynchus* spp. in the United States and Canada (Milligan et al. 1985, 1986; Merritt and Roberson 1986; Link and English 1996; W. Ambrogetti, personal communication, U.S. Fish and Wildlife Service, retired). Fish wheels provide a number of benefits, including low manpower requirements to operate and relatively safe operating conditions for sampling fast-flowing rivers. They provide constant effort, can have high catch rates, and produce live catches. Data from fish wheels can assist in providing species composition, stock characteristics, run timing, distribution, relative abundance, true abundance, and any other information afforded by the capture of live migrating fish. The fish wheel's utility has made it a regular part of fishery management programs in many areas (Milligan et al. 1986; Cappiello and Bromaghin 1997; Link and English 1996; Underwood et al. 2000a, 2000b). New projects are beginning for other major fisheries in Alaska on the Copper (K. Hyer, U.S. Fish and Wildlife Service, Office of Subsistence Management, Anchorage, personal communication) and Kuskokwim rivers (C. Kerkvliet, Alaska Department of Fish and Game, personal communication) in 2001. Fish wheels have been assumed to be a low-impact method of sampling fish until recently when Underwood et al. (2000b) suggested potential handling mortality and listed nine hypotheses as possible explanations for an inverse relationship between mark rate and distance from the marking site; hence our study.

Fish captured in fish wheels experience varied levels of trauma and stressors. Depending on the size of the fish wheel, some fish may be raised to a height of 3 m before dropping through the air onto a chute that diverts the fish into the live box. Other fish may gently slide from basket to chute to live box with minimal jarring. Sources of trauma from fish wheels include physical impacts from vertical drops, lacerations and punctures from wire or other basket construction materials, and effects

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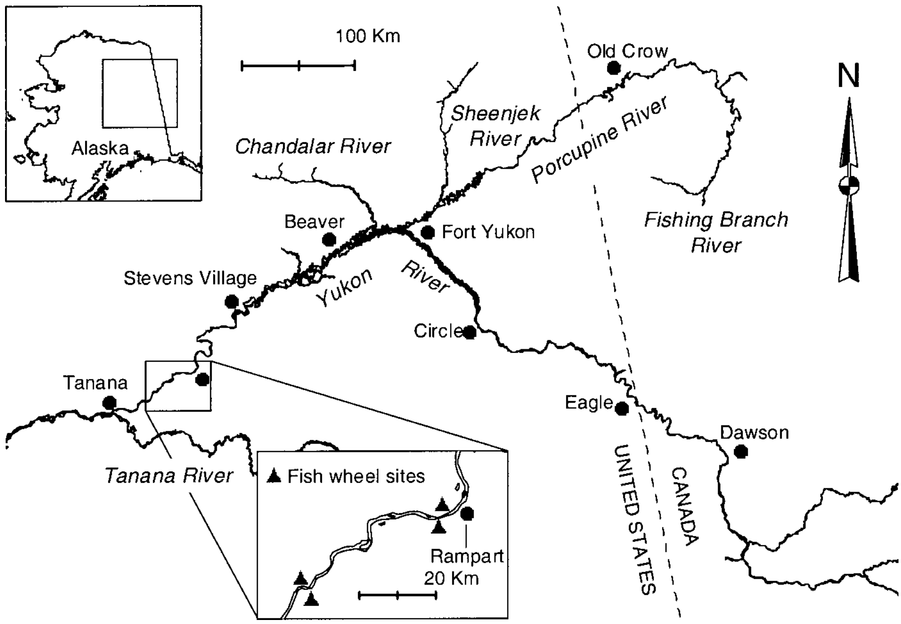

FIGURE 1.—Map of the Yukon River showing the 1996–1998 fish wheel marking and recovery (near Rampart) sites for chum salmon (denoted by dark triangles) and the location of villages (dark circles).

from flight behavior. In the live box fish may experience collisions with walls or other fish, and crowding. Lethal and sub-lethal effects caused by fish wheels have not been examined or reported, except for recovery and migration of radio-tagged fish after release from fish wheels (Eiler 1990). Effects of capture and processing of fish have been considered to be minimal where study assumptions require similar behavior of marked and unmarked fish (Killick 1955; Merritt and Roberson 1986).

Our objectives were to determine if mortality of adult chum salmon *Oncorhynchus keta* varied with distances from the marking site and to determine if mortality was associated with fish wheel capture and cumulative handling. To address our objectives, we examined data on the proportion of fish having tags, compared the rate of recapture between gear types, and examined tag loss at various locations upriver of the mark site. We also categorized the number of times a fish was captured during the course of a mark–recapture experiment and then calculated the probability of a tag being returned from somewhere other than our fish wheels, referred to as external recapture.

Study Area

The Yukon River (Figure 1) is over 3,200 km in length and drains about 860,000 km^2, of which about 330,200 km^2 lie in Canada and 529,800 km^2 in Alaska (Beacham et al. 1988). The Alaskan portion of the Yukon River upstream of the Tanana River drains portions of the Brooks Range on the north and numerous smaller highlands to the south. In Canada, the northwestern extension of the Rocky Mountains borders the drainage to the east, and the Wrangell–St. Elias Range lies to the southwest. Numerous smaller mountain ranges lie within the drainage. The river is turbid in summer, but clears to some degree in winter when the influence of glacial runoff, erosion, and tannic lowlands are reduced (Buklis and Barton 1984). River ice breaks apart in May and can cause pooling for miles when ice jams dam the river.

The study area of the mark–recapture experiment conducted from 1996 to 1998 was on the Yukon River main stem between river kilometer (rkm) 1,170 at a canyon upstream of the confluence with the Tanana River and rkm 1,221 at the village of Rampart, Alaska (Gordon et al. 1998; Underwood et al. 2000a, 2000b). This area is characterized by a meandering single channel with three islands (Figure 1).

Methods

Marking site sampling procedures.—The two fish wheels at the marking site were composed of floatation logs, two baskets, padded chutes, and live holding boxes (Figure 2). The baskets on these

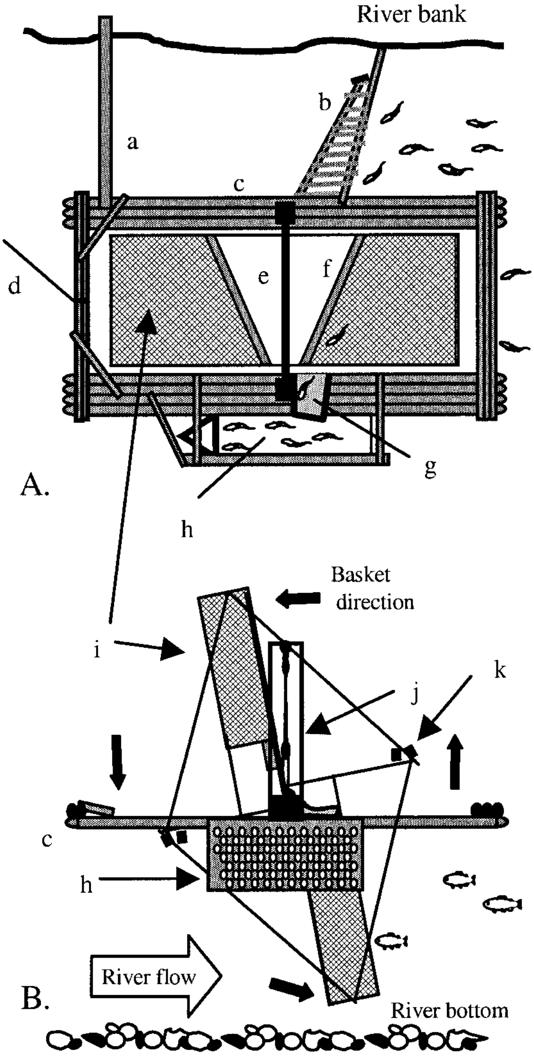

FIGURE 2.—**(A)** Aerial view and **(B)** side view schematics of the two-basket fish wheel used to capture chum salmon in the Yukon River, Alaska, for tagging and recapture in 1996–1998, showing (a) main spare, (b) fence or lead, (c) raft, (d) main cable, (e) axle, (f) chute, (g) chute extension, (h) live box, (i) baskets, (j) lifting frame for axle, and (k) paddles.

fish wheels were approximately 3.0 m wide and dipped to a depth of 4.5 m below the water's surface. Baskets were lined with wire, nylon, plastic, or chain link netting. Nylon seine netting was installed on the sides of the baskets to minimize injury to fish as they were lifted from the water. Closed-cell foam padding was placed along the chute and the ramp on the path to the holding boxes to reduce impact injury to fish. Live boxes were approximately 2.4 m long by 1 m wide by 1.2 m deep; the walls and floors contained many 5-cm diameter holes to allow a continuous flow of water but prevent a strong current that could potentially impinge or tire fish.

Fish wheels were placed across the river from each other on the north and south banks. Fish wheels floated next to the riverbank so that the shoreward tip of the basket swept within 30 cm of the bottom. Wheels were moved inshore or offshore to maintain the same proximity to the sloped bottom. A lead similar to a submerged picket fence was placed between the wheel and the shore to direct fish towards the dipping baskets.

Tagging commenced by August 3 and ceased approximately September 20 each year. Fish were marked 6 d/week, Monday through Saturday. During 1996 most fish were marked between 1000 and 1400 hours In subsequent years, operations were modified to balance the objectives of marking 400 fish/d, spreading the release of marks throughout the day, and reducing holding times in the live boxes. Crews marked fish starting at four different times (0800, 1200, 1600, and 1900 hours), attempting to mark 100 fish each time. Chum salmon were marked with individually numbered spaghetti tags applied with barbed (1996) or hollow (1997 and 1998) applicator needles. During 1996 a hole punched in the caudal fin was used as a secondary mark for the first 9 d of the season. During 1997 and 1998, half the left pelvic fin was clipped perpendicular to the fin rays as a secondary mark. Severely injured or diseased fish were released without marking. Fish wheels were operated up to 24 h/d when catch rates were low and about 6 h/d when catch rates were high.

Recovery site sampling procedures.—The river at the recovery site was wider and shallower than at the marking site, so the two recovery site fish wheels were sized accordingly. Live boxes were of similar size to those downstream. The south bank wheel was placed about 2 km downstream from the north bank wheel. Sampling commenced at both recovery wheels approximately 1 d after tagging commenced. Recovery wheels were operated 24 h/d for 7d/week. The frequency of emptying fish from the live box depended on the catch rates but generally was two to four times a day. The recovery site protocol limited the number of fish in a live box to less 200 fish; however, this number was exceeded at times in all years. Recorded data included a tally of marked and unmarked fish and the tag number of recaptured fish. All fish were released alive, except during scheduled openings of the subsistence fishery and in

1998 when 60 fish were sacrificed for blood analysis and necropsy.

External tag recovery.—Four methods were used to recover tags external to the mark and recapture study: (1) fishermen upstream returned tags, (2) fishery research projects in the United States and Canada operating elsewhere within the drainage, (3) face-to-face interviews with fishermen in three upstream villages (Beaver, Fort Yukon and Circle, Alaska) or by telephone interviews at other locations, and (4) arrangements made with specific fishermen to collect data in locations not close to a surveyed village. After 1996 some fishermen received a preseason briefing by telephone regarding identification of the primary (a spaghetti tag) and secondary (a ventral fin clip) marks. The tag-return data collected included the gear type, tag numbers, tallies of marked and unmarked fish, and tallies of fish with the secondary mark but missing the primary mark; however, some return data did not include all types of data.

Analysis of data.—Data regarding mark rates (proportion marked), tag loss, and gear type were tabulated. Mark rates were plotted on the *y*-axis against distance on the *x*-axis. Generalized linear models (Agresti 1990; McCulloch and Searle 2001) were used to model mark rates as a function of distance from the marking site. Because the number of fish marked in any one sample can be assumed to have a binomial distribution, model parameters—an intercept and slope for each year—were estimated using SAS PROC GENMOD with a binomial error term and an identity link (SAS Institute 1999). This method weights observed mark rates by the number of fish examined in the sample, in contrast to linear regression that would weight all samples equally. We tested whether slopes equaled zero within years and whether slopes among years were equal.

The probability of external recapture was modeled as a function of the number of times a fish was captured in project fish wheels (termed capture history) by using generalized linear models (Agresti 1990; McCulloch and Searle 2001). Models were fit to the data by using SAS PROC GENMOD (SAS Institute 1999) with an identity link and a binomial error structure. This model structure results in parameter estimates that are the observed sample portions. Likelihood ratio tests (Stuart et al. 1999) were used to test the hypothesis that recapture probabilities were equal for all capture histories within each of the 3 years separately.

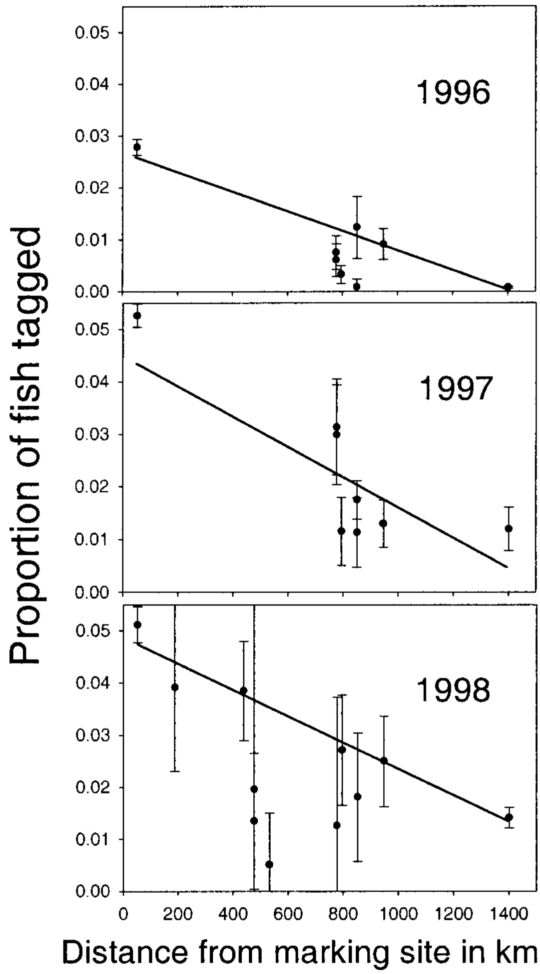

FIGURE 3.—Proportion of tagged chum salmon versus the distance in river kilometers (rkm) from the Yukon River, Alaska, tagging site by year, 1996–1998. Vertical lines are the 95% confidence intervals of plotted rates. Sloped lines were generated from estimated parameters of the linear model used to test for nonzero slopes and slope differences among years.

Results

The number of marked fish released were 17,568 in 1996, 18,632 in 1997, and 8,513 in 1998. The number of tags recovered externally using all four data collection methods totaled 594 in 1996, 1,007 in 1997, and 1,002 in 1998. Some of the data were obtained opportunistically, but trends were consistent among data sources and years. Within each year, tag rates decreased significantly with increased distance from the tagging site (Figure 3). Line slopes indicate a significant trend that differed from zero in 1996 ($\chi^2 = 1274.9$, df = 1, $P < 0.001$), 1997 ($\chi^2 = 1530.0$, df = 1, $P < 0.001$),

TABLE 1.—Comparison of mark rates in 1997 between colocated gear types, location, river kilometers (rkm) from tagging site, source and gear type, sample sizes, and the number and percentage of marked fish. The sources listed were broken into ''management projects'' (MP), which were conducted by government agencies or supervised personnel, and ''fishery,'' which were data from fishermen willing to participate.

Location	Distance from tagging site (rkm)	Source	Method used	Number of fish examined	Number of fish with marks	Percentage with marks
Chandalar River	474	MP	Carcass survey	1,414	43	3.0
Fort Yukon	437	MP	Interview	1,240	36	2.9
Nation River	702	Fishery	Gill net	983	11	1.1
Eagle City	777	Fishery	Fish wheel	2,500	32	1.3
Eagle City	777	Fishery	Fish wheel	2,700	32	1.2

and 1998 ($\chi^2 = 317.4$, df = 1, $P < 0.001$). Also, line slopes among years were not equal ($\chi^2 = 123.2$, df = 2, $P < 0.001$). Different gear types, carcass surveys versus interviews and gill nets versus fish wheels, had similar rates of recapture (Table 1). Tag loss was low. Of the 48,574 fish examined for tag loss between 1996 and 1998, 1,255 fish had tags and 5 were reported as having lost their primary mark. Of the five, one was from a main-stem survey and four were reported at the furthest monitoring site which is on a spawning ground.

The proportion of fish recaptured externally ranged from 0.12 to 0.028 (Table 2). A trend of decreased tag returns with an increase in our project fish wheel captures was indicated by the sample proportions and 95% confidence intervals (Figure 4). The results of likelihood ratio tests of the equality of the recaptured proportions within each year were statistically significant for 1996 ($\chi^2 = 15.7$, df = 2, $P < 0.001$), 1997 ($\chi^2 = 40.1$, df = 3, $P < 0.001$), and 1998 ($\chi^2 = 6.7$, df = 2, $P < 0.037$). This suggests that fish caught multiple times in the project fish wheels were associated with a reduced probability of recapture upriver.

Discussion

Our results document the declining ratios of marked to unmarked salmon with increasing distance from the marking site. Our data are corroborated by similar declines in mark rate with distance observed in Canada (S. Johnson, Department of Fisheries and Oceans Canada, personal communication). As discussed by Underwood et al. (2000a), possible explanations for these declines include (1) nonreporting, (2) immigration, (3) trap avoidance behavior, (4) excessive harvest of marks, (5) stock-specific selective sampling at the sample site, (6) nonstock-specific selective sampling at the sample site, (7) external recovery selective sampling upstream, (8) tag loss, and (9) handling mortality. Only data regarding handling mortality provided an effect with the direction and magnitude sufficient to explain the observed decline. Other explanations were considered unlikely because they were either inconsistent with avail-

TABLE 2.—Summary of statistics by year and capture history (number of times recaptured) of the proportion of tagged fish recaptured, including number of fish tagged, external recaptures (not in project fish wheels), proportion recaptured, and standard errors.

Year	Statistic	Number of times captured in mark–recapture experiment: 1	2	3	4
1996	Number of fish tagged	15,492	2,052	24	0
	Number of external recaptures	547	44	3	
	Proportion recaptured	0.035	0.021	0.125	
	SE	0.0015	0.0032	0.0690	
1997	Number of fish tagged	15,136	3,111	351	34
	Number of external recaptures	890	106	10	1
	Proportion recaptured	0.059	0.034	0.028	0.029
	SE	0.0019	0.0033	0.0089	0.0294
1998	Number of fish tagged	7,232	1,135	146	0
	Number of external recaptures	876	115	11	
	Proportion recaptured	0.121	0.101	0.075	
	SE	0.0038	0.0090	0.0219	

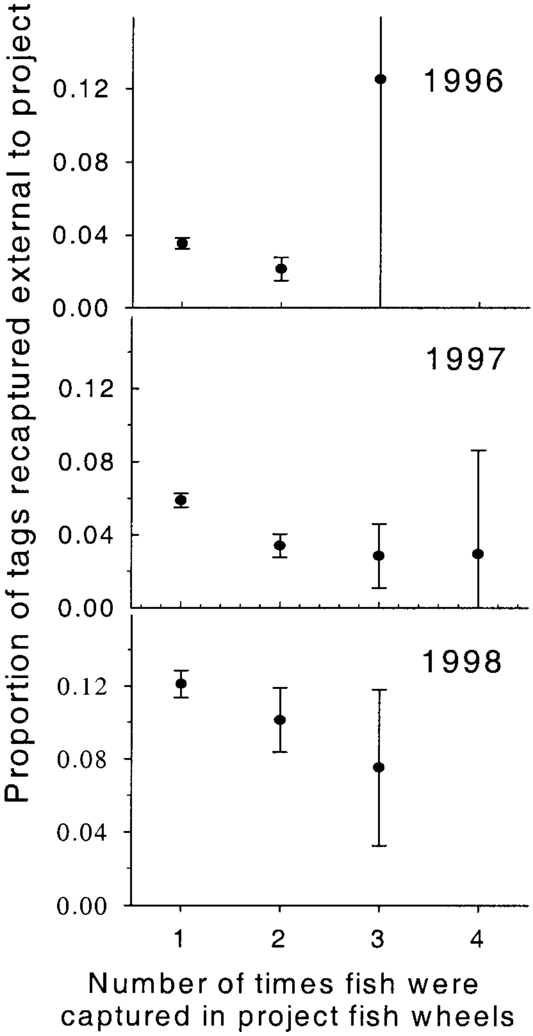

FIGURE 4.—Proportion of chum salmon recaptured externally and 95% confidence intervals, by capture history (number of times captured).

able data, predicted impossible run sizes, or the expected magnitude of the effect was insufficient to produce the observed trends. Incomplete reporting was unlikely because directed efforts to improve reporting did not change the trend, and the magnitude would be small. Immigration was unreasonable because the magnitude needed would be outside the realm of possibility for the population size. Trap avoidance was unlikely because similar mark rates were found using different gear types (fish wheel versus carcass counts versus gill nets) at similar distances from the tagging site (Table 1). Excessive harvest of marked fish upstream of the marking site was not observed, so it was not a likely cause. Stock-based selective sampling was unlikely because only low mark rates were observed upstream; no high values were observed. Nonstock based selective sampling was unlikely because the magnitude of the dilution needed would result in run sizes larger than possible. Tag loss was unlikely because data clearly show that tags were retained.

Mortality of marked fish was the most likely explanation for the observed reduced mark recovery rates upriver. Capture histories show the effects of capture to be cumulative, and the decrease in proportion captured is of a direction and magnitude that is consistent with the decreased recovery rates with increased distance. Mortality caused by capturing and handling fish is common in tagging studies (Seber 1982). Mortality caused by stress can be delayed (Stichney 1983), and effects of multiple stressors can be cumulative (Wedemeyer et al. 1990). The magnitude of mortality indicated should be considered a minimum because the ideal control group, fish not captured or handled, cannot be assessed. The total effect may be larger than indicated by this study.

The implications of mortality are immediate for management and research. For example, the mark–recapture experiment handled as many as 60,000 fish during 1996 (Gordon et al. 1998). Even a modest increase in mortality rates could affect significant numbers of fish needed for spawning escapement. Of additional concern are the negative effects potentially caused by the numerous other fish wheels used for research and monitoring salmon throughout Alaska and western Canada. General concepts regarding handling, stress, and mortality are well-documented (Stichney 1983; Adams 1990; Wedemeyer et al. 1990); however, specific investigations into stress and morbidity caused by fish wheels have not been well documented. Possible causes of elevated stress include trauma in the fish wheel, holding time in the live box, crowded conditions within the live box, handling procedures, and tagging. Any one or a combination of these factors could be causing the majority of the stress. Given the useful management data produced by fish wheels, further investigations to isolate individual stressors are warranted. Tests to isolate each potential cause may lead to procedures that minimize harmful effects or reduce them to an acceptable level. Alternatives to holding fish in live boxes for some uses, such as collection of catch per unit effort data, might be explored. For example, video image capture via computer (Hatch et al. 1998) could be applied to fish wheels, eliminating the need to retain captured fish in live boxes.

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