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ORIGINAL ARTICLE

Restrictions on leader length in an in-river sport fishery reduce catch of threatened wild chinook salmon *Oncorhynchus tshawytscha* and increase harvest of hatchery origin chinook

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Abstract

To achieve conservation and harvest objectives associated with Chinook Salmon, fisheries managers have relied on mark-selective and anti-snagging rules in freshwater whereby anglers are required to release wild Chinook and fish hooked in anatomical locations other than the head and mouth. However, in some cases these regulations have resulted in increased mortalities due to the number of fish (hatchery and wild) that require release. Regulations effective at increasing the number of fish hooked in the mouth have the potential to decrease total encounters (number of fish caught) of both hatchery and wild fish while increasing the total number of fish harvested; however, this has not been tested. A roving creel survey and a test fishery were used to describe the effect leader length and bait under a bobber has on catch rate and hooking location and simulate how a variety of restrictions on gear type would affect catch and harvest on wild and hatchery origin Chinook salmon. Results indicate that a 6-foot leader length restriction would result in the highest catch of hatchery fish harvested and reduce exploitation rate on wild fish by greater than 20%. Regulations limiting leader length to 3 feet are expected to result in the greatest reduction (75.7%) to total encounters on wild fish; however, this method was unpopular and resulted in few hatchery fish harvested. The use of bait suspended under a bobber resulted in intermediate results with a reduction of 60.0% to catch of wild Chinook and the smallest number hooked outside the mouth (0/30). These results provide the first evaluation of the effect of leader length in a mark-selective hook and line fishery and suggest that a 6-foot leader length restriction would be expected to reduce encounters on wild Chinook, increase harvest of hatchery fish and extend the fishing season.

KEYWORDS
fish, fisheries resources, salmon

1 | INTRODUCTION

Chinook salmon in Puget Sound are threatened under the Endangered Species Act (National Marine Fisheries Service, 2016). As a result, recreational, commercial and subsistence fisheries on the west coast of the United States are limited by estimates of exploitation rates (i.e. mortalities) on wild Chinook salmon bound for Puget Sound rivers. To reduce mortality on wild Chinook and access available hatchery origin fish, Washington Department of Fish and Wildlife (WDFW) and Native American treaty tribes in Washington state began removing the adipose fin from juvenile hatchery origin fish prior to release beginning in the mid-1990s. By clipping adipose fins at a high rate (>95%), managers and fishers are able to distinguish between hatchery and wild Chinook salmon. In addition, this tool has enabled fisheries managers to require the release of wild Chinook when landed (i.e. mark-selective fishing) in sport and commercial fisheries, has fuelled advancements in selective fishing techniques and monitoring (Naish et al., 2007; Dauer et al., 2009; Donaldson et al., 2011; Tuohy et al., 2019) and increased support for traditional indigenous methods (Menzies & Butler 2007; Atlas et al., 2020). Combined with estimates of release mortality assigned to caught and released wild fish, mark-selective fisheries aim to maximise the number of hatchery origin fish harvested while minimising exploitation rates on species of concern like wild Chinook.

With the advent of selective fisheries, managers across the globe have employed regulations that improve post-release survival and encourage anglers to rely on enticing the fish to strike natural or artificial lures (Dawson et al., 1992; Muoneke, 1994; Arlinghaus et al., 2007) rather than snagging them. These regulations represent an effort to promote ethical fisheries, allow for the release of species of concern and limit total encounters (the number of fish hooked and landed) on wild fish. Specifically, these regulations often include requirements for specific types of hooks (i.e. circle hook, barbless hooks etc.), rods (i.e. fly rods) and requirements to hang lures from a bobber or float. For example, in Washington State WDFW requires the release of all fish hooked in locations other than the mouth or the head (foul hooked) in addition to requiring the release of salmon with their adipose fin intact in selective fisheries.

Rules described above along with other 'anti-snagging' rules are meant to promote ethical fisheries and reduce the incidence of intentionally foul hooking of salmon. However, these rules can result in an increase in the total number of Chinook encountered by extending the time on the water (i.e. angler effort) for an angler to achieve their daily bag limit due to the release of landed fish that would otherwise be harvested. For example, greater than one hatchery origin Chinook was released for every one harvested as a result of fish hooked in locations other than the head and mouth in the 2012 sport fishery on the Nisqually river. In this way, rules meant to promote ethical fishing can have the undesired result of increasing the number of fish caught and released (both hatchery and wild) among anglers seeking to harvest their bag limit, ultimately limiting the season duration of fisheries as a result of high catch and release mortalities on species of concern (i.e. wild Chinook salmon).

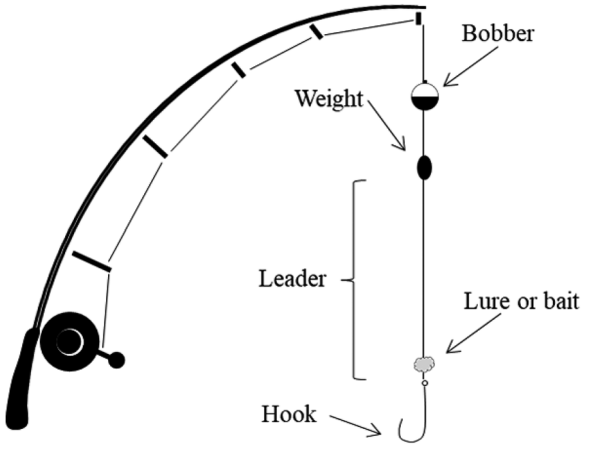

FIGURE 1 Standard fishing gear utilised in a hook and line sport fishery with the leader identified as the section of line between the weight and hook. Drift fishing gear is typically absent bobber above weight and relies on lure above hook to trigger a bite

A fishing regulation that has been utilised in salmon and trout fisheries in some states (e.g. Oregon and California) but not well tested is a restriction of the length of leader permitted. On a conventional fishing rod, a leader is the length of fishing line between any weight attached to the line and the fishing hook (Figure 1). In Washington State, anglers regularly use leaders in excess of 12 feet in length to increase the chance that the leader, and ultimately the lure and hook, will come in contact with the fish. In 2013, WDFW proposed imposing a leader length restriction with the intention of limiting this behaviour and reducing the high rate of foul hooking that is assumed to occur when this method is employed. During the preseason planning process, this proposed regulation was supported by some members of the public and opposed by others. Ultimately, the rule was not adopted in Washington State because the rule's effectiveness remains untested and it is uncertain what effect a leader length restriction would have on metrics used to evaluate salmon sport fisheries (i.e. encounter rate, exploitation rate, number harvested).

In this study, we sought to describe the effect leader length has on anatomical hooking location in a hook and line fishery targeting Chinook salmon in south Puget Sound rivers. We compare encounter rates and hooking location across three leader lengths and two fishing techniques, drift fishing and fishing with bait suspended under a bobber (BUB). We then use results to estimate how regulation changes would affect the two most important metrics to managers in a Chinook mark selective fishery, encounters of the species of concern and number of fish harvested. By doing so, managers will be better equipped to evaluate the potential that leader length restrictions have to maximise harvest opportunity while meeting conservation objectives in mark selective salmon fisheries.

2 | METHODS

2.1 | Study overview

A multi-part study was designed to estimate total Chinook encountered and total released by gear type, describe the relative use of

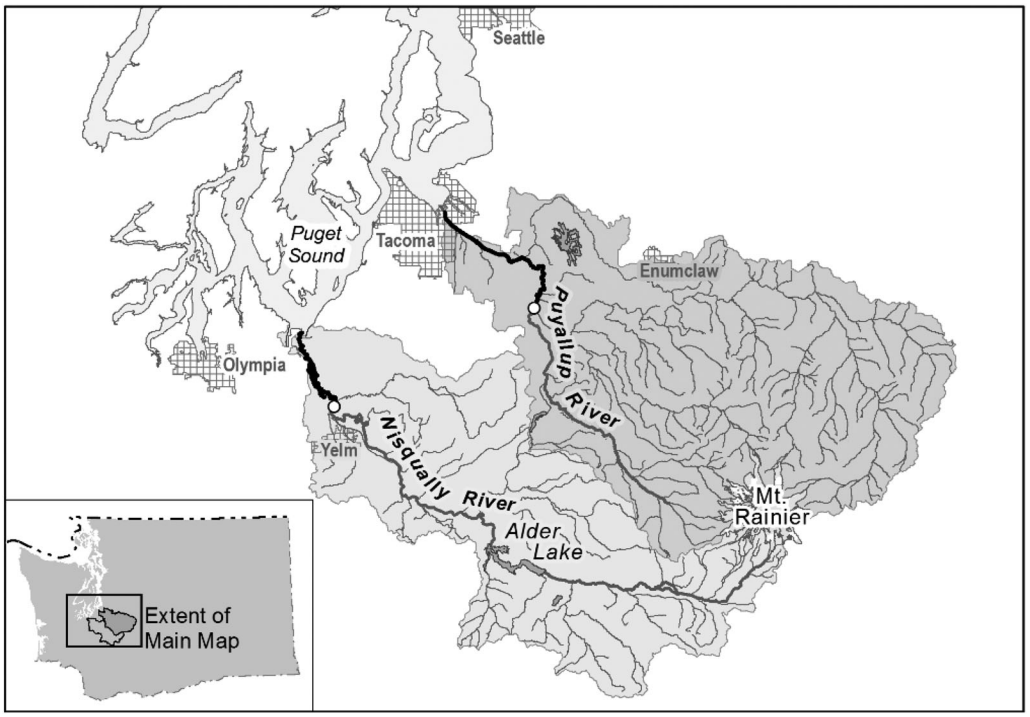

FIGURE 2 Study area on the Nisqually and Puyallup Rivers where sport fisheries targeting Chinook salmon occur (bold lines)

different gear types on the terminal end of hook and line equipment and describe the relationship between leader length and hooking location on landed fish in hook and line fisheries targeting salmon in Puget Sound rivers. Specifically, this was achieved by analysing data collected from surveys of angler gear type, creel survey and a test fishery in two rivers in south Puget Sound, Washington. This information was then used to estimate the expected encounter rates and associated Chinook mortality under a variety of leader length restriction scenarios to aid in the application of these results for fishery managers.

2.2 | Study area

This study took place in the Puyallup and Nisqually rivers, two watersheds located in western Washington (Figure 2). Both rivers originate from glaciers on Mt. Rainier, are composed of numerous tributaries and drain to South Puget Sound, Washington State. In the fall, both wild and hatchery origin Chinook salmon complete their ocean migration and return to freshwater where they are targeted by sport fishers in selective fisheries in lower reaches of the Nisqually and Puyallup rivers. During the study period, regulations in these rivers required the release of wild Chinook in the Nisqually and Puyallup rivers (mark-selective fishery) and release of all salmon hooked in locations other than the head and mouth (foul hooked). Anglers were also required to stop fishing once their bag limit (two adult hatchery origin Chinook) had been achieved.

2.3 | Creel and gear type survey

Creel surveys in the Nisqually river in 2010–2012 and Puyallup river from 2006 to 2010 encompassed the entire Chinook fishing period (August through October). Observers arrived before the legal fishing time and started and remained present until the end of legal fishing time; by regulation, fishing was limited to daylight hours only. A modified stratified random survey design was used to conduct roving creel surveys, following the methods outlined in Malvestuto et al. (1978), Pollock and Pine (2007) and Hahn et al. (2000) and more specifically Bentley et al. (2015). Information gathered included angler type (boat or bank), number of anglers in the group, angling start time, interview time, whether the trip was incomplete or complete, fishing location(s) and number of fish caught. If an angler had caught a fish, the species, origin (hatchery or wild), whether it was harvested or released, fishing method, gear type and hooking location were recorded.

To evaluate the type of gear used by sport anglers in the study area, anglers were interviewed on the Nisqually and Puyallup rivers in 2015. Surveys took place twice weekly (one weekday and one weekend day) during the Chinook salmon fishing period. Data collected included start time, trip completion status, gear type (e.g. drift, BUB, fly fishing), leader length for drift fishers, target species, number harvested for each species, number released for each species, reason for release and (coded wire tag CWT) present or absent in harvested fish.

2.4 | Test fishery

To describe the hooking location on fish landed across different leader lengths and between drift fishing gear and BUB, trained WDFW fisheries technicians who were also experienced salmon anglers were employed to fish the Nisqually and Puyallup rivers from shore using standard drift and BUB techniques in 2015, 2016 and 2017. When fishing with drift fishing gear, anglers were equipped with three pre-made leaders rated to 20 lbs. strength (test) fashioned with a size 1/0 barbless hook. Leaders were cut to three different lengths measured in imperial units to conform to standards in the geographic area where the study took place: 3.0 feet (0.9 m), 6.0 feet (1.8 m) and 9.0 feet (2.7 m). At the beginning of each fishing trip, anglers estimated the time that they would fish and recorded location. Anglers then randomly selected one of three leaders (to control for bias associated with angling success at beginning vs. end of the fishing trip) and made an effort to divide their total fishing time equally across three leaders so that each was represented equally on a trip. Test fishers also utilised BUB opportunistically and recorded start and end time when doing so. For BUB, anglers used a 3-foot leader length. During all fishing trips, the start and end time utilising each gear type or leader length was recorded to allow for estimates of catch per unit effort (CPUE). When a fish was landed, anglers recorded the species, status of adipose fin (clipped vs. unclipped), gear type used and whether the fish was harvested or released and recorded the anatomical location where the fish was hooked.

Hooking location data were then binned into seven general body regions. These included the mouth (inside mouth and jaw including maxillary), head (all areas anterior to the posterior edge not including mouth or jaw), anal fin, belly (area ventral to the lateral line and posterior to the operculum not including fins), back (area dorsal to lateral line and posterior to the operculum not including fins), caudal fin (includes caudal peduncle), dorsal fin, pectoral fin and pelvic fin.

2.5 | Data and statistical analysis

To test for differences in the contribution of fish hooked in legal body locations (mouth and head) versus those hooked in illegal body locations (non-mouth and head) across leader lengths and BUB, a Chi-square test was used. For this test, all years (2015–2017) were grouped to increase sample size.

To estimate encounter rate, defined as the proportion of the run that was landed, and total exploitation rate, defined as the proportion of the total run that incurred mortality as a result of harvest or release mortality, the estimated number of hatchery and wild Chinook that were exploited (harvest plus release mortality) was divided by the total runsize of Chinook salmon to the Puyallup and Nisqually rivers. Total runsize estimates are produced by WDFW by summing stock-specific estimates of escapement and harvest in all fisheries. Full description of runsize estimates is described in Losee et al. (2019). In this paper, Losee and co-authors compare trends in abundance, size and survival of five species of salmon and steelhead trout across 45 years in Puget Sound Washington.

CPUE (landed fish/hour) was calculated for the test fishery by dividing the number of Chinook landed (harvested and released) by the number of hours fished for each test fisher. CPUE was then averaged for each gear type across anglers. Legally hooked catch per unit effort (LHCPUE) was calculated by dividing the number of Chinook landed that were hooked in the mouth or head by the numbers of hours fished. First, CPUE was compared across gear types using a one-way ANOVA (Type I sum of squares) followed by a Bonferroni post hoc test for pair wise differences between gear types. Next, a series of T-tests allowed for a comparison between CPUE and LHCPUE for each gear type. For this, a Bonferroni correction was used, resulting in an adjusted level of 0.01 to achieve a p-value of 0.05 (i.e. $\alpha = 0.05/4 = 0.01$) across multiple comparisons presented as realised experiment-wide error rate.

Exploitation rate was calculated by adding the number of fish harvested plus the number of fish released multiplied by 0.1 to account for release mortality. Ten per cent is the comanager agreed to rate of release mortality in freshwater mark-selective fisheries in Puget Sound (Pacific Salmon Commission [PSC] 2016; Joint Chinook Technical Committee [CTC], 2018).

Results from creel, gear type survey and test fishery allowed for estimation of expected changes in the total number of fish landed by origin (hatchery vs. wild), hooking location and exploitation rates on wild Chinook across various leader lengths and BUB regulations. Specifically, the gear type survey provided the contribution of gear types to the harvest and exploitation rate observed in creel survey. We then calculated exploitation rates associated with varying gear type regulations based on hooking location patterns and CPUE observed in the test fishery. For example, to estimate expected rates of the number of fish encountered and rates of exploitation under a 6-foot maximum leader length rule, it was assumed that the proportion of anglers who fished with a leader length less than 6 feet and with BUB would experience the same rates of exploitation as observed in creel and would fish at the same effort. Based on this assumption, the associated encounter rates and hooking locations measured in the creel and test fishery were applied to this group. Under the 6-foot leader length restriction scenario, we assumed the proportion of anglers who fished a leader greater than 6 feet would shift their patterns of fishing (CPUE, hooking locations etc.) to mimic anglers fishing with the maximum leader length allowed (3- to 6-foot leader) (opposed to not fishing or fishing with a 3-foot leader or BUB).

Multi-factor ANOVA was used to test for an effect of gear type (leader lengths and BUB) on total Chinook landed, hatchery-origin Chinook landed, legally hooked hatchery-origin Chinook landed and wild Chinook landed while controlling for the effect of year and river. Difference in catch patterns was investigated further using Bonferroni multiple comparison test. For these analyses, total Chinook landed, hatchery-origin Chinook landed, legally hooked hatchery-origin Chinook landed and wild Chinook landed were compared among the three leader length restriction scenarios (i.e. sampled fishery, 6 ft maximum, 3 foot maximum) and BUB.

TABLE 1 Runsize of Chinook salmon to the Nisqually and Puyallup rivers and freshwater sport fishery encounter (landed catch hatchery + wild) rate, hatchery release rate and wild fish encounter rate

Site	Years	Chinook run to the river	Encounter rate	Hatchery release rate	Wild fish encountered
Nisqually river	2010	44,500	0.14	0.47	99
	2011	31,821	0.19	0.57	105
	2012	32,274	0.33	0.37	315
	2013	36,088	0.24	0.36	249
Puyallup river	2004	8397	0.17	0.43	228
	2005	7886	0.28	0.09	164
	2006	10,218	0.36	0.53	621
	2007	12,674	0.21	0.21	526
	2008	10,605	0.36	0.07	455
	2009	8742	0.44	0.11	589
	2010	7564	0.08	0.00	136
		Mean	0.25	0.29	317

3 | RESULTS

3.1 | Creel and gear type study

During the study period, creel surveyors sampled an average of 20.8% of salmon anglers in the Puyallup and Nisqually rivers. When expanded for unsampled anglers, an estimated 2605 ± 1184 SD Chinook were landed on the Puyallup river annually and 6029 ± 3411 on the Nisqually during the study period. When compared with the total run to the river, sport anglers encountered an average of 24.8% ± 10.5% of the total Chinook entering the rivers (Table 1). These encounters were composed of both hatchery and wild Chinook salmon. As mentioned earlier, regulations required the release of wild Chinook in the Nisqually and Puyallup rivers (mark-selective fishery) and release of all salmon hooked in locations other than the head and mouth (foul hooked) during the study period. Of the estimated 33,008 hatchery-origin Chinook salmon landed during the study period, an estimated 29.2% ± 19.2% were released (Table 1). Inquiries during creel surveys regarding the 'reason for release' suggested that foul hooked fish and fish quality were the most common reasons for release (69.0% and 26.4%, respectively) but 'fishing catch and release' was also reported as the reason for release among 4.6% of creeled anglers. The total number of wild Chinook landed during the study period was 4902.

In 2015, 304 anglers were surveyed in the Puyallup and Nisqually rivers (N = 101 and 203, respectively) to evaluate gear type utilised. Results indicated that anglers in the study area predominantly used drift fishing gear (98.2%; Figure 1) with leaders greater than 3 foot representing the overwhelming majority (49.0% 3–6 foot and 47.0% 6–9 foot; Figure 3). Fly-fishing and BUB represented less than 2% of the gear type used in both rivers (Figure 3).

3.2 | Test fishery

Between 2015 and 2017, two test fishers fished a total of 121 hours across 31 days and landed a total of 146 Chinook salmon. These landings were composed of 14 wild Chinook and 132 hatchery Chinook. All leader lengths resulted in anglers hooking some fish in locations other than the mouth and head. In contrast, when anglers used BUB, 100% of fish landed were hooked in the mouth (Figure 4). The proportion of total Chinook landed and number of fish hooked in locations outside the head and mouth decreased with decreasing leader length. Specifically, when using the 9-foot leader length, 32.3% (n = 22/68) of fish landed were hooked in locations other than the head and mouth. For 6- and 3-foot leaders, the percentage of fish hooked in locations other than the mouth and head was reduced by 39.7% (n = 8/41)

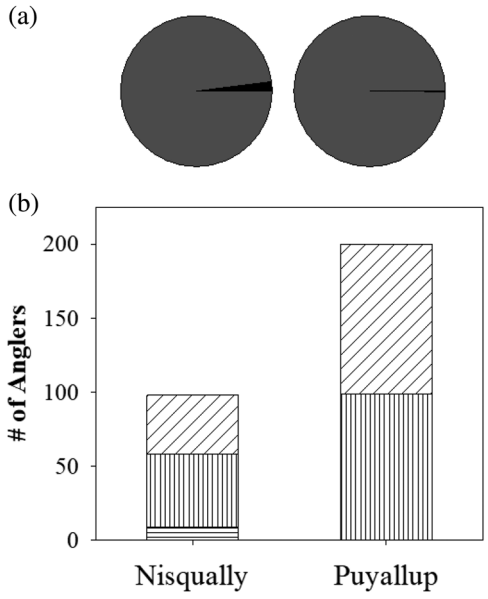

FIGURE 3 Pie graph showing proportional contribution of gear types (a) including bait under a bobber (black), drift (grey) and fly fishing (white) and length of leader used among "drift" fishers, (b) 0- to 3-foot leader (horizontal lines), 3–6 foot (vertical lines) and 6–9 foot (diagonal lines) on the Nisqually and Puyallup Rivers in 2015

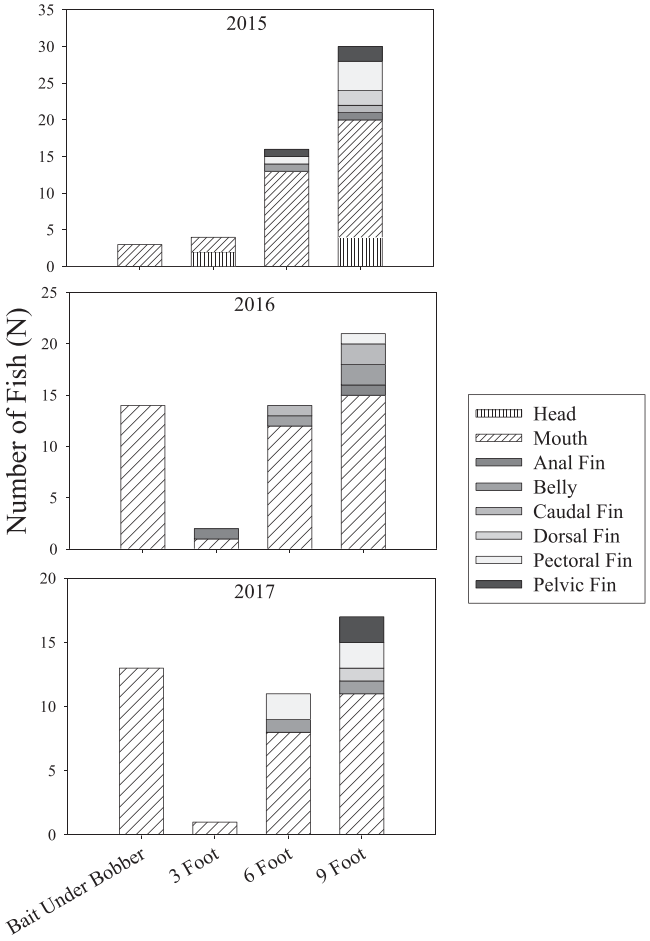

FIGURE 4 Number of Chinook salmon landed and hooking location by test fishers in the Puyallup and Nisqually rivers utilising alternative gear types in 2015, 2016 and 2017

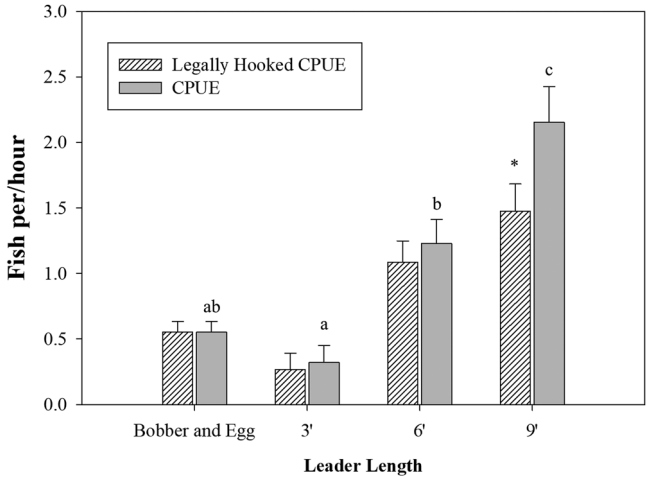

FIGURE 5 Mean catch per unit effort (CPUE) of all landed (grey) versus legally hooked Chinook salmon (hatched, LHCPUE) and standard error across differing gear types in the Nisqually and Puyallup rivers. Letters above grey bars represent results from pairwise comparisons of CPUE between gear types. Bars which do not share a lowercase letter are significantly different than each other ($P < 0.05$). Asterisks above hatched bars represent results from pairwise comparison between CPUE and LHCPUE. Bars with an asterisk above them are significantly different than neighbouring grey bar ($P < 0.05$)

and 55.8% ($n = 1/7$), respectively. When test fishers used BUB, 100% of fish landed (30/30) were hooked in the mouth. Pairwise comparisons suggested that fishing with a 9-foot leader length resulted in fish hooked in different body locations than when fishing with bait under a bobber or with a 3-foot leader length ($p < 0.01$ and 0.61, respectively).

CPUE was significantly different (ANOVA, $p < 0.001$, $\eta^2 = 0.35$) across gear types with a significantly greater CPUE (landed fish per hour) associated with 9-foot leader (CPUE = 2.2) compared to other leader length categories (Bonferroni, $p < 0.05$; Figure 5) and overall decreasing CPUE with decreasing leader length (6 ft = 1.2, 3 ft = 0.3). When using a 6-foot leader, CPUE of test fishers was significantly different than the 3- and 9-foot foot leaders but not bait under a bobber. When using bait under a bobber, CPUE was intermediate to 3- and 6-foot leaders (0.6 landed/hour). Comparison of CPUE versus legally hooked CPUE (LHCPUE) for each gear type revealed a significant difference for the 9-foot leader but not other gear types (*T*-test, $p < 0.05$). Specifically, for the 9-foot leader, total landings for fish hooked in anatomical locations that would permit harvest were 31.8% less than total landings (1.5 LHCPUE vs. 2.2 CPUE; Figure 5).

3.3 | Effect of leader length regulations

Estimating expected changes in catch across different leader lengths and BUB during the study period revealed significant differences in catch between gear types while controlling for the effect of river and year (ANOVA, $p < 0.05$; Table 3). The results indicate that the number of fish legally hooked is expected to be significantly higher when a 6-foot leader length restriction is in effect (Figure 6; Fisher's PLSD, $p < 0.05$). Specifically, results of analysis suggested that anglers would experience a 2.7% increase in the number of hatchery fish hooked legally when restricted to fishing gear with a leader 6 foot in length or less, including using bait under a bobber compared to no gear restrictions (Table 2). In this scenario, exploitation on wild fish is expected to decrease by 20.2% (Table 2) as a result of significantly fewer total fish landed that require release due to foul hooking with no significant difference in total landed Chinook (Fisher's PLSD, $p > 0.05$). When a maximum leader length of 3 foot is imposed, an even greater reduction in foul hooking and total exploitation rate on wild fish is expected (Figure 6) with a significant reduction in catch of both wild and hatchery fish relative to all other fishery scenarios (Fisher's PLSD, $p < 0.05$) except BUB. However, the number of legally hooked hatchery origin Chinook is expected to decrease by 67.8% (938 vs. 2915) compared to what was observed when no leader length restriction was in effect (Figure 6; Table 2). BUB regulations provided an intermediate benefit to wild Chinook with a 59.9% reduction in exploitation rate compared to exploitation rate reductions when regulations require a 6-foot and 3-foot leader length restriction (20.2% and 75.7%, respectively; Table 2). Assuming effort remained the same

TABLE 2 Comparison of the annual average number of Chinook salmon (hatchery origin and wild) encountered (landed), rate of annual wild exploitation and number of hatchery origin Chinook salmon hooked in legal body locations and landed in the Nisqually and Puyallup Rivers across four fishery scenarios. These include the creeled fishery (no leader length regulation), simulated fishery with 6-foot maximum leader length, 3-foot maximum leader restrictions and bait under a bobber

	Sampled fishery		6-foot leader			3-foot leader			Bait under a bobber		
	Mean	SD	Mean	SD	Savings	Mean	SD	Savings	Mean	SD	Savings
Total landed	4537	2931	3684	2463	853	1215	941	3322	2020	1582	2517
Hatchery origin landed	4220	2743	3432	2316	788	1140	904	3079	1898	1517	2322
Legally hooked hatchery origin	2915	1804	2994	2185	−79	938	786	1977	1898	1517	1018
Wild origin landed	317	188	252	146	65	74	37	243	122	64	195
Wild exploitation rate	2.55%	1.05%	2.03%	0.82%	0.51%	0.62%	0.22%	1.93%	1.02%	0.40%	1.5%

TABLE 3 Multi-factor analysis of variance (ANOVA) for an effect of angler gear type, year and river on total Chinook landed, hatchery-origin (HOR) Chinook landed, legally hooked hatchery-origin (Legal HOR) Chinook landed and wild Chinook landed in the Nisqually and Puyallup Rivers between 2004 and 2013

Response	Explanatory	df	Sum of squares	Mean squares	*F* ratio	*p*-value
Total landed	Gear	3	75,927,017	25,309,006	19.77	<0.001
	Year	1	100,084,942	100,084,942	78.19	<0.001
	River	1	38,275,793	38,275,793	29.90	<0.001
	Gear × year	3	14,449,788	4,816,596	3.76	>0.05
	Gear × river	3	4,730,438	1,576,813	1.23	>0.05
	Residuals	32	40,962,337	1,280,073		
HOR landed	Gear	3	65,102,152	21,700,717	20.17	<0.001
	Year	1	103,333,068	103,333,068	96.03	<0.001
	River	1	42,403,693	42,403,693	39.41	<0.001
	Gear × year	3	15,372,119	5,124,040	4.76	>0.05
	Gear × river	3	5,650,554	1,883,518	1.75	>0.05
	Residuals	32	34,432,441	1,076,014		
Legal HOR landed	Gear	3	31,087,277	10,362,426	15.13	<0.001
	Year	1	64,757,912	64,757,912	94.56	<0.001
	River	1	26,977,118	26,977,118	39.39	<0.001
	Gear × year	3	6,563,426	2,187,809	3.20	>0.05
	Gear × river	3	2,452,115	817,372	1.19	>0.05
	Residuals	32	21,913,848	684,808		
Wild landed	Gear	3	416,877	138,959	8.93	<0.001
	Year	1	25,934	25,934	1.67	>0.05
	River	1	105,669	105,669	6.79	>0.05
	Gear × year	3	15,857	5286	0.34	>0.05
	Gear × river	3	42,225	14,075	0.91	>0.05
	Residuals	32	497,754	15,555		

as observations in creel surveys during the study period, a regulation requiring all anglers to utilise BUB is expected to result in the least number of fish foul hooked but also a significant reduction in total Chinook landed relative to no gear restrictions (Fisher's PLSD, $p < 0.05$).

4 | DISCUSSION

This study demonstrates the relationship between gear type and anatomical hooking location on Chinook salmon and provides the first estimate of the effect of regulations that limit leader length in a hook

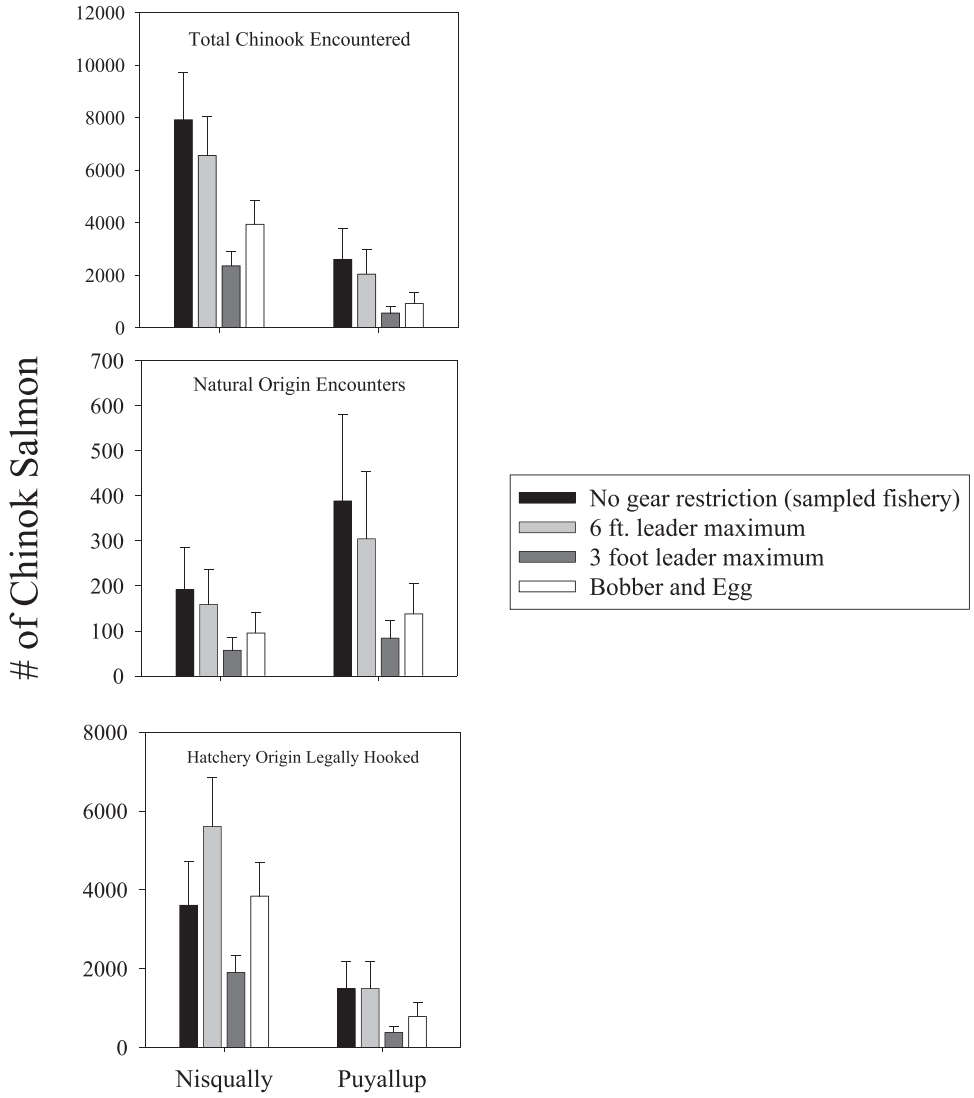

FIGURE 6 Estimated number of total Chinook and wild Chinook encountered (caught) and legally hooked hatchery origin Chinook salmon in the Puyallup and Nisqually Rivers with standard deviation. Note that *Y*-axis is not consistent between tiles

and line sport fishery targeting salmon. Furthermore, by simulating the sport fishery under a variety of gear regulations this work shows that rules restricting the length of the leader used by anglers would be expected to result in fewer wild fish landed overall with an increasing rate of fish hooked in anatomical locations that permit harvest (mouth and head). In Puget Sound, the majority of fisheries targeting Chinook salmon are limited by stock-specific exploitation on wild fish (Puget Sound Indian Tribes and Washington Department of Fish and Wildlife, 2017), with a large proportion of the total exploitation annually resulting from release mortality associated with mark-selective hook and line fisheries in marine and freshwater (Joint Chinook Technical Committee [CTC], 2018). For this reason, a fishery plan expected to reduce the number of wild fish caught and released in freshwater sport fisheries has the potential to extend the duration of these fisheries or allow opportunity in times and/or places where it would not have existed, ultimately increasing the number of hatchery fish harvested.

While this study showed the potential to reduce total encounters through restrictions on gear type, the intermediate leader restriction tested (6 ft maximum) may represent a 'sweet spot' in leader length regulations for both fishery managers and anglers. When applied in the current study area, where a large proportion of anglers utilise leader lengths in excess of 6 feet, our analysis suggested a regulation that permits a maximum leader length of 6 foot in combination with bobber and eggs and fly fishing and provided the greatest benefit through a reduction in encounters of wild fish and an increase in the number of hatchery fish hooked legally. In contrast, a 3-foot leader length restriction, while providing the greatest benefit to wild fish, reduced the number of hatchery fish landed by more than threefold. This is important because restrictions to fishing that are expected to reduce total encounters have been shown to have a negative effect on angler satisfaction and participation (Veinott et al., 2018; Van Poorten & MacKenzie 2020), ultimately affecting the ability to

meet fish management objectives associated with angling opportunity, sales of fishing licenses and the public's engagement with the natural resources (Nguyen, 2009; Cooke et al., 2019). In Washington State, Chinook salmon are prised as a high-quality food fish, and sport fisheries in Washington state have a long history of targeting this species for harvest (Lichatowich, 1999; Haw, 2015). For that reason, fisheries managers seek to develop regulations that maximise the number of hatchery origin Chinook salmon harvested while minimising the impact on species of concern, like wild Chinook. It is possible that regulations such as a restriction on leader length to 6 feet maximum length, as tested here, may serve to satisfy conservation goals and the desires of both harvest-oriented anglers and those interested in maximum time on the water.

This study provides evidence that restrictions on leader length could reduce the catch rate per angler trip on an Endangered Species Act (ESA)-listed fish, increase harvest opportunity and extend fisheries; however, data limitations do exist and some assumptions were not considered. For instance, we did not consider that Chinook salmon released may have been caught more than once and could effect estimates of the total number of individual fish captured. However, this would not be expected to effect results of this research comparing differences in catch across gear types. Additionally, we did not attempt to estimate changes in fishery participation associated with restrictions on gear type. Veinott et al. (2018) showed that significant regulation changes in sport fisheries targeting Atlantic salmon resulted in a significant reduction in anglers compared to more conservative changes. In the creel surveys that collected data on gear type, very few anglers were observed fishing with a 3-foot leader, likely because it is not effective at catching fish as revealed from our test fishery. For that reason, a leader length restriction of 3 foot should be expected to change angler behaviour (participation, compliance, gear type etc.) in uncertain ways. An additional factor not accounted for in the current study was angler compliance to rules. Current anti-snagging rules are meant to improve the culture and behaviour of anglers in hook and line fisheries and require anglers to use gear that will result in fish actively taking the lure. Additional regulations such as those evaluated here could provide further improvements to ethics around fishing; however, if anglers are unwilling to conform to regulations or they are too difficult to enforce, regulations changes could result in the opposite outcome. In a study focused on warmwater species, Page and Radomski (2006) demonstrated a negative relationship between angler awareness and rule violations and suggested that tools that improve education and outreach by fish managers should be expected to improve compliance with new regulations. Currently, angling education and information materials produced by WDFW are limited to online platforms and an annual fishing pamphlet and do not rely on signage in most fishing access areas. Given that the results reported here represent a field of research not well studied and are based on a small sample size in a small geographic area, a successful approach to implement these gear restrictions should be multifaceted and include additional research, focused outreach, education and a well-designed plan for enforcement.

Management of recreational fisheries in the presence of federally protected species is complex and requires an understanding of social and biological factors to achieve objectives around conservation and fishing opportunity. In Puget Sound, where this study took place, abundance of hatchery Chinook has increased at the same time that threatened wild Chinook salmon have decreased (Losee et al., 2019), exacerbating these challenges. With an increasing number of people interested in accessing a diminishing resource, creative angling regulations may be necessary to ensure goals of both opportunity and recovery are achieved. Together, these results provide the first evaluation of the effect of leader length in a hook and line fishery and suggest that a 6-foot leader length restriction along with designated areas permitting BUB would provide the greatest benefit to the resource and anglers. Through effective outreach and communication, these regulation changes are expected to limit encounters on wild fish, increase the number of hatchery origin fish harvested and maximise the length of fishing seasons in the presence of ESA-listed Chinook salmon. To maximise engagement of anglers, managers should prioritise regulations that support conservation objectives and provide meaningful opportunity over more traditional approaches that result in short fishing seasons and closure of water bodies.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

James Losee was involved in study design, data collection, analysis and writing.

ETHICS STATEMENT

Ethical and legal approval was obtained from Washington Department of Fish and Wildlife prior to the start of the study and sampling and associated exploitation rates conformed to comanager agreed to fisheries permitted under ESA.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study will be available upon request.

PEER REVIEW

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