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Survival of spring chinook salmon captured and released in a selective commercial fishery using gill nets and tangle nets

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Abstract

We tested the potential for using live capture, selective harvest as an alternative to a conventional gill net fishery to protect depressed wild stocks of spring chinook salmon (*Oncorhynchus tschawytscha*) while still allowing harvest of fish from abundant stocks. We conclude that using modified fish handling techniques and replacing conventional 8 or 5.5 in. gill nets with smaller meshed tangle nets significantly improves the survival of spring chinook salmon released from the gear. Tangle nets are similar to small meshed gill nets and capture fish by the snout rather than by the gills or body, reducing injury and allowing them to continue respiring while they are in the net, theoretically allowing live capture and improving the likelihood of survival after release. Experienced gill netters used modified fishing techniques to fish nets constructed of tangle nets joined to conventional gill nets. Captured fish from each net type were tagged and released for recovery in subsequent recreational and commercial fisheries, at hatchery racks, and during spawning ground surveys. Control fish that had not been captured in the fishing gears were tagged and released from a trap near the fishing area. More than 95% of the adult chinook salmon survived the initial capture in any net type. Spring chinook released from the 4.5 in. tangle net were recovered at 1.9 times the rate of fish released from the 8 in. gill net, and 1.2 times the rate of fish released from the 5.5 in. gill net. The 4.5 in. tangle net was as effective at capturing spring chinook as the 8 in. gill net, but less effective than the 5.5 in. gill net.

Keywords: Pacific salmon; Commercial fishing; Selective fishing; Post-release survival; Gill net; Tangle net

1. Introduction

In the Pacific Northwest of the United States and Canada, different species and stocks of Pacific salmon (*Oncorhynchus* sp.) commingle as they migrate towards spawning areas. This often results in mixed-stock fisheries in which some stocks are abundant while others require protection. These fisheries have generally been managed using gear restrictions and time and area closures, which by definition limit fishing opportunity. Where few stocks or species need protecting, these management tools allow viable fisheries, but if many stocks need protection, the fishing industry can be decimated even though there may be abundant stocks that could be harvested if the weaker stocks could be avoided. Severe declines of Pacific salmon stocks prompted fish managers in this region to combine fishery restrictions with the alternative strategy of implementing “selective fishing” methods and regulations (more accurately described as “live

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capture, selective harvest") during fishery openings to provide fishing opportunity on abundant stocks while requiring release of non-target species and stocks with minimal mortality. The intent of these fisheries is to reduce encounters with non-target species or stocks, and then to reduce the incidental mortality of those that are encountered. While different species can be easily sorted, stock selective fisheries in the Pacific Northwest rely on a physical mark, in this case adipose fin excision, that allows fishers to easily distinguish between healthy hatchery stocks that can be retained and unmarked wild stocks that must be released. However, the ability to release a fish from a given gear does not indicate that the conservation goal will be met because the immediate and delayed mortality caused by encounters with commercial fishing gears are often high (see review by Chopin and Arimoto, 1995). Regardless, because of considerable political and social pressure to protect salmon in this area without closing the commercial fishery, selective fisheries were implemented without testing whether or not the released fish survive to contribute to rebuilding their populations.

The survival of fish captured and released in sport fisheries has been shown to vary considerably, and likely depends on the species captured, the skill of the fisher in releasing the fish, the water temperature, and the fishing method (Bendock and Alexandersdottir, 1993; Gjernes et al., 1993; and see Muoneke and Childress, 1994 for a review). Because most commercial fisheries, particularly those using gill nets, are managed to harvest the captured fish, few studies have evaluated the long-term effects of capture and release from commercial fishing gears. Candy et al. (1996) used ultrasonic telemetry to estimate that about 77% of chinook salmon (*O. tshawytscha*) captured in and released from seine nets survived. However, this data is unlikely to be directly applicable to gillnet fisheries because the very different method of capture would likely influence post-release survival. Several authors estimated survival of fish after capture in gill nets followed by confinement in net pens. Thompson et al. (1971) observed virtually no survival of sockeye salmon removed after entanglement in gill nets that were enclosed within net pens in Washington. Murphy et al. (1995) captured spotted seatrout (*Cynoscion nebulosus*) in gill nets in Florida with 72% survival after 48 h. Survival of lake trout (*Salvelinus namaycush*) captured in gill nets in Lake Superior and held in tanks for 48 h varied seasonally from 68 to 77% (Gallinat et al., 1997) and studies using revival techniques for coho salmon (*O. kisutch*) released from commercial fishing gears in British Columbia have shown that mortality of those fish held in net pens for 24 h was less than 3% (Farrell et al., 2001a). However, evaluations of post-release survival of fish held in the artificial confines of net pens are unlikely to reflect the post-release survival of free-swimming fish, because the fish in net pens are not subject to predation, currents, or encounters with obstacles to migration which a severely stressed fish, such as those captured in commercial fishing gears (Farrell et al., 2000) must contend with.

Our primary objective was to test the fundamental premise of a selective commercial fishery for spring chinook salmon—that released non-target salmon survive at acceptable levels and that this is therefore an effective management strategy for protecting weak stocks. Tangle nets are being considered as a substitute for the larger mesh size commercial gill nets to improve survival of released fish in selective fisheries. Tangle nets are similar to gill nets but have a smaller mesh size (3.5–4.5 in.; 8.9–11.4 cm) than a conventional spring chinook salmon net (8 in.; 20.3 cm). Both gears are fished similarly, but the mesh of the tangle net catches fish by the snout or teeth, allowing it to continue respiring in the net so it can be released live. In a non-selective gill net fishery, the amount of time that the nets are left to drift is unrestricted and a drift of an hour or more would be normal. Little attention would usually be given to careful handling or revival of fish before release, if release were required. In this study, and in fisheries where live release is an objective, fishing practices needed to be modified, including the use of revival boxes, short drift times and careful fish handling, to maximize the survival of released fish.

We chose the Columbia River, one of the largest chinook salmon producing rivers in the world, for our study. This Pacific Northwest river was closed to non-treaty harvest of spring chinook salmon from 1977 through 2000 to protect endangered stocks. The year 2001 marked the re-opening of the commercial fishery with the largest recorded return of spring chinook salmon. This provided an opportunity to evaluate the ability of commercial nets to harvest chinook salmon from abundant hatchery stocks while protecting the weak wild stocks. Our experiments included estimating the post-release survival of spring chinook salmon captured in tangle nets and conventional gill nets, comparing the immediate mortality and catch efficiency of the two gears, evaluating physical characteristics of fish caught in each gear, and comparing the capture of non-target species in each gear.

Our principal hypothesis was that the survival of spring chinook salmon captured and released from the tangle net was not significantly different from that of spring chinook salmon captured in and released from a 5.5 in. (14 cm) or 8 in. gill net. During this study, we also tested the hypothesis that there was no significant difference in the immediate survival, catch efficiency, or capture type of adult spring chinook salmon between the two net types. Our assumptions for this study were that the control fish were from the same population as the test fish, and that they were subject to the same natural and fishery mortality above the dam as the control group and were therefore representative of the test fish, that the differences in tag colors would not bias their recovery, and that all groups were equally affected by the application of tags.

2. Methods

The Columbia River is the second largest river in the United States, draining an area of 668,200 km^2. From its source in British Columbia, Canada, to its mouth at the Pacific Ocean between the states of Washington and Oregon, the Columbia River flows 2050 km. Bonneville Dam, the first mainstem hydroelectric dam, is located at river kilometer (rkm) 234. Spring chinook salmon going further upstream encounter nine more mainstem hydroelectric dams before they reach the impassable Grande Coulee Dam at rkm 955. Fish venturing up the Snake River, the largest tributary to the Columbia River, encounter seven more dams. Spawning grounds for spring chinook salmon are dispersed throughout the Columbia River basin, as are a number of hatcheries that produce spring chinook salmon for supplementation and harvest. Consequently, spring chinook salmon returning to the Columbia River belong to a number of stocks that commingle as they enter the river, then disperse as they move upstream. Harvest on spring chinook salmon occurs through tribal ceremonial, subsistence and commercial fisheries, all-citizens commercial fisheries and recreational fisheries.

We contracted four local fishers to fish downstream of Bonneville Dam from 4 April to 24 May 2001 and two from 1 April to 21 May 2002 (Fig. 1). In 2001, the test fishery occurred up to 32 km from Bonneville Dam, while in 2003, it was confined to within 25 km of the dam. There are no tributaries between these fishing locations and the dam. In 2001, the fishers used nets that were 137.2 m of tangle net (1.5 mm $\times$ 4 strands, 3.5 in. (8.9 cm) or 4.5 in. (11.4 cm) mesh size hung at a ratio of 3:1 and 2:1, respectively) shackled to 137.2 m of conventional gill net commonly used in their areas for the target species (monofilament, 8.0 in. mesh size, hung at a ratio of 2:1). The hang ratio describes the length of mesh relative to the length of cork line. In 2002, managers decided that the 8 in. gear would no longer be used for the commercial fishery, so we compared a 5.5 in. (14 cm) gill net, which was allowed in the fishery, to the 4.5 in. tangle net, hung similarly to the previous year. Each year, both gear types were of similar depth, and the depth and color of the nets were suitable to the area fished. In 2001, one fisher used a diver net, which sinks and follows the bottom contours, as opposed to a floating net that remains at the surface. Each vessel was equipped with a hydraulic reel and a roller mounted in the bow that was used to deploy and retrieve the nets. Fishers contracted for this project had many years of experience gillnetting for salmon in the study area and were asked to mimic the fishery both in manner and location fished.

When possible, we alternated the end of the net that was closest to shore on subsequent sets so that the fishing effort of each net type was similar. The nets were set by reeling them across the river (typically in a curved pattern) and allowing both ends to drift freely. Fishers were instructed on proper fish handling as they removed fish from the net, particularly to avoid touching the gill area or holding fish by its caudal peduncle. As possible, fishers also looked over the bow as the net was pulled up so that they could lift fish over the roller.

All vessels were equipped with a revival box similar to that described by Farrell et al. (2001a), made from 2 cm thick plywood painted black. The revival boxes were built with two compartments for holding fish, each compartment was about 107 cm long, 41 cm high, and 19 cm wide. The compartments of the revival

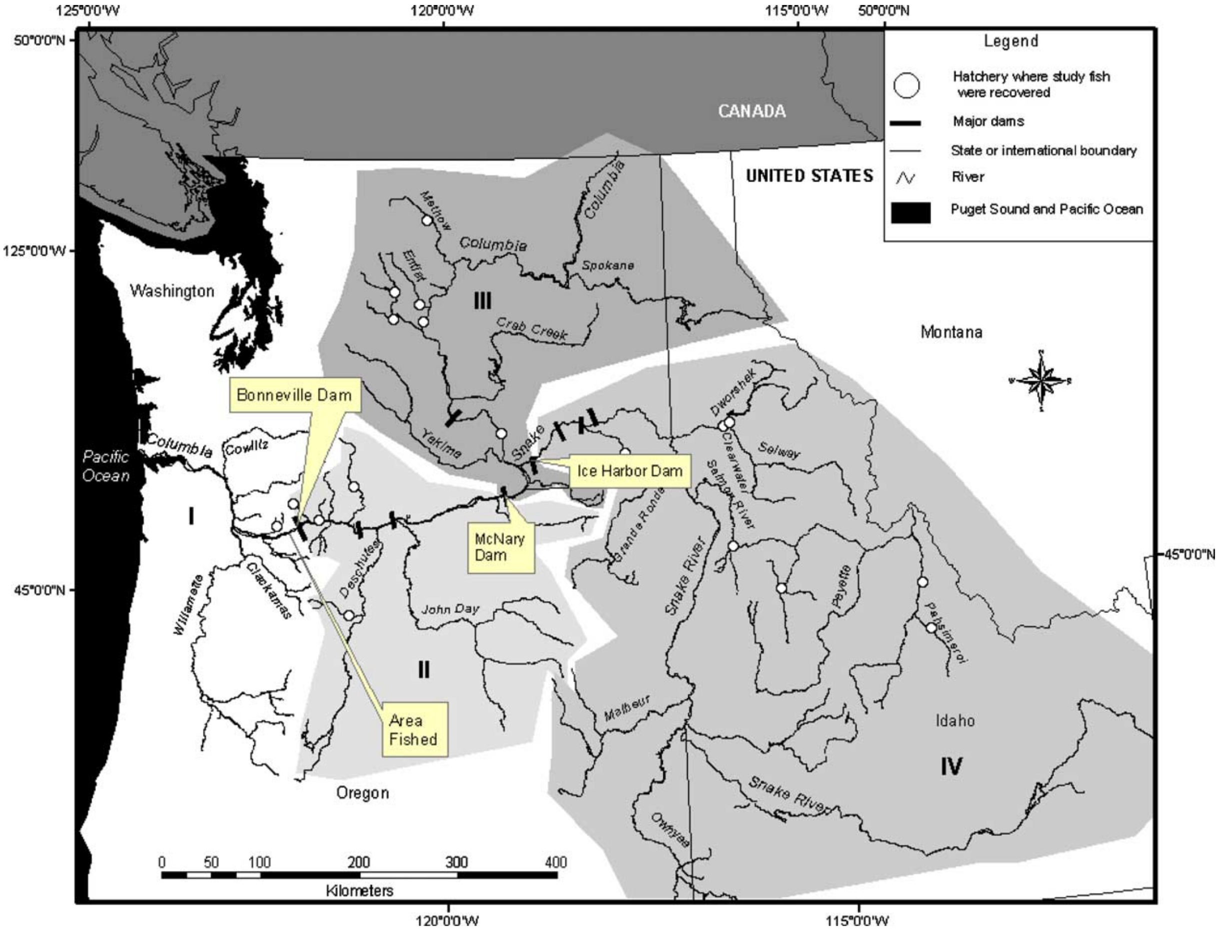

Fig. 1. Test fishing area, site of the adult trapping facility at Bonneville Dam where the controls were captured, and recovery areas. Recovery areas were summarized by general geographic areas as I: below Bonneville Dam; II: between Bonneville and McNary dams; III: Upper Columbia above McNary Dam; and IV: Snake River above Ice Harbor Dam.

box were wide enough to allow a chinook salmon to fit with its head facing the fresh water flow but narrow enough to prevent the fish from turning around. A 12 V, 240 L/min submersible bilge pump was connected to a discharge hose that supplied fresh water through pipes located at the front and near the bottom of the box.

Two observers were on board each vessel during test fishing. One observer primarily recorded data, while the other monitored and tagged fish. For each set (one deployment and retrieval of the net), observers recorded the time when the first part of the net was placed in, then removed from the water, the time the shackle between the two nets was removed from the water, the time the end of the net was brought on board, the longitude and the latitude for the set (using a Magellan handheld GPS unit), which net type was put in the water first and which net type was removed from the water first. Observers also recorded the date, the set number, weather conditions, water and surface temperatures, presence of seals and any other observations pertaining to a particular set. Fishers removed each fish from the net and either placed it in a holding tank of fresh water located in the bow, or released it overboard, as directed by the observer. For each spring chinook salmon caught, the observer noted the net type where it was captured (tangle or gill), the type of capture, whether the adipose fin was missing and the condition of fish at capture. The observer then measured the fork length and tagged the fish with a numbered jaw tag covered with a plastic sheath and printed with a number. The plastic sheaths were colored to correspond to the net type where the fish was captured. We characterized the type of capture as tangled by teeth or mouth, gilled (net around the gills), wedged (web around body posterior to the gills) or mouth clamped (net wrapped around mouth, clamping it closed). A captured fish was ranked as condition 1 if it was lively and not bleeding, condition 2 if it was lively but bleeding, condition 3 if it was lethargic but not bleeding, condition 4 if it was lethargic and bleeding, and condition 5 if it showed no visible movement or ventilation. Fish ranked as condition 1 or 2 were tagged and released overboard immediately. Fish in conditions 3–5 were held in the revival boxes until they either revived to condition 1 or 2 and could be released, or died. Loss of scales, damaged fins and other visible injuries were recorded. Non-target species encountered were counted according to the net type where captured and released overboard.

A control group of spring chinook salmon was collected and tagged with a colored jaw tag at the adult fish trap located in the fish ladder at Bonneville Dam on the Washington shore of the Columbia River. In the trap, fish pass through a series of diverters and chutes and into a holding tank. Although our test fish were not anesthetized on board the boats, and we could have tagged the fish at the dam without anesthetic, we were required to follow the standard procedures at the collection facility, so clove oil was added to the holding tank to temporarily anesthetize the fish. Each spring chinook salmon in the control group was measured and tagged, and the sampler noted whether it was missing its adipose fin and had other visible injuries. Fish were then transferred to fresh water until they revived back into lively condition and were released into a chute and diverted back to the fish ladder to continue their migration. Trapping occurred throughout the test fishery to ensure the same populations of migrating fish were tagged in each group. Several studies (Anderson et al., 1997; Wagner et al., 2002; Pirhonen and Schreck, 2003) have evaluated the effects of anesthetization with clove oil on salmonids and have found that it is generally unharmful and appears to have no long-term detrimental effects. Any positive or negative effect of the clove oil is likely to be very small, so we did not adjust our survival estimates to account for anesthetization.

To evaluate the survival of released fish, we monitored the number of tagged spring chinook salmon recovered in fisheries (by voluntary returns and fishery surveys), at hatcheries and on spawning grounds. Anglers, hatchery crews, and stream surveyors were asked for the date of harvest, location of harvest, tag color, and tag number. While a few jack spring chinook salmon (early maturing males 60 cm fork length or less) are captured in the tangle nets, they were omitted from all analyses.

For each day we were able to consistently alternate the ends of the net nearest the shore, we compared the catch per hour of adult spring chinook salmon in the tangle nets to the gill nets. Because we recorded only the time the first cork went in the water, and not when the shackle went in, we designated the time to set the first net as 3 min in every case. The total fishing time for each net was then calculated as the time from when the first cork was placed in the water to the time when the last cork of the same net was removed from the water.

The frequency distributions of spring chinook salmon by condition at capture were compared using a chi-square analysis ($P = 0.05$). Set times, total soak times, fish lengths, and the numbers of non-salmonids in sets with and without dead fish were compared using *t*-tests ($P = 0.05$). We chose a conservative approach for comparing the post-release survival of spring chinook salmon released from each net and used the *Z*-statistic as described in Zar (1984) for comparing two proportions. To eliminate bias in how catch efficiency may be related to fish abundance, the catch efficiencies of each net type were compared using a sign test. Where appropriate in 2001, we combined the results for both tangle net types (3.5 and 4.5 in. mesh sizes) for comparison to the 8 in. gill net, and each year, data were pooled among skippers and across fishing days to represent a more balanced picture of a fishing season.

3. Results

Using tangle and conventional gill nets, we test fished day and night periods for a total of 61 boat days in 2001 and 63 boat days in 2002 (a boat day is de-

Table 1
Immediate survival of adult spring chinook salmon captured during test fishing in each net type on the Columbia River

Mesh size (in.)	Immediate survival (%)	*N*
2001		
3.5	95.7	188
4.5	97.4	348
8	99.0	836
2002		
4.5	99.5	1262
5.5	99.1	1900

N is the number of adult spring chinook salmon encountered, and includes fish recaptured in subsequent sets.

fined as an individual boat-date combination and usually lasts about 6 h). In 2001, we captured 1372 adult spring chinook salmon (including 20 recaptures). Of those, 25 fish (1.8%) could not be revived (Table 1). The remaining 812 chinook salmon captured in the 8 in. gill net were tagged and released (three escaped overboard before they could be tagged), as were the 512 chinook salmon captured in the 3.5 and 4.5 in. tangle nets. In 2002, we captured 3162 adult spring chinook salmon (including 65 recaptures). Of those, 23 (0.73%) could not be revived. The remaining 1839 spring chinook salmon captured in the 5.5 in. net were tagged and released (10 escaped or were released before they could be tagged), as were 1218 captured in the 4.5 in. net (7 were released without tags). Throughout the test fishing period, we tagged 1194 spring chinook salmon in 2001 and 1034 in 2002 for the control group at Bonneville Dam. None died during handling. For fish recaptured during the test fishery, the time between the initial and the second capture ranged from 50 min (a subsequent set on the same day) to 551 h (about 23 days). All fish survived the second capture and were released in good condition.

Tagged salmon were recovered throughout the Columbia River in sport fisheries, commercial fisheries, at hatcheries and on spawning grounds (Table 2). Tags were recovered from early April through September each year. Not all of the tag colors were reported, and some of the tag numbers were illegible, such that 12 tags in 2001 and 33 tags in 2002 could not be assigned to the original net they were captured in, or to other subcategories identified at the time of capture.

Most recovered fish were reported in good condition. Recoveries were clumped in areas with popular recreational fisheries and at hatcheries. These are the areas with the most intensive sampling, but do not indicate that tagged fish did not return to other areas. We assumed that fish tagged in each net type were from the same populations, and therefore their tags were equally likely to be recovered, so that observed differences in tag recovery rates were due to survival differences. Tagged fish from each group were represented in each of the recovery areas (Table 2), and we believe our assumption is therefore valid.

Relative to the control group, we estimated that 93% (95% CI = 86.6–96.1%) of the fish released from the tangle nets survived to be recovered, while 51% (95% CI = 41.7–58.7%) of those released from the 8 in. gill net survived in 2001 (Table 2). Significantly more spring chinook salmon captured and released from tangle nets were recovered than those captured and released from the 8 in. gill net ($Z = 3.4$, $P < 0.001$). In 2002, 68% (95% CI = 61.0–73.7%) of the fish released from the 4.5 in. tangle net survived, signifi-

Table 2
Recovery of tagged spring chinook salmon released from the test nets and from the adult collection facility at Bonneville Dam

Geographic area	2001			2002		
	Control	8 in.	3.5 and 4.5 in.	Control	5.5 in.	4.5 in.
I. Below Bonneville Dam	3	3	1	2	6	4
II. Bonneville Dam to McNary Dam	44	18	22	110	88	76
III. Upper Columbia above McNary Dam	20	3	8	57	64	39
IV. Snake River above Ice Harbor Dam	78	26	27	42	57	49
Total	145	50	58	211	215	168
% recovered	12.2	6.2	11.3	20.4	11.7	13.8

Tags were recovered from hatcheries, subsequent fisheries, and spawning grounds.

cantly more than the 57% (95% CI = 50.5–63.9%; $Z = 1.7$, $P = 0.04$) of those released from the 5.5 in. gill net.

In pairs of sets where we consistently switched net ends, the 8 in. gill net caught from 2 to 10 times more fish than the 3.5 in. tangle net and overall was significantly more effective than the 3.5 in. tangle net (Wilcoxon sign test; $T = 0$, $t = 0$, $P < 0.05$). However, there was no significant difference between the number of fish caught in the 4.5 in. tangle net and the 8 in. gill net ($T = 10$, $t = 5$, $P > 0.05$). The 5.5 in. gill net was significantly more effective at capturing spring chinook salmon than the 4.5 in. tangle net ($T = 36$, $t = 525$, $P < 0.025$).

In 2001, more than 84% of all fish were captured in condition 1. In 2002, this rate was reduced especially for the 5.5 in. gill net (Table 3). Fish in conditions 1 or 2 were tagged and released overboard with minimal holding. We attempted to revive fish in conditions 3, 4, or 5 to condition 1 or 2 for release. Holding times in the revival box ranged from 2 to 81 min, with most fish showing a quick improvement in condition. We successfully revived and released 95% of adult spring chinook captured in conditions 3, 4, or 5.

Fish captured in conditions 3 and 5 in the tangle net were typically captured by tangling or mouth clamping, methods that rarely occur when using the 8 in. gill net. Fish captured in the 5.5 in. gill net showed intermediate capture types, with the majority being tangled or mouth clamped, but with a portion also being gilled. Capturing fish around the gills often caused bleeding, and the fish were then classified as condition 2 at capture. This capture type is common with conventional gill nets, but rare with the tangle net. Capture around the gills occurred in the tangle net when meshes were torn, such that the effective mesh size was larger than the original constructed mesh size, or when small fish were encountered.

Nearly every adult chinook salmon captured in the 8 in. gill net had net marks around the body in front of the dorsal fin or around the gills, and virtually every adult captured in the tangle nets and the 5.5 in. gill net had net marks around the snout. Net marks on the body tended to be severe—scales were dislodged and missing, and the underlying skin was often abraded and red. While not visible, a loss of the protective slime layer would be associated with this injury. Net marks were dark lines where the net pressed on the skin, and tended to be on the lower snout and jaw. They were less severe as the snout does not have scales. The slime layer on some of these fish may have been disturbed if they rubbed against the net, or if the fish rolled itself into the net. Other injuries observed on fish removed from both net types included damaged fins, hook wounds and seal wounds. We noted seal wounds on 15% of the fish captured in 2001 and on 12% of the fish captured in 2002. Wounds ranged from scars to open wounds with substantial tissue trauma. In 2001, seals were infrequent visitors to the nets, so most recent wounds likely occurred during the upriver migration. Seals and sea lions are common near the mouth of the Columbia River. In 2002, seals were observed in the fishing area during half of the sets, and one third of the sets had fish with seal wounds.

Table 3
Percent of adult spring chinook salmon (including recaptured fish) scored in each condition at capture category (% Cap) showing the number in each category that could not be revived (# Died)

Mesh size (in.)	Condition at capture									
	1		2		3		4		5	
	% Cap	# Died	% Cap	# Died	% Cap	# Died	% Cap	# Died	% Cap	# Died
2001										
3.5	88.3	0	1.6	0	4.8	3	1.1	0	4.3	5
4.5	84.2	0	1.4	0	8.6	2	0	0	5.8	7
8	86.6	0	8.1	0	3.7	1	0.7	0	0.8	7
2002										
4.5	80.0	0	3.4	0	14.0	1	0.7	0	1.9	5
5.5	66.1	0	2.5	0	27.3	9	1.2	2	2.9	6

Condition 1: lively; condition 2: lively, bleeding; condition 3: lethargic; condition 4: lethargic, bleeding; condition 5: no visible movement or ventilation.

The tangle nets captured many more non-target species than the gill nets, as would be expected because smaller fish that would pass unhindered through the gill nets would be trapped in the tangle nets. Shad (*Alosa sapidissima*), sturgeon (*Acipenser* sp.), suckers (*Catostomus* sp.), and Northern pike minnow (*Ptychocheilus oregonensis*) were the most common species encountered. Sturgeon were generally released in good condition, while the condition of the other species was variable. All 77 steelhead (*O. mykiss*), another species of concern on the Columbia River, that were encountered during both years of test fishing were released in good condition.

We recovered tags from spring chinook salmon captured in each condition category, but those captured in condition 1 were disproportionately represented in the recoveries from every net, each year. Overall, 76.7% of the released fish had been ranked as condition 1 at capture, while 81.4% of the recovered fish had been ranked in condition 1 at capture. This suggests that although fish captured in other conditions can recover to a state where they appear to be in condition 1 at release, physiologically, they have not fully revived. Longer holding in the revival box before release could improve survival.

4. Discussion

Managing depressed or endangered stocks in areas where there is strong political or social pressure to allow continued harvest in any sector, such as on the Columbia River, is complicated. If population levels are too low to withstand any harvest, the only option is to close all fisheries in which those stocks could be encountered, because no fishing method can meet a 0% mortality goal. However, there are many instances where even depressed stocks can sustain some level of harvest, albeit lower than before. Lowering harvest rates is typically accomplished by time and area closures, gear restrictions, and fleet reductions. When these options are exhausted, we have shown that combined with modified fishing and handling practices, the use of the tangle net reduced the post-release mortality of spring chinook salmon considerably. Even with modified fishing and handling practices, we observed a substantial mortality of spring chinook salmon released from conventional 8 and 5.5 in. gill nets.

Whether the observed reduction in mortality is sufficient to allow a depressed stock to recover depends on biologists being able to correctly estimate the allowable mortality rates, those rates falling within the possible limits of the gear, and managing the fleet to achieve those rates. If the first and second requirements are met, our conversations with fishers and managers indicate that a fleet can adapt to selective fishing methods, especially when the alternative is to close the fishery altogether. In 2002, the commercial gill net fleet on the Columbia River was given the opportunity to participate in a selective fishery which allowed retention of marked spring chinook salmon, but required the release of unmarked salmon. The fleet was regulated to use nets with meshes no larger than 5.5 in., set times that were a maximum of 45 min, and revival boxes for fish in poor condition. Many fishers chose to try the new techniques, even though they are more labor intensive because of the short set times and fish sorting and revival. Many displayed great innovation and creativity in adapting their techniques and observers showed that they were able to obtain initial mortality rates as low as we did during the experiments. Other fishers will cheat, and enforcing behaviors on a large river is obviously difficult. It is therefore critical to have extensive enforcement and observer programs so that the realized mortality is accurately estimated. This was also implemented with the fishing methods.

Even with all of these measures, fishing opportunity has of course been restricted on the Columbia River. Spring chinook salmon are a very high quality product and can command high market prices. Most fishers we spoke to indicated that given reasonable fishing opportunity, they would more likely achieve economic success if they developed specialized markets for selling very fresh fish, or if they could market the concept that the capture method reduced impacts on endangered fish, similar to the “dolphin-friendly” tuna marketing. In addition, because they do not have net marks on their bodies (or the associated internal injuries), salmon captured in a tangle net may realize higher market prices than fish captured in a gill net.

We observed considerable variation in our estimate of the post-release survival of fish captured in the tangle nets in 2001 and in 2002. The reason for this difference is not clear, and could be caused by any number of environmental factors. An increase in seals in the fishing area was observed between 2001 and 2002, which could easily have influenced the survival of fish released from our gears. If the decline between 2001 and 2002 is caused by increased seal predation, this suggests that these predators can have a significant impact on the migrating population. Given that our fish handling techniques would likely have improved from the first to the second year, we do not believe that this is a contributing factor. Also, because we did not advertise which tag color represented any group, we do not believe there was any bias in reporting tags of a particular color. This interannual difference is interesting, and suggests that several years of data should be collected before survival estimates are applied to untested years.

The 5.5 in. gill net appeared to capture fish in a manner intermediate to the tangle net and the 8 in. gill net. The capture methods showed increased gilling and wedging compared to the tangle nets, but not as much as the 8 in. gill net. The long-term mortality of fish released from the 5.5 in. gill net was significantly lower than that of the tangle net, but the relative difference was not as great as between the 8 in. gill net and the tangle nets. With the greater catch efficiency and lower capture of non-salmonids, the 5.5 in. net could be a useful choice in some fisheries where a higher mortality on released salmonids would be acceptable.

Our control fish had passed through all the same predatory pressures as the fish caught in the gears as well as similar fishing pressures, but had not been captured in our test gears. There were no tributaries between the fishing site and the trap where fish may have turned away. However, because the fish captured in the trap had also passed through one additional sport fishing area at the tailrace of the dam and had successfully located the fish ladder, they may have had an advantage compared to the spring chinook salmon released from the test gear that would be reflected as a higher post-release survival rate. While this would affect the actual survival estimates, the effect on each net would be the same, and thus the relative survival of fish from each net would not be affected.

We suggest two possible reasons why the fish released from the tangle net survived better than the fish released from the gill net, given that the method of capture was the only difference between the two groups. First, unlike those caught in the tangle net, fish captured in the gill net are more likely to sustain considerable external injury in the way of scale loss, skin abrasion and loss of the protective slime layer. We suspect that some of these injuries impair the fishes' ability to fight off disease, particularly the ubiquitous *Saprolegnia* sp. fungus (spring chinook salmon migrating to the Columbia River generally enter the river about 4–5 months before spawning), to osmoregulate, and to successfully navigate the river. Second, while removing chinook salmon from the nets, we observed that fish from a gill net tended to be lively, difficult to hold, and generally fighting to get out of the holding tanks. Fish removed from the tangle net were noticeably calmer, even in a slight stupor. We hypothesize that this behavior carries over from when they were in the net–spring chinook salmon captured around the body fight the net the entire time they are captured, and that those captured around the face tend to remain calm while in the net. If true, spring chinook salmon coming on board from the gill net would be nearing exhaustion even though they appear lively and able to swim at release. Farrell et al. (2001a) showed that coho salmon captured in commercial gill nets were physiologically exhausted and stressed as a result of capture. In contrast, spring chinook salmon coming on board from the tangle net were apparently in better physiological condition at release, and better able to avoid predators, navigate barriers, and adapt to changing currents than tired fish. This hypothesis could be tested by using underwater cameras to observe the behavior of the fish captured in the nets, and by analysis of stress hormones and lactic acid in blood samples from spring chinook salmon brought on board from each gear.

While we showed that tangle nets reduce post-release mortality of spring chinook salmon, we need to understand how the stress related to this capture method affects reproduction and gamete quality. The stress response may impair reproductive fitness (Schreck et al., 2001), so while spring chinook salmon survived capture and release, their ability to reproduce may have been compromised, countering the potential conservation benefits of increased survival. However, spring chinook salmon spawn about 4 months after the fishery occurs, which could give them time to recover and resume the reproductive process. We recommend experiments examining the physiological responses of spring chinook salmon to capture and the resulting effects on reproduction.

Several studies have found minimal mortality of salmonids after capture and a short holding period in net pens. Farrell et al. (2001a) found that 2.3% of coho salmon captured in gill nets and held for 24 h died. Farrell et al. (2001b) found no post-capture delayed mortality after 24 h of holding coho salmon captured by troll fishing in net pens. Buchanan et al. (2002) showed improvements in the immediate survival of coho salmon bycatch from a gill net when using modified gear, short net soak times, careful handling of fish and a revival box. In particular, mortality reduction was associated with shorter soak times. To evaluate post-release survival, these researchers conducted swim tests and found the fish attained a velocity comparable to speeds of physiologically recovered fish (Farrell et al., 2001a). Gallinat et al. (1997) found mortality of lake trout captured and released from gill nets varied seasonally between 23 and 32% after 48 h of holding. Holding spring chinook salmon in net pens on the Columbia River for 72 h after capture in gill nets showed 7% mortality while 3% of those captured in tangle nets died (P. Frazier, Oregon Department of Fish and Wildlife, 17330 SE Evelyn Street, Clackamas, OR, 97015, unpublished data). These short-term observations of mortality are often used to represent the post-release mortality of free-swimming fish, because it was thought that most fish die within a short time of capture. However, our data indicate a much greater relative post-release mortality rate. Either the assumption that holding fish in net pens is indicative of their free-swimming mortality during the observation period is invalid, or the assumption that most of the post-release mortality occurs within a few days of capture is invalid. Certainly, our results suggest caution in using holding mortality to represent post-release mortality.

We expect the post-release mortality to vary between species, and with changing environmental conditions. Different species are known to have different responses to the same stressors (Schreck et al., 2001), and so may not respond to capture and release from the nets in the same ways. A given species may also display a different response in a more stressful environment than a less stressful environment. In our study, the environment was likely favorable to capture and release because the water was relatively clear and cool during the spring chinook salmon migration. Fishing in poorer conditions (e.g. higher velocity, warmer, or more turbid water, more predators present) would most likely increase mortality, although we do not know the magnitude of the difference.

The two-chambered revival box used for lethargic fish was effective for reviving spring chinook salmon. Farrell et al. (2001a) found these types of revival boxes effective for reviving coho salmon, although we were unable to achieve their 93.5% revival of fish captured in gill nets in condition 5 (no visible movement or ventilation). The reason for this difference is unclear, but may be species specific, because of the capture method, or a higher water flow was required. We also found that although a fish was observed to revive to a lively condition in the box, this did not necessarily mean the fish would survive after release, likely because a true physiological recovery requires much longer than the time for which we held fish, and much longer than would be practical in a competitive fishery. Post-release survival could probably be improved by holding fish for as long as possible, especially if the fish was brought on board in poor condition, or by holding the fish in a cage alongside the vessel to promote active swimming during revival (Farrell et al., 2001b).

The tangle net has shortcomings. As expected, it captured many more non-target species than the conventional gill net. As with any selective fishing operation, fishers using the tangle net must learn and use careful handling techniques to maximize survival of released fish. These include significant changes to fishing practices, which are difficult to enforce. Finally, there is a capital investment that is required by each fisher to purchase new nets, revival boxes and other related equipment, as well as additional time needed to develop markets.

5. Conclusions

This experiment represents the first study we know of that evaluated the post-release survival of free-swimming fish released from commercial fishing nets and showed that the method of capture is critical to their survival. We observed more than a four-fold decrease in post-release mortality of spring chinook released from the tangle nets compared to the 8 in. gill net. The tangle net therefore warrants consideration for selectively harvesting hatchery spring chinook salmon on the Columbia River while still protecting wild stocks. Coupled with the careful fishing and handling procedures we used, the tangle net would likely be useful for selective harvest of other salmonid species, and in other areas. Achieving this potential requires that we overcome problems with the tangle net and refine handling techniques to maximize post-release survival.

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