Preliminary analysis

Evaluate selective fishing in the Willapa River, a Pacific Northwest estuary

Final report for Saltonstall Kennedy #NA03NMF4270133

Ashbrook, C.E., J.F. Dixon, K.E. Ryding, K.W. Hassel, and
E. A. Schwartz

Washington Department of Fish and Wildlife
600 Capitol Way N.
Olympia, WA 98501

Email: ashbrcea@dfw.wa.gov

Telephone: (360) 902-2672

Facsimile: (360) 902-2944

January 2007

Abstract

Selective fishing is defined as the ability of a fishing operation to avoid non-target species and stocks, or when encountered, to capture and release them in a manner that minimizes mortality. Commercial and sport gears were tested in an estuary environment to selectively harvest adult hatchery coho (*Oncorhynchus kisutch*) and release natural coho and fall Chinook salmon (*O. tshawytscha)* bycatch. Experienced commercial fishers fished tangle nets (8.9 cm (3.5”) mesh size, multifilament net) and gill nets (14.6 cm (5.75”) mesh size, monofilament net) suitable for a coho fishery. To minimize mortality as much as possible, fishers also used careful handling techniques, a revival box, a shorter net, and shorter soak times. During the same time period, experienced sport fishers fished using barbless hooks and herring. Live fish were tagged and released for recovery in sport fisheries, commercial fisheries, at hatchery racks, and during spawning ground surveys.

Overall, although the tangle net performed better for evaluations such as condition at capture for both coho and Chinook and immediate survival for Chinook, there was no difference detected in post-release survival between fish caught in tangle nets and gill nets for either species; this latter result could be due to a lack of statistical power. Sample sizes for coho were much larger, (430 and 580 for tangle and gill net, respectively) than for Chinook (158 and 182 tagged releases for tangle and gill net, respectively). Because many fish needed to be revived, a successful commercial selective fishery in this setting is expected to require a high ratio of marked hatchery to wild fish.

A reproductive success study to evaluate the progeny of fish captured in fishing gears showed a significant difference between tangle net and gill net captured adults. The eyed egg to fry and fry abnormality rates were highest for tangle net captured fish. However, this imparted a 5.5% survival advantage, which from a biological perspective seems negligible.

Too few fish were captured in sport gear for analysis. A modified purse seine was used as a control. Because the purse seine could not fish in the same locations as the commercial and sport gears and too few fish were captured for survival estimation, this gear is not useful as a control for the Willapa system. However, all coho and Chinook captured in this manner were in excellent condition and consequently, this gear should be further analyzed as a live capture selective harvest method.

Table of Contents

List of Figures

List of Tables

Acknowledgements

We are grateful for the financial support of the National Marine Fisheries Service (NMFS), Saltonstall- Kennedy Program, without which this research could not have occurred. Reviews of this report occurred at various stages and we are grateful to Enrique Patino and Kevin Ford, both of NMFS, Steve Schroder Washington Department of Fish and Wildlife (WDFW) and John Skalski of the University of Washington Columbia Basin Research, for their edits and advice. Test fishing was provided by Eric Petit, Norris Petit, and Bruce Ogren for the gill net and tangle net studies. Marty Kuller led the purse seine fishing.

We are also grateful for the help of many WDFW employees. Intellectual energy and advice were received from Steve Schroder, Geraldine Vander Haegen, Cindy LeFleur, and Tim Flint. The Forks Creek Hatchery Crew provided assistance with the reproductive success study. Sport fishing assistance was received from Mark Carr and Chris Waldbillig. Technical support was provided by Jeff LeBrun, Sara Lukas, and Dave Parrao. Kurt Holt led the stream surveys and Patrick Verhey directed sport and commercial fishery sampling for jaw tags.

Executive summary

In the presence of endangered and threatened species, the status of bycatch animals not harvested becomes just as or more important than the number harvested. One way to minimize bycatch mortality is through live capture and selective harvest methods, more commonly referred to as selective fishing. Selective fishing methods have been successful for spring Chinook (*Oncorhynchus tshawytscha)* captured in freshwater. However, their success for coho (*O. kisutch) a*nd fall Chinook in an estuarine environment was unknown. Survival differences between these two environments were expected because in an estuary water temperatures may be relatively warmer, salmonids are captured as they are undergoing physiologic transformation from salt to fresh water, coho and fall Chinook spawn soon after capture and release, and because of differences in species and race. The goals of this study included estimating survival, evaluating condition at capture, comparing fishing gears, testing a modified purse seine as a way to capture control fish, and evaluating reproductive success to learn if selective fishing is a reasonable management tool in an estuary setting.

During 2003, experienced commercial fishers used 8.9 cm tangle nets (3.5" mesh size, multifilament net) and 14.6 cm conventional gill nets (5.75" mesh size, monofilament net) combined with revival boxes, shorter soak periods, shorter nets, and careful handling techniques. Sport fishers used barbless hooks and careful handling techniques. Coho and Chinook salmon captured in these gears were tagged and released for later recovery in sport fisheries, commercial fisheries, at hatchery racks, and during spawning ground surveys. A modified purse seine was used to collect control fish to obtain actual (as opposed to relative) survival estimates. A comparison of the reproductive success of coho that had been captured and released from these gears with coho that had not been previously caught was performed at the Forks Creek Hatchery.

For coho, we found that the tangle net was as effective at capturing fish as the conventional gill nets. Fish captured by the tangle net were also in better condition than fish caught in traditional gill nets. The immediate survival (from capture to release from the boat) of adult coho salmon caught in the tangle net was not significantly different than for fish caught in the gill net. We were not able to detect differences in relative recovery rates, and hence long-term survival, between tagged adult coho released from the two net types. Differences in egg-to-fry survival were found to be associated with gear type, with fry produced from adults captured in tangle nets faring better than those that were captured by conventional gill nets. More non-target species were captured in the tangle net than the gill net. Immediate survival was affected by water temperature and by minutes fished for both gear types (tangle net and gill net). Egg-to-fry survival differences also occurred by gear type, with the progeny of tangle net captured adults faring better. Too few fish were captured in the sport gear to evaluate the effects of a selective fishery for coho.

For Chinook salmon, the tangle net was not as effective as the gill net at capturing fish but fish captured by the tangle net were in better condition, larger, and had higher immediate survival as compared to Chinook caught by the gill net. Despite the larger size of the Chinook, the 8.9 cm net acts as a tangle net and the 14.6 cm net acts as a gill net. Chinook survival by temperature and minutes fished was also significantly different between the tangle net and gill net. As with adult coho, we could not detect differences in tag recovery rates, and subsequently long-term survival, between Chinook caught in tangle nets and those caught in gill nets owing primarily to the small number of tag releases. Too few fish were captured in the sport gear to evaluate the effects of this type of selective fishery for Chinook.

Further research is needed to provide managers with survival estimates for bycatch salmon released during an estuarine commercial selective fishery. Although our study developed methods to estimate survival, and control fish captured using a modified purse seine method were in excellent condition, the modified purse seine did not provide a suitable control for Willapa Bay because this gear could only be used in a few locations . All salmon captured using the modified purse seine were in excellent condition, hence we believe this gear should be more completely evaluated in the future.

We did not detect a difference in the long term survival of coho and fall Chinook released from tangle nets and gill nets and conclude that the data did not contain enough information to make inference on whether there were or were not post-release survival differences. To estimate long term survival, we recommend further studies using tags with higher detection probabilities. We did observe that many coho and Chinook captured in tangle nets and gill nets in this environment were lethargic and needed to be revived. This differs from similar studies in the Columbia River, where most spring Chinook and steelhead were in vigorous condition at capture. The reason for this difference is unknown and could be from the following factors: low dissolved oxygen from warm water temperatures, the immediacy of physiologic transformation, or the immediacy of spawning for coho and fall Chinook. Because many fish needed to be revived, we expect that successful commercial selective fisheries in this setting will require a high ratio of marked hatchery to wild fish.

Purpose

Pacific Northwest salmon are typically harvested in mixed stock fisheries where different species and stocks intermingle. In the 20th century, this mixture usually consists of both weak and robust species and stocks. In the past when this situation was less common, fish managers used time and area closures to protect weak stocks. In the present day, these management methods often result in severe reductions in salmon harvest despite the presence of healthy stocks. This is not a desirable result because fishing communities can be financially decimated despite the presence of harvestable fish, and the goal of using hatchery programs to produce harvestable fish is not fulfilled.

Ideally, new management and fishing methods that allow harvest on abundant stocks with little or no impact to weak stocks need to be developed. One strategy that is receiving much attention is "live capture selective harvest," where fish are captured live so that individuals from weak stocks can be returned to the water with little harm. This method fits within the larger umbrella of "selective fishing," and can be combined with time and area restrictions. As a result, a fishing operation can avoid non-target species or stocks, but when encountered, capture and release those animals in a manner that minimizes mortality. This fishing method has been available for years for species other than salmon. The United Nations FAO defines "selective fishing" as

> "…the ability to target and capture fish by species, size or sex during harvesting operation, allowing all by-catch to be released unharmed. By-catch may include small (juvenile) fish, non-target fish species, birds and other marine organisms encountered during fishing "(United Nations FAO, 1994, Expert Consultation for the Code of Conduct for Responsible Fishing Operations).

For Pacific Northwest salmon, this definition must be expanded so that bycatch can include non-target stocks of a fish species. In addition, it seems more reasonable to change "allowing all by-catch to be released unharmed" to "allowing all by-catch to be released with minimal mortality" because some mortality will occur during even the most careful fishing operation.

One crucial component of having a selective fishery for salmon is the ability to visually distinguish the targeted healthy stocks from non-targeted weak stocks. This is possible through a program that began in 1995 to adipose clip all harvestable hatchery salmon. This mass marking program has been expanded recently in Washington State with federal legislation that requires that as of 2005, state and federal hatcheries remove the adipose fin of hatchery produced coho and Chinook salmon prior to their release as juveniles. Consequently, more hatchery fish can now be visually distinguished from naturally produced fish. Salmon fisheries in the Pacific Northwest where mass marked fish are retained, and non ad clipped fish are released are commonly referred to as "mark selective fisheries".

Another crucial component to selective fishing is the fishing operation. Gears and techniques must be used that enable non-targeted fish to be released alive, yet enable a harvest that is economically viable. Commercial fishers must be willing to develop and try new methods with the hope that, as a result fishing can remain a career option. Moreover, sport fishers must be willing to experience new management and gear regulations to ensure that they can continue to recreationally harvest salmon.

Ultimately, for selective harvest to be successful, a conservation goal must be achieved for the species and stocks of concern. This means that fish released from commercial and sport fisheries must survive and contribute to the rebuilding of their population. Equally important is the willingness of fishers to use the new methods and gears. This is a multi-dimensional issue that includes social mores, economics, and is likely different for sport versus commercial fisheries. For this study we expected that fishers would change to the new gear provided it worked as well as the old.

Although many tagging studies that evaluate migration and population sizes suggest that fish can be captured and released with some measure of survival, these types of studies are not specifically directed at the effects of capture gears on survival. Gallinat et. al, (1997) discuss that in mixed stock fisheries commercial net fleets are often assessed 100% mortality on encountered fish, even though they may be able to release some of those fish live. In a recent study, spring Chinook salmon released from gill nets were shown to survive their release when additional modifications such as a revival box, shorter nets and shorter soak times were also implemented (Vander Haegen et al., 2004).

In the many studies for sport captured fish, the mortality of released fish appears to be variable and dependent on the species captured, the skill of the fisher in releasing the fish, the environment, and the fishing method (Muoneke and Childress 1994). Survival of lake trout captured in gill nets in Lake Superior and held in tanks for 48 hours varied seasonally from 68% to 77% (Gallinat et al. 1997). In addition, studies evaluating coho salmon released from commercial fishing gears in British Columbia have shown that mortality of fish held in net pens for 24 hours was less than 3% (Farrell et al. 2001a). Although holding fish in net pens is efficient and relatively inexpensive, post-release survival of salmon held in net pens is unlikely to reflect the post-release survival of free-swimming fish because fish held in net pens are not subject to predation, currents, or encounters with obstacles to migration (e.g. dams, shallow parts of rivers, etc.) that fish released back into the environment must navigate.

In some cases standard fishing gears can be modified to enable fish to be captured alive. A modification to commercial gear that has been successful is the replacement of the traditional gill net with a tangle net. The tangle net combined with a revival box, shorter soak times, and a shorter net resulted in a higher post-release survival of salmon compared to when a gill net was used (Vander Haegen et al., 2004). In another study, tangle nets were shown to induce less stress in salmon than conventional gears (Farrell et al., 2001b). Although salmon may survive their release, stress resulting from capture could affect their ability to reproduce. To our knowledge, no studies have evaluated the reproductive success of salmon following their release from a selective fishery.

Based on the success of tangle nets for spring Chinook, fish managers have implemented selective tangle net fisheries in Washington State. The tangle net (Figure 1) and (Figure 2) is a possible substitute for gill nets that has been shown to meet the criteria for selective fishing for spring Chinook salmon (Vander Haegen et al., 2004). Tangle nets look similar to a gill net but have a smaller mesh size and are made from multifilament web. Gill nets are typically made from monofilament web. Both gears can be fished using the same method and in the same locations, but unlike a gill net, which captures an adult salmon around the gills or body, the mesh size of the tangle net captures target fish by the maxillary or teeth, which allows the fish to continue respiring in the net so that it can be released alive. External and associated internal injuries are also reduced using this capture method. Modifications in fishing practices, including the use of fish revival boxes (Farrell, 2001(a)), short soak times, and careful fish handling, are as important as the gear in ensuring that fish are released live and unharmed.

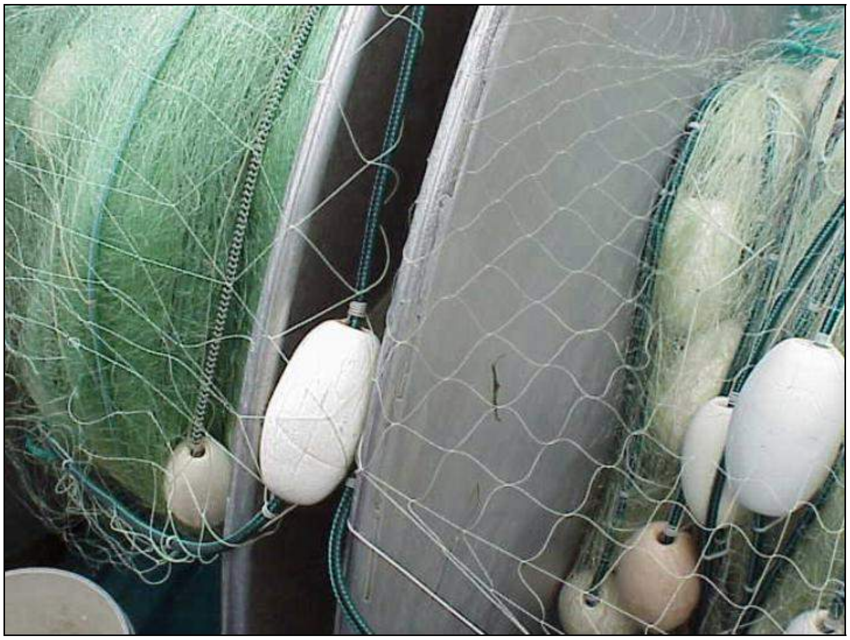

Figure 1. Photograph that shows conventional gill net (left) beside a tangle net (right). Photo provided by the Oregon Department of Fish and Wildlife Lower Columbia Management Office.

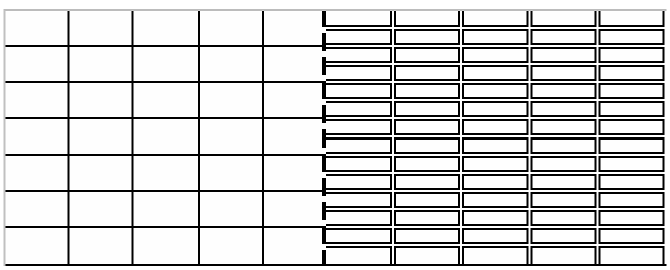

Figure 2. Diagram of gill net (left) shackled to a tangle net (right). Drawing is not to scale.

Fish managers have also implemented selective sport fishing methods and technologies throughout Washington State waters as a way to reduce impacts on depressed and listed stocks and on non-target species. These strategies include barbless hooks only in saltwater fisheries and the release of adipose present fish (representing wild fish) in most freshwater fisheries. The range for hook mortality in sport fisheries is considered to be 10% to 24% (including drop-off) throughout the state (Gjernes et al., 1993). (Drop-off rate is defined as the proportion of fish encountered by the gear that is killed without being brought to the vessel intact, e.g., pinniped predation). These mortality rates are values agreed to by the co-managers of the resource and are almost exclusively based on ocean hook mortality studies, even for terminal fisheries. Estimates that incorporate additional mortality resulting from the physiological transition that occurs when salmon migrate through an estuary are unavailable, and more accurate estimates would greatly improve harvest models.

Many mixed stock fisheries occur in estuary environments, where the fish are in the process of physiologic transformation from a salt to a fresh water environment. Consequently, survival rates for salmon captured and released in this type of habitat may differ from salmon captured and released in freshwater. Further, salmon captured in this type of habitat that spawn soon after entering freshwater may experience different survivals than fish such as spring Chinook, which spawn about six months following their entry into freshwater.

This study addressed the following questions:

1. Will salmon that are captured in an estuary survive following release?
2. Will salmon that spawn soon after release reproduce successfully?
3. In a commercial selective fishery, do tangle nets capture fish as well and in better condition than traditional gill nets?
4. Are the selective fishing methods used reasonable to expect of an actual fishery?
5. Are there survival differences between commercial and sport gears?

We consequently designed a study to evaluate live capture selective harvest methods for salmon captured in commercial and sport gears for fish migrating through an estuarine habitat. To increase the sample size it was necessary to assume that adipose clipped fish survive similarly to naturally produced fish. This study required an estuary setting with commercial and recreational fleets, the presence of healthy salmon stocks, and at least one hatchery where many of the fish would return. Willapa Bay, Washington, met these requirements and further, two previous years of research using tangle nets and gill nets in this area had shown mixed results (Vander Haegen et al., 2002). Further, fish managers were concerned that the need to conserve the natural Chinook in Willapa Bay could limit future coho fisheries in this area, making the evaluation of live capture selective harvest crucial.

Present day fall fisheries in the Willapa Basin target hatchery coho so this study was developed around a selective fishery whose focus was coho. The non-target bycatch salmon species included natural coho, Chinook, and chum. Originally there were five objectives but a no-cost time extension in our contract allowed us to add a sixth objective. The six objectives were:

1. Compare the number and condition of coho salmon caught in tangle nets and conventional gill nets.
2. Using coho captured in a modified purse seine as a control, estimate and compare the immediate and long-term survival of coho caught in the tangle net, the conventional net, and with hook and line.

3. Enumerate bycatch and compare the immediate mortality of untargeted salmon stocks and species (bycatch) captured in the tangle net, the conventional net, and with hook and line using the modified purse seine as a control.
4. Compare the egg-to-fry mortality and abnormality rate of the progeny for coho released from the tangle net, the gill net and hook and line gears that return to a hatchery.
5. Estimate the hooking mortality rate for coho captured in an estuary. Compare this rate with the value currently used by fish managers and with other ocean and freshwater hooking mortality studies.
6. Compare the number and condition of Chinook salmon bycatch caught in the coho test fisheries.

Approach

Site Description

We held sport and commercial test fisheries in Washington State from Willapa Bay (Figure 3), to just inside the Willapa River at about river kilometer (rkm) 8.1, which reaches from the town of Tokeland to the town of South Bend. Both Willapa Bay and the lower Willapa River are subject to tides, and salt or brackish water reaches 29.1 km from the river mouth upstream to Mill Creek. There is a Washington state salmon hatchery located on Forks Creek near its confluence with the Willapa River at rkm 49.9 and we expected most of the fish to return to this facility. Fish could also return to the spawning grounds or to state hatcheries located on the Nemah and Naselle Rivers.

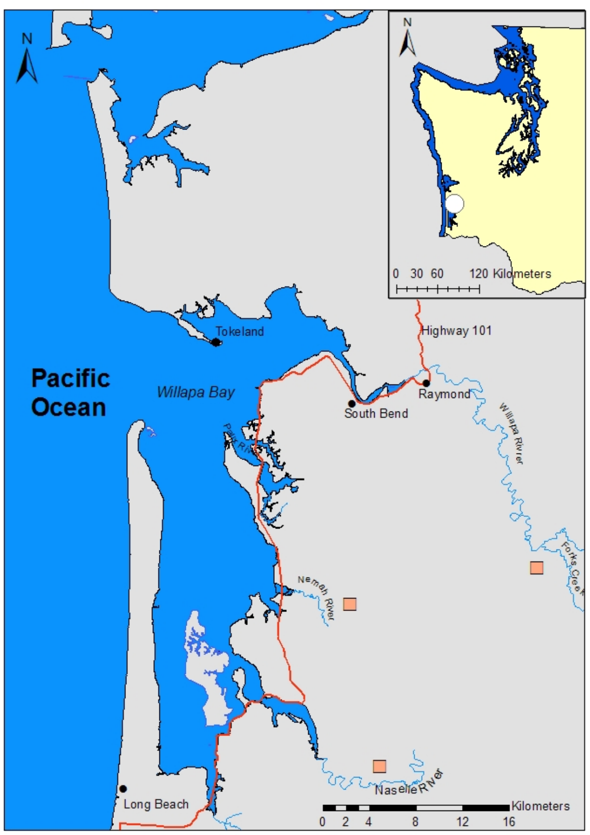

Figure 3. Map of study area, showing Willapa Bay, Willapa River, and hatcheries.

Fieldwork: General method for collection and evaluation

We contracted local fishers who had experience fishing for salmon in the study area and asked them to fish in traditional areas using standard methods. Fishing occurred during daylight and at optimal tides.

All fishing vessels contained a plastic tote box that was partially filled with water from the river. Captured fish were placed in the totes as soon as they were removed from the gear to lower their stress and enable condition evaluation, length measurement, and tag application. The gill net and tangle net as well as the purse seine vessels were also equipped with a revival box for reviving weak fish. The boxes were constructed of 1.27 cm marine grade plywood painted black. Each box had two rectangular compartments for holding fish. The compartments measured about 97.8 cm long, 29.2 cm high and 17.2 cm wide. The compartments were wide enough to allow a salmon to fit with its head facing the fresh water in-flow but narrow enough to prevent them from turning around. A 12-volt, 14,385 l /hr submersible bilge pump was connected to the box with a 3.81 cm discharge hose which supplied fresh water to each compartment through pipes located at the bottom of the box. Overflow outlets were located at the top of the box and on the opposite end.

Two observers were on board each vessel during every fishing trip. As fish were brought onto a vessel, one observer primarily recorded data, while the other handled fish. For each set (for gill net fishing, set time is defined as the time from when the first cork goes into the water until the last cork is removed from the water), the following information was recorded: gear type; time; location using a handheld global positioning unit; fisher's name; boat name; observers' names; weather conditions; surface water temperatures; and presence of seals.

Observers informed fishers when to begin fishing and fishers avoided touching the gill area or holding a captured fish by its caudal peduncle. After removal from the gear, fish were placed immediately into the tote of river water and any observations involving the handling of fish from gear to tote were recorded.

For each salmon, we noted the species, the net type, where it was captured, the type of capture, whether the adipose fin was missing, the condition at capture and the sex. At capture, a fish was assigned a condition as shown in Table 1. Because we observed many dead fish that clearly died from seal predation, we added a new condition, 6, to reflect pieces of fish that arrived dead in the boat because of seals (e.g. gill rakers, a head, part of the body).

Table 1. Condition number assigned to captured fish based on visual characteristics.

Condition	Characteristics
1	Fish lively and not bleeding
2	Fish lively and bleeding as a result of capture
3	Fish lethargic
4	Fish lethargic and bleeding as a result of capture
5	Fish shows no movement or ventilation
6	Piece of fish arrives in fishing gear due to pinniped predation

We also recorded visual injuries such as the loss of scales and damaged fins. Metal jaw tags covered with a plastic sheath and printed with a unique number were applied to the mouth of coho and Chinook. The plastic sheaths were color-coded to correspond to the net type and where the fish was captured. Depending on gear and fish condition, captured fish were released overboard immediately or were revived before release. Dead fish were donated to a local food bank. Non-target species encountered during fishing were counted and recorded according to gear type and then released.

To evaluate long-term survival of released fish, we encouraged anglers to return tags through contacting the local fishing club, posting flyers, and preparing a news release. We requested the date and location of harvest, the tag color, and tag number. For tags that could not be distinguished by both number and color, we assigned tags with numbers only to mesh size and tags with color only to mesh size. When there was confusion about the number and color of a tag, we first tried to assign the tag by number to a mesh size and if this did not fit with the data (i.e. the tag number was not used for that mesh size), we then tried to assign the tag by its color to a mesh size. Commercial sampling surveys were conducted at fish buying stations in the Willapa Bay area. Staff at Nemah, Naselle, and Forks Creek hatcheries collected jaw tags when coho and Chinook returned. Annual state spawning ground survey crews also collected tags and information.

Fieldwork: Specific collection methods by gear

Commercial: tangle net and gill net

For the commercial fishery, we compared the standard gill net with the tangle net, used a revival box, and used shorter nets and shorter soak times. The traditional gill net for coho salmon is 14.6 cm monofilament. Based on previous research (Vander Haegen et al., 2002), we used an 8.9 cm multifilament net as the tangle net.

Multiple vessels were contracted and we asked the fishers to fish simultaneously and near each other to mimic the fishery and to maximize the probability of recaptures. In all, three local fishers with many years of gillnetting experience made 31 fishing trips from the mouth of the Willapa River to river mile (RM) 5, near South Bend, Washington (Figure 4). They fished nets constructed from 80 fathoms of 3.5" tangle net shackled to 80 fathoms of 5.75" conventional gill net that is commonly used in this area for catching coho salmon. We used a monofilament single-strand mesh hung at a ratio of 2:1 (gillnet) and a four-strand 1.5 mm multifilament mesh hung at a ratio of 3:1 (tangle net). The hang ratio describes the amount of mesh relative to the corkline. The gill net measured 45 meshes deep and the tangle net measured 74 meshes deep so that both nets fished to the same depth. The nets were light green and the depths of the nets were suitable to the area fished. Each vessel was equipped with a hydraulic reel to deploy and retrieve the nets. Two of the boats had the reels mounted in the bow (bow-picker) and one boat had a reel mounted on the stern deck (stern-picker).

The fishing effort of each net type was similar for each area fished. The nets were laid out in a curved pattern across the river and allowed to drift freely. WDFW observers selected the appropriate soak time (the time from when the first cork was laid out until we began to retrieve the net) for each set. Please note this is different from the set time (set time is defined as the time from when the first cork went into the water until the last cork was removed from the water.)

One observer primarily recorded data while the other observer primarily handled fish. For each set, observers recorded the following times: when the first cork was put into the water; when the first cork was removed from the water; when the shackle was removed from the water; and when the last cork was removed from the water. Observers also recorded which net type entered the water first and which net type was removed from the water first. Other information recorded included the boat name, set number, and any other observations pertaining to a particular set.

When possible, fishers looked over the bow as the net was pulled up so they could spot incoming fish and lift the fish over the roller. After removal from the net, fish were placed immediately into a tote of fresh water. Any observations involving the handling of fish from net to tote were recorded.

Fish in conditions 1 or 2 were tagged, measured and released overboard immediately. We attempted to recover fish ranking in conditions 3, 4, or 5 to condition 1 or 2 before release. Some fish recovered unaided while in the holding tank. Other fish in need of recovery were recovered using the revival box. Many fish in need of recovery were assisted by placing a hose directly in the fish's mouth to force a constant the flow of fresh water across their gills. We characterized the type of capture as follows: tangled by teeth or mouth, rolled in net, gilled, wedged (web around body further than gills), or mouth clamped (net wrapped around mouth, clamping it closed).

Control: purse seine

To obtain a survival estimate, a control was needed and for this we chose to capture fish using a modified purse seine. We contracted one fisher with many years of purse seining experience in Alaska and many years of gill net fishing locally to fish for 7.5 days in Willapa Bay, near Tokeland (Figure 4). The fisher used a net constructed from 180 fathoms of 8.9 cm mesh net that measured 9.1 m deep. The net was dark and the depth of the net was suitable to the area being fished. A skiff was used to deploy and retrieve the net. As the net was pursed, a plunger was used to keep fish from escaping. Fish were then brought up singularly and placed into the tote for sampling. The fisher and WDFW observers selected soak times and adjusted this based on the number and condition of the fish captured. The set time was defined as the time from when the net was completely deployed in the water until the net was completely removed from the water. A half purse method was used for most fishing trips.

One observer primarily recorded data while the other observer primarily handled fish and recorded information similar to that collected in the gill and tangle net fisheries. Determining fish condition and capture type remained the same. For each purse seining set, observers recorded the following times: when the skiff went out; when the net was deployed; when the skiff came in; when the net was pursed or rings came up; and when the net was emptied.

Sport: hook and line

For the sport fishery, we used standard fishing gear. Washington State Department of Fish and Wildlife (WDFW) employees with experience sport fishing in Willapa Bay captured and tagged fish for five days just outside the mouth of the Willapa River (Figure 4.) In addition, local fishers who did not intend to retain their fish were asked to contact and give these fish to the WDFW fishers. Sport fishing ceased after five days (instead of the planned 10 days) because atypical fishing conditions resulted in too few fish being captured. Unlike previous years, the fishers speculate that because of rain events and warm water temperatures, the fish moved upstream earlier during 2003, with the result that fewer fish were available for capture in the sport fishing area.

For this component of the study, fishers used herring with twenty pound test line and barbless hooks. Rubberized nets were used to bring the fish aboard. WDFW employees fished and collected data. After removal from the net, fish were placed immediately into a tank of fresh water and any observations involving the handling of fish from net to tote were recorded.

Unlike the other test gears we did not attempt to revive fish to condition 1 or 2 before release. Most fish recovered unaided while in the holding tank. Both coho and Chinook were given jaw tags prior to release. All other species we encountered were counted, recorded, and returned to the water. We characterized the type of capture as follows: hooked deep inside mouth or hooked on edge of mouth. For fish captured with hooks deep inside the mouth, the line was cut and the hook was not removed. For fish captured by hook on the edge of the mouth, the hook was removed.

Data Analysis

Data were analyzed to address whether the gears met conservation needs and performed as well as standard gears. Objectives 1,3, and 6 evaluate performance and all objectives address conservation. All tests were conducted at the $\alpha =$ 0.05 level.

Objective 1: Compare the number and condition of coho salmon caught in tangle nets and conventional gill nets.

The lengths of fish captured were compared for the tangle net and gill net using a two-sample t-test assuming unequal variances (Zar, 1999). We compared mortality, condition at capture, capture method, and catch efficiency for coho adults captured in both net types using chi-square tests for homogeneity (Zar 1999). The Wilcoxon signed rank test (as described in Zar, 1999) was used to compare catch efficiency between the two net types. Water temperature was compared with immediate mortality.

Objective 2: Using coho salmon captured in a modified purse seine as a control, estimate and compare the immediate and long-term survival of coho caught in the tangle net, the conventional gill net, and with hook and line.

This study was the first time a modified purse seine was used for a test fishery in the Willapa River. Meant to provide a control, the net was smaller than a typical salmon purse seine net and was half pursed during retrieval so that the crew could capture fish with a hand brail. To further ensure the fish were retrieved in as benign a manner as possible, most often a rubber coated brail was used. The fish were placed into a half tote filled with fresh water. One observer examined the fish and the other wrote down data about the fish and set and tagged the fish when it was ready for release.

To estimate immediate, post-release, and total survival probabilities following capture in a tangle net, the methods shown below were developed. We planned to use these same methods to estimate survivals for fish captured in the gill net and using sport gear. However, because too few fish were recovered, we were unable to estimate post-release and total survival probabilities.

Immediate survival $\left(\hat{S}_I\right)$ was estimated from the binomial likelihood

$$L\left(S_I \middle| T, n\right) = \binom{n}{T} S_I^T \left(1 - S_I\right)^{n-T} \qquad (1)$$

with maximum likelihood estimator

$$\hat{S}_I = \frac{T}{n}, \qquad (2)$$

where

n = total number of fish captured with the tangle net,
T = number of fish released from the tangle net that lived.

The sample variance for immediate survival was estimated by

$$\mathrm{Var}\left(\hat{S}_I\right) = \frac{\hat{S}_I\left(1 - \hat{S}_I\right)}{n} \qquad (3)$$

with confidence intervals estimated by the normal approximation (Zar 1984:379.)

Post-release survival $(\hat{S}_P)$ was estimated using the Ricker relative recovery method with likelihood model

$$L\left(S_p, S_c, p \middle| t, T, c, C\right) = \binom{C}{c} \left(S_c p\right)^c \left(1 - S_c p\right)^{C-c} \cdot \binom{T}{t} \left(S_p S_c p\right)^t \left(1 - S_p S_c p\right)^{T-t}, \qquad (4)$$

where

T = number of tangle net fish released,
t = number of tags recovered from tangle net fish,
C = number of control fish released,
c = number of tags recovered for control fish,

S_p = post-release survival for tangle-net fish released,

S_c = post-release survival for control fish released,

p = probability of post-release recovery probability.

However, the parameters S_c and p are not separately estimable; in which case, likelihood model (Equation 4) is rewritten as

$$L\left(S_p, \lambda \middle| t, T, c, C\right) = \binom{C}{c} \lambda^c \left(1-\lambda\right)^{C-c} \binom{T}{t} \left(S_p \lambda\right)^t \left(1 - S_p \lambda\right)^{T-t}, \tag{5}$$

where $\lambda = S_c p$. The maximum likelihood estimates are

$$\hat{\lambda} = \frac{c}{C}$$

$$\hat{S}_p = \frac{\left(\frac{t}{T}\right)}{\left(\frac{c}{C}\right)}. \tag{6}$$

The variance of $\hat{S}_p$ is approximated by the delta method (Seber 1982:7-9) as

$$\mathrm{Var}\left(\hat{S}_p\right) = \frac{S_p\left(1 - S_p\lambda\right)}{T\lambda} + \frac{S_p^2\left(1-\lambda\right)}{C\lambda}. \tag{7}$$

and estimated by the quantity

$$\widehat{\mathrm{Var}}\left(\hat{S}_p\right) = \hat{S}_p^2\left[\frac{1}{c} - \frac{1}{C} + \frac{1}{t} - \frac{1}{T}\right]. \tag{8}$$

Assumptions of likelihood model (Equation 4) include the following:

1. Fate of each fish is independent.
2. Both control and tangle-net fish have the same handling mortality $\left(1 - S_c\right)$ and upriver recovery probability $\left(p\right)$, i.e., λ.
3. All fish within a treatment have equal probabilities of survival and recovery.

Total survival $\left(\hat{S}_T\right)$ was calculated as the product of immediate and post-release survival estimates, where

$$\hat{S}_T = \hat{S}_I \cdot \hat{S}_P,$$

with variance

$$\mathrm{Var}\left(\hat{S}_T\right) = \hat{S}_I^2 \cdot \mathrm{Var}\left(\hat{S}_p\right) + \hat{S}_p^2 \cdot \mathrm{Var}\left(\hat{S}_I\right) + \mathrm{Var}\left(\hat{S}_p\right) \cdot \mathrm{Var}\left(\hat{S}_I\right)$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{S}_T\right) = \hat{S}_I^2 \cdot \widehat{\mathrm{Var}}\left(S_p\right) + \hat{S}_p^2 \cdot \widehat{\mathrm{Var}}\left(\hat{S}_I\right) - \widehat{\mathrm{Var}}\left(\hat{S}_I\right) \cdot \widehat{\mathrm{Var}}\left(\hat{S}_p\right). \tag{9}$$

An asymptotic 95% confidence interval estimate of total survival can be calculated as

$$\hat{S}_T \pm Z_{1-\frac{\alpha}{2}} \sqrt{\hat{\mathrm{V}}\mathrm{ar}\left(\hat{S}_T\right)}. \tag{10}$$

Alternatively, the joint likelihood for the product of models (1) and (4) can be used to calculate a profile likelihood confidence interval (Fisher 1956, Box and Cox 1964, Kalbfleisch and Sprott 1970, Hudson 1971) using Program USER (http://www.cbr.washington.edu/paramest/user/).

Objective 3: Enumerate bycatch and compare the immediate mortality of untargeted salmon stocks and species (bycatch) captured in the tangle net, the conventional gill net, and with hook and line using a modified purse seine as a control.

Observers collected the same information for non-target salmonids as was collected for the target coho. Because of time limitations, observers were asked to write comments on the data sheets if large numbers of dead non-salmonid bycatch were observed. Data tables were created for untargeted salmon and other bycatch species that were captured in the various gears to document number captured by gear type. Immediate mortality was estimated using the equations presented in Objective 2.

Objective 4: Compare the egg-to-fry mortality and abnormality rate of the progeny for coho released from the tangle net, the gill net and hook and line gears that return to a hatchery.

We approached this objective by comparing the gametes and progeny of treatment fish with control fish. To accomplish this, we collected adults returning to the Forks Creek Hatchery. Returning fish with jaw tags identified the treatment groups and enabled us to differentiate gill net and tangle net captured fish. A treatment group for hook and line was not possible because too few fish were captured during the hook and line test fishery. Control fish were chosen based on not having jaw tags and not showing visual signs of being captured in nets. The fish were spawned in a series of factorial crosses where each cross consisted of two females and two males to create a total of four single pair matings (Table 2). Each factorial cross consisted of a treatment male, control male, treatment female, and control female. The protocol used to fertilize eggs was based on work done by Schroder and Ames (2004). Milt was collected from each male and 0.2 cc was used to fertilize about 100 eggs. The milt and eggs were combined in a plastic weighing boat, and then placed in two hundred milliliters of water. The egg, milt, and water mixture sat in a beaker for 2 minutes and then was decanted into labeled containers, or isolettes. The isolettes were made from cutting about a 4" diameter PVC pipe into 5.1 cm depth containers and had a screen at both openings. The labels listed the female number and origin, the male number and origin, and the date of fertilization.

Table 2. Example of a 2X2 factorial cross to evaluate gill net captured coho reproductive success.

	Gill net captured female	Control female
Gill net captured male	Gill net female X Gill net male	Control female X Gill net male
Control male	Gill net female X Control male	Control female X Control male

The factorial cross design enabled us to compare average egg to fry survival probabilities and rates of developmental abnormalities between different treatment groups. Observers documented the following information on data sheets: date, female number, male number, isolette label, visible injuries, condition of milt, number of dead eggs, total number of eyed eggs, total eggs in isolette, number of dead alevins, number of live fry, abnormalities, and any comments. The comments section often was used to describe abnormalities, (e.g. scoliosis, atrophied body, conjoined fish, large yolk, albino). We analyzed success data using a weighted one-way analysis of variance (ANOVA) and analysis of deviance (ANODEV). The ANODEV was conducted using a generalized linear model (McCullagh and Nelder, 1989) that account for the binomial error structure of the dependent variable (i.e., the stage specific survival probabilities) using the logit link function (Nelder and Wedderburn, 1972). Both analyses were performed using the software program S (Insightful Corporation).

Because observations in the reproductive study were survival probabilities, the use of these data in analysis of variance (ANOVA) would violate the assumptions of normality and homogeneity of error variances. However, data transformations and weighting each observation by the inverse of its variance can induce normality and resolve problems associated with non-equal error variances. As an alternative to the ANODEV, we conducted an ANOVA on the survival probabilities, p_{ij} using the square root arcsine (Zar 1984; 238) expressed as follows,

$$\arcsin\sqrt{p_{ij}} = \mu_j + \varepsilon_{ij},$$

where p_{ij} = the survival probability for the ith observation in the jth treatment;

τ_j = the jth treatment mean;

ε_{ij} = the error for the ith observation, jth treatment, distributed $\left(0,\sigma^2\right)$.

The square-root arcsine transformation ($\arcsin\sqrt{p}$) is used to induce normality in proportion data (Zar 1984: 238). Neter et al. (1996; pg 773) suggest the use of $2\arcsin\sqrt{p}$, however, omission or inclusion of a scalar did not affect results.

Because variances were not equal across observations (heterogeneous), observations were weighted by the inverse of the variance of the square-root arcsine transformation, i.e., $1/Var\left(\arcsin\sqrt{p_{ij}}\right)$, expressed as function of the sample size as follows,

,

$$Var\left(\arcsin\sqrt{p_{ij}}\right) = \frac{1}{m_{ij}}.$$

where $m_{ij} =$ denominator (i.e., eggs, eyed eggs, or fry) for the ith observation in the jth treatment. Mean values for each treatment group, $\hat{p}_j$, were estimated by

$$\hat{p}_j = \frac{\sum_{i=1}^{n_j} y_i}{\sum_{i=1}^{n_j} x_i}, \qquad \text{(Equation 1)}$$

with variance,

$$V\hat{a}r\left(\hat{p}_j\right) = \frac{\sum_{i=1}^{n_j}\left(y_{ij} - x_{ij}\hat{p}_j\right)^2}{\hat{p}_j^2 n_j\left(n_j - 1\right)} \qquad \text{(Equation 2)}$$

Objective 5: Estimate the hooking mortality rate for coho captured in an estuary. Compare this rate with the value currently used by fish managers and with other ocean and freshwater hooking mortality studies.

We planned to use the equations presented in Objective 2 to evaluate the survival of coho following being captured in a sport fishery. Too few fish were captured to conduct this analysis.

Objective 6: Compare the number and condition of Chinook salmon bycatch caught in the coho test fisheries.

The lengths of fish captured were compared for the tangle net and gill net using a two-sample t-test assuming unequal variances (Zar, 1999). We compared mortality, condition at capture, capture method, and catch efficiency for coho adults captured in both net types using chi-square tests for homogeneity (Zar 1999). The Wilcoxon signed rank test (as described in Zar, 1999) was used to compare catch efficiency between the two net types.

Findings

Objective 1: Compare the number and condition of coho salmon caught in tangle nets and conventional gill nets.

We fished with tangle nets and gill nets near the mouth of the Willapa River in the vicinity of South Bend (Figure 4) for 10 days between 8 September and 6 October 2003 (Figure 5) for a total of 31 boat trips and an average set time of 18.9 minutes. A graph of the number of coho released by gear type (Figure 5) shows that the two gears tracked fairly well although there were a few interesting fluctuations during the first two weeks of the test fishery. Test fishing trips occurred before and after the actual fishery. During the first few weeks, soak periods were shortened from the planned 20 to 25 minutes and we sometimes fished nets individually to ensure that fish were captured in good condition and survived their immediate capture at high rates. We made this change because during the first week of fishing many fish were in poor condition and immediate mortality was higher than expected in both gears, issues potentially caused by high water temperatures. We captured 1164 adult coho salmon (including 19 recaptures) and 26 jacks (2 year-old adult < 50 cm).

For marketability, fishers are interested in how the two gear types compare for catching fish by size, number, and condition. We measured forklength to evaluate size differences in the captured fish (Table 3 and Figure 6) and found a very significant difference between the fork length of adult coho salmon captured in the tangle net (67.6 cm, n=496) versus the gill net (69.8 cm, n=653) ($P(|Z|>6.0817) < 0.0001$). However, this is unlikely biologically significant.

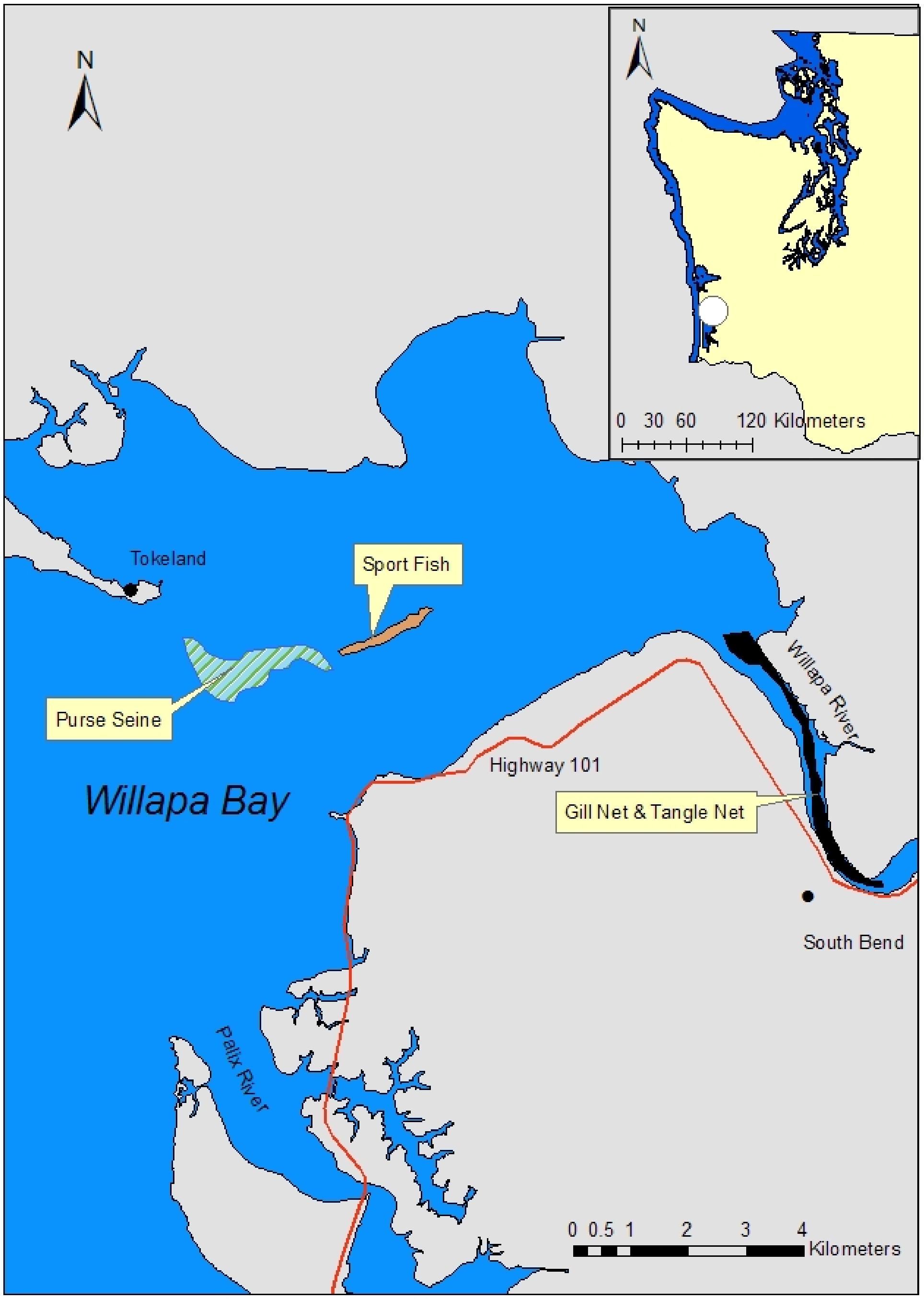

Figure 4. Location of test fishing on the Willapa River.

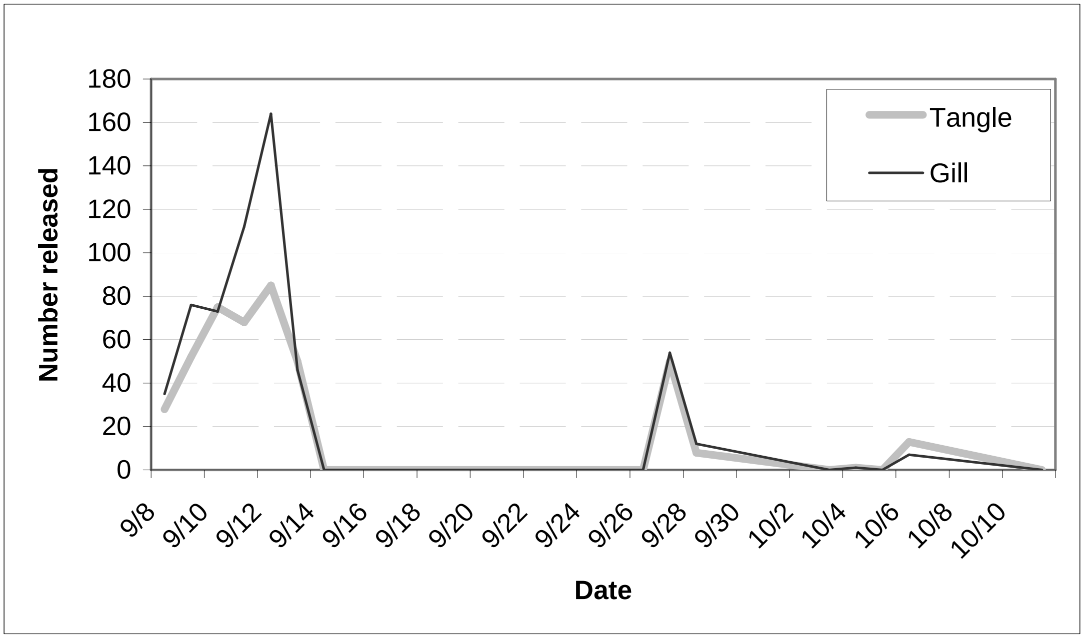

Figure 5. Coho released by day from the tangle net and gill net during the 2003 Willapa test fishery.

Table 3. Length of adult coho salmon captured by net type during 2003 Willapa test fishery.

Adult coho length (cm)	Tangle net	Gill net
Average forklength	68	70
Standard error	0.321	0.197
Range	51-87	58-87

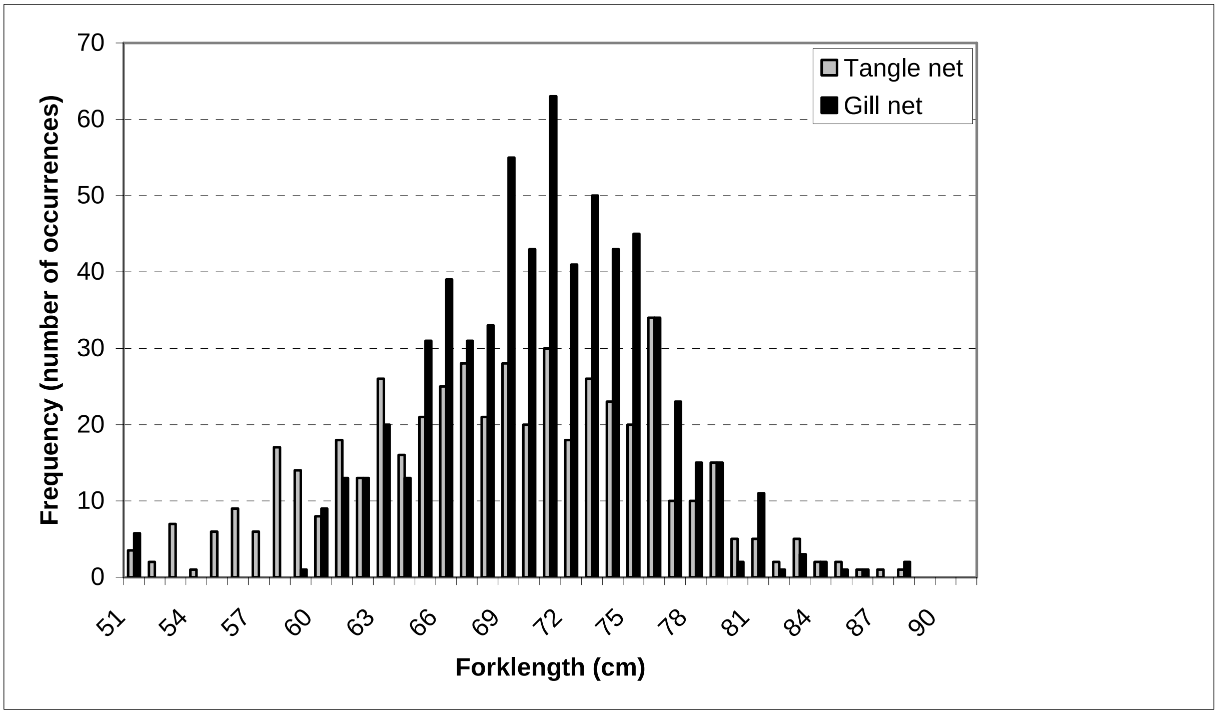

Figure 6. Histogram of forklength for coho salmon captured in the tangle and gill nets (P(|Z|>6.0817)< 0.0001).

Catch efficiency (Figure 7) was obtained by comparing the difference of catch per hour in each net type for each day when the time the nets fished was the same. There were as many as 8 more fish captured in the gill net on 2 days and the tangle net captured fewer fish overall than the gill net. However, the Wilcoxon paired sample test (Zar, 1999) showed these to not be significantly different ($0.10<P(T_-=9)<0.20$).

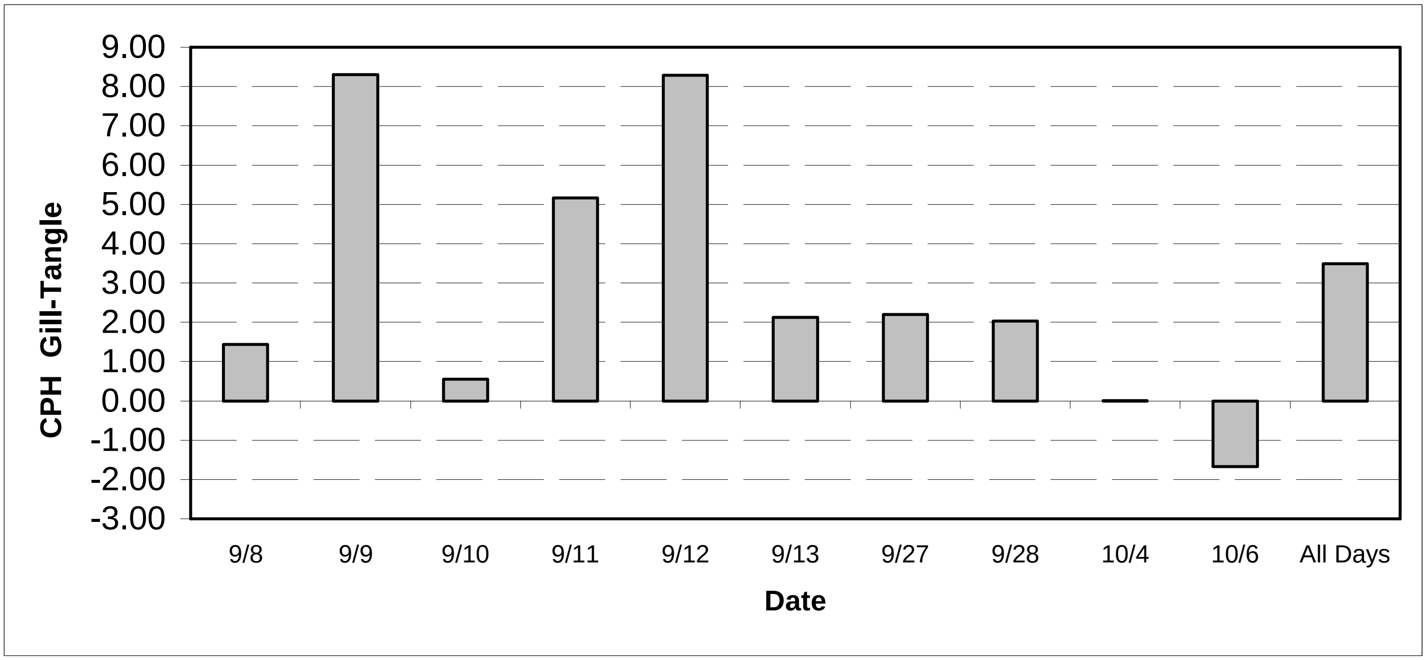

Figure 7. Catch per hour (CPH) of coho adults captured in the gill net and tangle net during the 2003 Willapa test fishery. The bars reflect the difference in catch between the two nets by day fished, where bars >0 represent days the gill net captured more fish and bars <0 represent days the tangle net captured more fish.

Using a chi-square test, we found that the method of capture for coho adults captured in the tangle net and gill net (Table 4) was different, with most fish in the tangle net captured by tangling and most fish captured in the gill net captured by gilling or wedging (P(χ^2_3 = 685.58) < 0.0001). The chi square test was done for the following categories: gilled; mouth clamped; tangled; and wedged.

Table 4. Number and percent of adult coho caught in the tangle and gill nets by capture method during the 2003 Willapa test fishery.

Capture method	Tangle net		Gill net	
	n	Percent	n	Percent
Gilled	9	1.8	230	34.8
Mouth Clamped	93	18.1	51	7.7
Rolled	0	0.0	1	0.2
Tangled	386	75.2	67	10.1
Wedged	20	3.9	306	46.3
Unknown	5	1.0	6	0.9
Total	513	100.0	661	100.0

We also used chi-square tests to evaluate the condition at capture by gear type. For all these analyses, conditions 5 and 6 were pooled because the fish died in both cases and fish in the unknown category were not used. The initial condition assigned to coho adults upon their arrival in the boat (

Table 5) was significantly different for coho adults captured in the two net types, (P(χ^2_5 >52.62) < 0.001), with fish captured in the tangle net in better condition.

Table 5. Condition assigned to coho adults upon their arrival in the boat during the 2003 Willapa test fishery.

Condition at capture	Tangle net		Gill net	
	n	Percent	n	Percent
1	228	45.3	310	46.9
2	7	1.4	29	4.4
3	193	38.4	188	28.4
4	6	1.2	63	9.5
5	62	12.3	64	9.7
6	6	1.2	6	0.9
Unknown	1	0.2	1	0.2
Total	503	100	661	100

We attempted to revive all fish to condition 1 or 2 prior to release. This was done by placing fish in the revival box or placing a tube of flowing freshwater in their mouth while they were in a partially filled tote of water. We observed that the responsiveness of coho and fall Chinook to these revival techniques was not as successful as has been shown for previous studies (Farrell et al., 2001a,b; Vander Haegen et al., 2004). Because fish were revived when possible the condition at release would be expected to be different than at capture. Many fish were in lethargic condition at capture, and some could not be revived to excellent condition prior to release. We compared the condition at release (Table 6) for fish captured in the tangle net and the gill net with a chi-square test for homogeneity using 4 categories (Conditions 1, 2,3, and 6) and found difference in final condition between the two net types was significantly different (P(χ^2_3 > 7.815) < 0.001).

Table 6. Final condition assigned to coho adults during the 2003 Willapa test fishery.

Final condition	Tangle net		Gill net	
	N	Percent	n	Percent
1	429	85.3	544	82.3
2	5	1.0	25	3.8
3	11	2.2	19	2.9
4	0	0.0	0	0.0
5	0	0.0	0	0.0
6	57	11.3	72	10.9
Unknown	1	0.2	1	0.1
Total	503	100.0	661	100.0

The next step was to compare the condition assigned to fish with the number of fish that survived to be recovered post-release. About 51% (219/433) of fish released from the tangle net were in excellent condition (condition 1) at capture and 60% (42/70) of the recoveries were from this group. The gill net released fish performed similarly, with about 53% (307/580) captured in excellent condition and 63% (50/79) of fish from that group recovered.

Fish were revived as possible and their condition at release noted. To learn if there was a difference in post-release recovery by condition and gear type, we performed a three dimensional chi square test and found there was a significant relationship (Table 7, $P(\chi^2_{13} > 65.9023) < 0.001$), with more fish than expected recovered that were in condition 1 and fewer fish than expected recovered in the other conditions.

Table 7. Condition assigned to coho adults at their capture in the gill net and their recovery by condition.

Recovered by release condition	Number of tags recovered post-release					Number of tags not recovered post-release				
	1	2	3	4	5	1	2	3	4	5
Tangle net	42	0	28	0	0	177	7	149	5	25
Gill net	50	5	18	4	2	257	23	150	51	20
Total	92	5	46	4	2	434	30	299	56	45

Water temperature, fertility stage (ripeness), and physiologic transformation are all potential stressors that may affect survival. We hypothesized that if one gear was more stressful than another, an additional stress such as warm water may result in higher mortality for the more stressful gear. There was little data for this analysis and no relationship between water temperature and immediate mortality by gear type was apparent (Table 8).

Table 8. Survival of coho captured in the tangle net and the gill net by water temperature during the 2003 Willapa test fishery.

Temperature	Tangle net				Gill net			
	No. caught	No. lived	No. died	Survival (%)	No. caught	No. lived	No. died	Survival (%)
14	2	2	0	100.00	1	1	0	100.00
15	21	19	2	90.48	8	8	0	100.00
16	27	25	2	92.59	54	52	2	96.30
17	19	16	3	84.21	49	43	6	87.76
18	68	61	7	89.71	87	66	21	75.86
19	15	15	0	100.00	2	2	0	100.00
Unknown	351	308	43	87.75	460	417	43	90.65
Total	503	446	57	88.67	661	589	72	89.11

Similar to previous years' research, we observed that more tangle net fish were captured around the face and jaws while more gill net fish were captured by the gills or wedging. Comparing all the visible injuries observed by net type, we found that the difference between visible injuries by net type was very significant, with many more fish captured in the tangle net having net marks on their head and many more fish captured in the gill net having net marks around their body (

Table 9, P(χ^2_6 > 176.85) < 0.001). For this analysis, seal injuries and gill and opercula injuries were pooled.

Table 9. Visible injuries observed on coho captured during the 2003 Willapa test fishery.

Injury	Tangle net	Gill net
Descaling	17	14
Net marks on body	6	154
Net marks on head	217	111
Seal scrape	3	1
Seal wound	8	9
Torn fin	6	5
Torn gill	0	3
Torn opercula	2	10
Hook mark	6	7

Objective 2: Using coho captured in a modified purse seine as a control, estimate and compare the immediate and long-term survival of coho caught in the tangle net, the conventional gill net, and with hook and line.

Immediate survival

There were no mortalities of the control group, purse seine captured fish. All fish in this gear were captured and released in excellent condition, with the exception of one fish that was vigorous but bleeding as the result of a seal wound (Condition 2). Fish captured by the purse seine and sport gears had the highest immediate survivals (100%) while coho captured by the tangle net and gill net gears showed a greater than 88% immediate survival (

Table 10). A chi square test of homogeneity among the four gears was significant (P(χ_3^2 > 16.186) = 0.001), with more fish dying than expected in the tangle net and gill net gears and fewer fish than expected dying in the purse seine and sport gears. An attempt was made to tag every coho before release but this did not happen in every instance; as a result the number of fish that immediately survived capture is not the same as the number of fish that received tags (
Table 10).

Table 10. Adult coho captured, immediate survival, and number released with a tag during the 2003 Willapa test fishery by gear type. Standard errors were calculated using Equation 3.

Gear	Captured fish	Died	Percent immediate survival	SE	Released with a tag
Tangle net	503	57	88.7	1.413	430
Gill net	661	72	89.1	1.212	580
Purse seine (control)	121	0	100.0	----	121
Sport	10	0	100.0	----	9

Because we wanted to know if a survival advantage existed for coho adults captured by the tangle net as compared to the gill net, a chi square test of homogeneity was run for these gears; the result was not significant (P (χ_1^2 > 0.056) = 0.813). Only the tangle net captured jack coho and their immediate survival was greater than 88% (Table 11).

Table 11. Capture and immediate mortality (the fish died before it could be released) of jack coho salmon by the tangle and gill net gears on the Willapa River during 2003. Standard error was calculated using Equation 3.

Gear	Captured	Died	Survived	Percent immediate survival	S.E.
Tangle net	26	3	23	88.5	6.266
Gill net	0	0	0	----	----

Post-release survival

The first tag recovery was reported on 15 September, and the final tag was recovered on 1 December 2003, or from one to 72 days following capture and release from the test fishery. The recovery of coho in succeeding fisheries and at hatcheries ranged from 8 to 45 days following their release from test gears.

Tags were recovered from fish returning to hatcheries, through spawning ground surveys, and during harvest sampling efforts. Tagged fish returned to Forks Creek, Naselle, and Nemah hatcheries (Table 12 and Figure 8). Sixty-three percent of the total tags recovered were from the Forks Creek Hatchery. The "Other" tags included tags recovered in commercial samples taken in Tokeland and from sport fishers in Willapa Bay and throughout the Willapa Basin.

Table 12. Recovery locations and number of coho salmon tags recovered by gear type for the 2003 Willapa Test Fishery.

Recovery Location	3.5" gill	5.75" tangle	Sport	Purse seine	Total
Forks Creek Hatchery	45	56	1	4	106
Naselle Hatchery	3	0	0	4	7
Nemah Hatchery	8	1	0	3	12
Other	14	22	0	6	42
Total	70	79	1	17	167

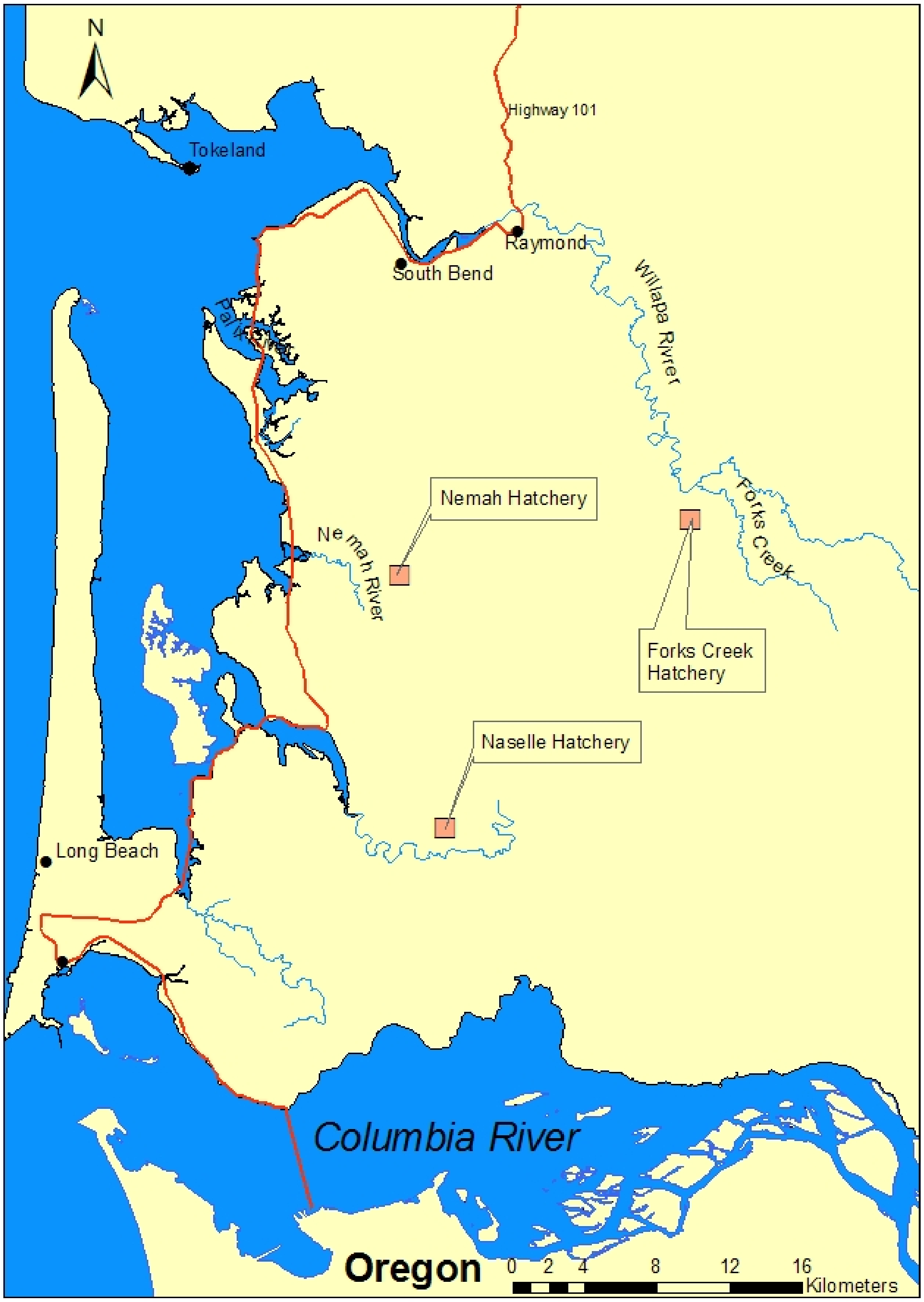

Figure 8. Hatcheries where fish released during the 2003 Willapa test fishery were recaptured.

Post release survival was evaluated by gear type. Of all the gears fished, coho released from the tangle net had the highest recovery (16.3%, Table 13). A chi square test of homogeneity was used to evaluate post release recovery by gear and the result was not significant (P(χ_3^2 >1.787) = 0.6177). The post release recoveries of tangle and gill net captured coho were also not significantly different (Table 13, P(χ_1^2 >1.027) = 0.3108) by gear types.

Table 13. Recovery of coho adults by gear type for 2003 Willapa test fishery. Standard errors were calculated using Equation 3.

Gear	Tagged and released	Recovered	Percent recovered	Percent S.E.
Tangle net	430	70	16.3	1.781
Gill net	580	79	13.6	1.424
Sport	9	1	10.0	10.48
Modified purse seine	121	14	11.6	2.908

Fisher effects

Because the manner in which fishermen interact with gears and fish could influence fish survival, we evaluated immediate survival by skipper (Table 14 and

Table 15) using a chi square test of homogeneity; the result was not significant for either net type (tangle net: (P(χ^2_2 > 0.1726) = 0.9994; gill net: P(χ^2_2 > 1.1558) = 0.9490). Interestingly, when we tested whether recovered tags (indicating post release survival), gear type, and fisher were mutually independent using a 3 dimensional chi square test, the null was rejected ((Table 16, P(χ^2_7 > 77.5047) < 0.001), indicating that there is a difference for the number of recovered fish by skipper and net type. This result is an indication of an interaction effect between fisher and gear type. That is, post-relaese survival probabilities are dependent on specific fisher-gear type combinations and may not necessarily be reflected in immediate survival results.

Table 14. Adult coho captured in the tangle net by fisher that immediately died or survived.

Fisher	Tangle net		
	Captured	Died	Survived
A	191	26	165
B	139	17	122
C	183	15	168

Table 15. Adult coho captured in the gill net by fisher that immediately died or survived.

Fisher	Gill net Captured	Died	Survived
A	283	3	251
B	259	15	244
C	119	25	94

Table 16. Three dimensional contingency table of recovered coho tags by fisher and gear for the 2003 Willapa test fishery.

Gear type	Number of tags recovered by fisher			Number of tags not recovered by fisher			Total
	A	B	C	A	B	C	
Tangle	21	18	31	138	92	130	430
Gill	23	43	13	223	198	80	580
Total	44	61	44	361	290	210	1010

<u>Objective 3: Enumerate bycatch and compare the immediate mortality of untargeted salmon stocks and species (bycatch) captured in the tangle net, the conventional gill net, and with hook and line using the modified purse seine as a control.</u>

Bycatch information was collected for each gear fished. The sport gear had the smallest amount of bycatch, with ten Chinook captured. This was followed by the gill net, tangle net, and finally, the purse seine with the greatest amount of bycatch (

Table 17). Generally all bycatch were released alive and in good condition.

Table 17. Bycatch by gear type captured during the 2003 Willapa test fishery.

Common Name	Scientific name	Tangle Net	Gill Net	Purse Seine	Sport Gear
Anchovy	*Engraulis mordax mordax*	1	0	About 1500	0
Crab (primarily Dungeness)	*Cancer sp.*	3	0	1285	0
Chinook salmon	*Oncorhynchus tshawytscha*	168	214	20	10
Chum salmon	*Oncorhynchus keta*	0	1	11	0
Spiny dogfish	*Squalus acanthias*	18	0	6	0
Starry flounder	*Platichtys stellatus*	2	0	1	0
Pacific herring	*Clupea harengus pallasi*	2	0	500	0
Shiner perch	*Sebastes sp.*	0	0	6	0
Striped perch	*Sebastes sp.*	4	0	1	0
Pink salmon	*Oncorhynchus gorbuscha*	1	0	0	0
Shad	*Alosa sapdissima*	13	0	16	0
Steelhead salmon	*Oncorhynchus mykiss*	20	20	2	0
Sturgeon	*Acipenser transmontanus*	0	1	2	0
Unspecified trout	*Oncorhynchus sp.*	1	0	0	0

Because coho and Chinook commingle as they migrate to the spawning grounds, during the 10 days we used tangle nets and gill nets to fish for coho, we also captured many Chinook adults and a few Chinook jacks (

Table 18). The total Chinook salmon captured by the commercial gear included 8 recaptures. In addition, four jack Chinook were captured by the tangle net. The immediate survival for adults captured in the tangle net was significantly greater than that of fish captured in the gill net (P(χ_1^2 > 13.099) < 0.001).

Table 18. Capture and immediate mortality (the fish died before it could be released) of Chinook salmon captured in the tangle and gill nets during the 2003 Willapa test fishery. Standard error (S.E.) was calculated using Equation 3.

Species	Net	Captured	Died	Survived	Percent immediate survival	Percent SE
Chinook Adults	Tangle	164	6	158	96.3	1.466
	Gill	214	32	182	85.0	2.438
Chinook Jacks	Tangle	4	0	4	100.0	----
	Gill	0	0	0	----	----

<u>Objective 4: Compare the egg-to-fry mortality and abnormality rate of the progeny for coho released from the tangle net, the gill net and hook and line gears that return to a hatchery.</u>

Two high water events at the Forks Creek Hatchery resulted in lower than expected adult returns to the hatchery and so fewer tagged fish were available for the gamete quality study. As a result, we were unable to collect the eight pair of female and male adults that had been captured in each gear as recommended by our power analysis. At the Forks Creek Hatchery, we collected three pairs of fish that had been captured by the gill net, four pairs of fish captured by the tangle net, and zero pairs of fish captured by recreational gear. As a control group, we chose fish that did not have a jaw tag (and so were not captured in our test fishery) and showed no physical scars indicating previous capture by commercial or recreational gears. This enabled us to make 3 factorial crosses for fish captured by gill net, 4 factorial crosses for fish captured by tangle net, and 4 factorial crosses for the control group. Of the tagged fish that were used for the gamete quality study, the average forklength was 69 cm for both net types (Table 19).

Table 19. Average fork length of adult coho by sex captured during the 2003 Willapa test fishery.

Net	Sex	Average fork length in cm	n	S.E.
Tangle	Male	69	4	1.0000
Tangle	Female	69	4	5.6125
Gill	Male	68	3	1.6330
Gill	Female	71	3	0.8165

Analysis of variance (ANOVA) and analysis of deviance (ANODEV) were performed for the 3,5, and 7 treatment models to assess treatment effects on green-egg to eyed-egg survival, eyed-egg to fry survival, and fry abnormality rate. The three treatment model separated the fish by treatment only; i.e. gill, tangle, and control. The five treatment model separated the fish by treatment and whether the treatment was for one or both parents. The seven treatment model separated the fish by treatment and sex: for example female gill net with control male; female control with male gill net, female gill net with male gill net, and female control with male control. In two cases the number of fry enumerated was greater than the number of eyed eggs. The results presented in this table assume that the survival in each of those cases was 100%. Additional tests were run that removed these two cases from the analysis. However, the significance level did not change.

Table 20. Summary of ANODEV analysis. F test statistic (F=) and P-value (P=) for the test of no difference from reproductive study for three, five, and seven groups for three categories (egg to eyed egg survival, eyed egg to fry survival, and fry monstrosity rate). Degrees of freedom are listed as "D.F." and an asterisk (*) shows when the result is significant (P<0.05).

Group	Three group model DF=2,25	Five group model DF=4, 23	Seven group model DF=6,21
Green egg to eyed egg survival	F=0.4043 P=0.6721	F=0.4639 P=0.8277	F=0.7755 P=0.598
Eyed egg to fry survival	F=6.9626* P=0.0039*	F=3.3441* P=0.0269*	F=2.2418 P=0.0791
Fry abnormality	F=1.3730 P=0.2718	F=34.7542 P=0.2899	F=32.6240 P=0.3113

The ANOVA and ANODEV test the null hypothesis that the mean survival probability is equal among all treatment groups versus the alternative that at least two groups are different. Based on this analysis, we observed a difference in survival of progeny from the eyed egg to fry life stage between at least two groups in the three and five group models (Table 20 and Table 21). The results therefore show differences in survival by gear type and by whether one or both parents were captured in treatment gear (as compared to one parent captured by treatment gear and the other one a from a control group), regardless of the sex of the parent. At the eyed egg to fry life stage, a Tukey Test for different sample sizes (Zar, 1999) showed that the progeny of tangle net captured fish survived as well as the control fish (

Table 22; Figure 9; Figure 10; Equations 1 and 2) and 5.46% more than the progeny of gill net captured fish.

Table 21. Summary of ANOVA analysis, F values (F=) and P values (P=) for the ANOVA test of no difference from reproductive study for three, five, and seven group models.

Group	Three group model DF=2,25	Five group model DF=4, 23	Seven group model DF=6,21
Green egg to eyed egg survival	F=0.4947 P=0.6156	F=0.4617 P=0.763	F=0.7893 P=0.5883
Eyed egg to fry survival	F=7.7449* P=0.0024*	F=3.6029* P=0.0202*	F=2.3797 P=0.0653
Fry abnormality	F=0.5195 P=0.6011	F=0.4427 P=0.7765	F=0.7325 P=0.6289

Table 22. Survival rate for green egg to eyed egg, eyed egg to fry, and rate of fry abnormality for progeny of coho salmon captured during the 2003 Willapa test fishery. Standard error is shown in parenthesis.

Group	Green egg to eyed egg survival	Eyed egg to fry survival	Fry abnormality
Control x Control	0.5313 (0.3290)	0.9681 (0.0445)	0.0026 (0.0038)
Control x Gill	0.5701 (0.4221)	0.9144 (0.0535)	0.0051 (0.0079)
Gill x Gill	0.7958 (0.2550)	0.9117 (0.0406)	0.0067 (0.0115)
Control x Tangle	0.6383 (0.2954)	0.9733 (0.0286)	0.0026 (0.0025)
Tangle x Tangle	0.6924 (0.2376)	0.9665 (0.0448)	0.0017 (0.0025)

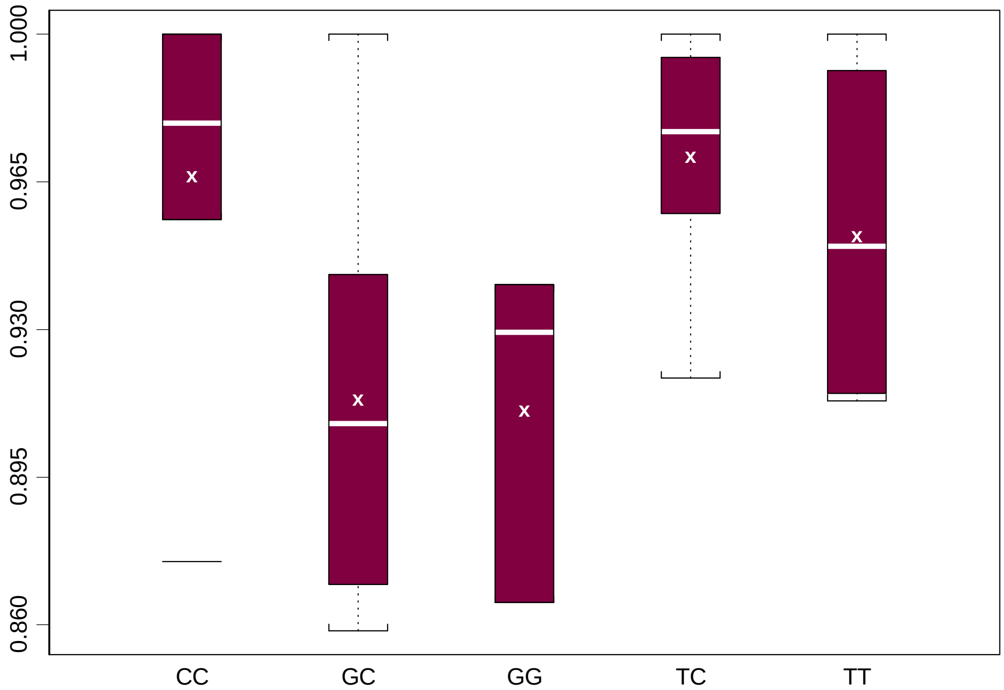

Figure 9. Box and whisker plot of five treatment model for eyed egg to fry survival. Bars in the boxes indicate the median and "X" the mean survival probabilities for each group.

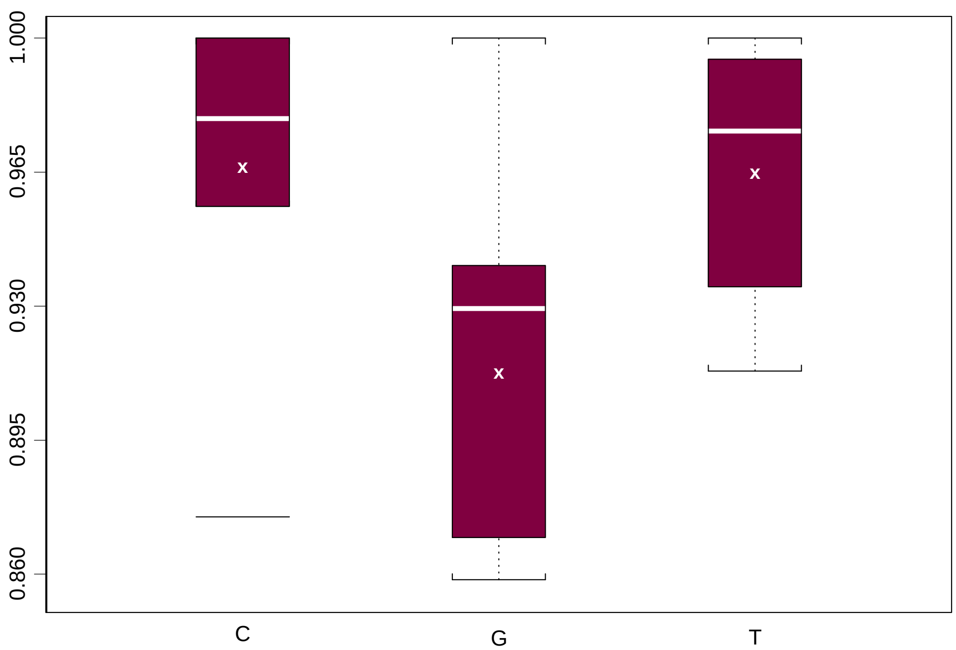

Figure 10. Box and whisker plot of three treatment model for eyed egg to fry survival. Bars in the boxes indicate the median and "X" the mean survival probabilities for each group.

<u>Objective 5: Estimate the hooking mortality rate for coho captured in an estuary. Compare this rate with the value currently used by fish managers and with other ocean and freshwater hooking mortality studies.</u>

All coho captured by hook and line survived their immediate capture (Table 23). Long-term survival cannot be estimated because of the few fish captured (10), none were recovered. Further, estimating mortality requires a control. The purse seine used during the 2003 test fishery arrived too late to capture fish at the same time as we fished with recreational gear. Logistically, the purse seine can fish the same area and at the same time as the recreational fishery.

Table 23. Immediate survival of adult coho captured by sport gear during the 2003 Willapa test fishery.

Gear type	Captured	Died	Immediate survival	S.E.
Sport	10	0	100.0%	----

<u>Objective 6: Compare the number and condition of Chinook salmon bycatch caught in the coho test fisheries.</u>

Because coho and Chinook are differently sized, a net that acts as a tangle or gill net for coho is not expected to act the same for Chinook. While we fished for coho, we also collected length, capture method, and condition at capture data for Chinook. We captured a total of 378 adult Chinook salmon and 4 jacks (2 year-old adult Chinook < 60 cm). A graph of the number of Chinook released by gear type (Figure 11) shows that the two gears had differences the first week of the test fishery and tracked fairly well the remaining two weeks of the test fishery.

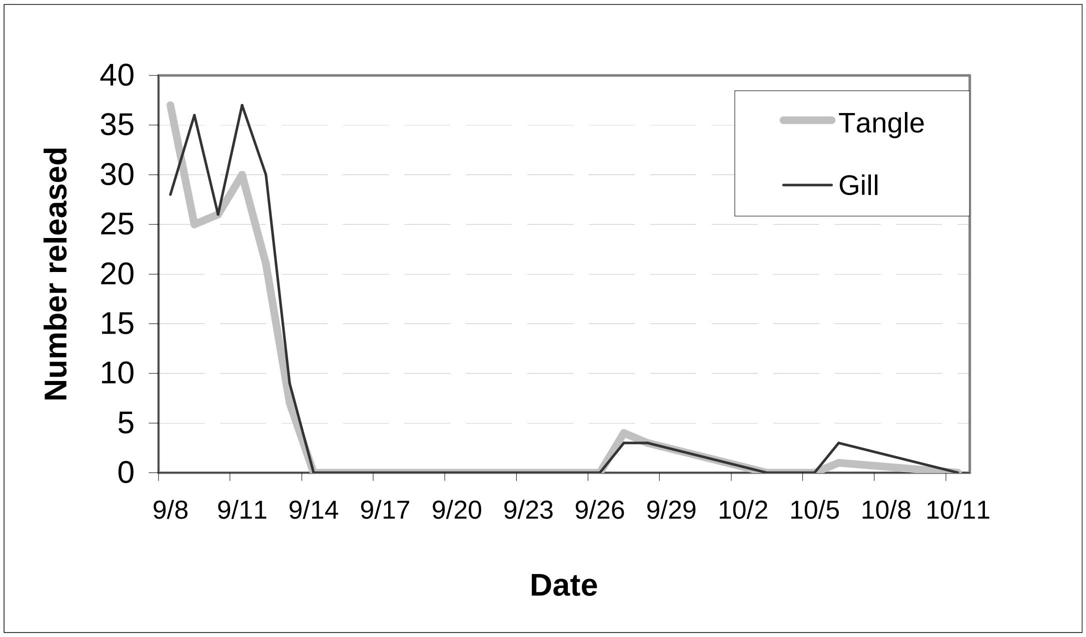

Figure 11. Chinook released by day from the tangle net and gill net during the 2003 Willapa test fishery.

We found (Table 24 and Figure 12) a significant difference between the forklength of adult Chinook salmon captured in the tangle net (85.1 cm, N=163) versus the gill net (82.7 cm, N=212) (P(|Z|>2.594)=0.0098). However, this is unlikely biologically significant.

Table 24. Length by net of adult Chinook salmon captured during 2003 Willapa test fishery.

Adult Chinook length (cm)	Tangle net	Gill net
Average forklength	85	83
Standard error	0.613	0.665
Range	56-110	57-115

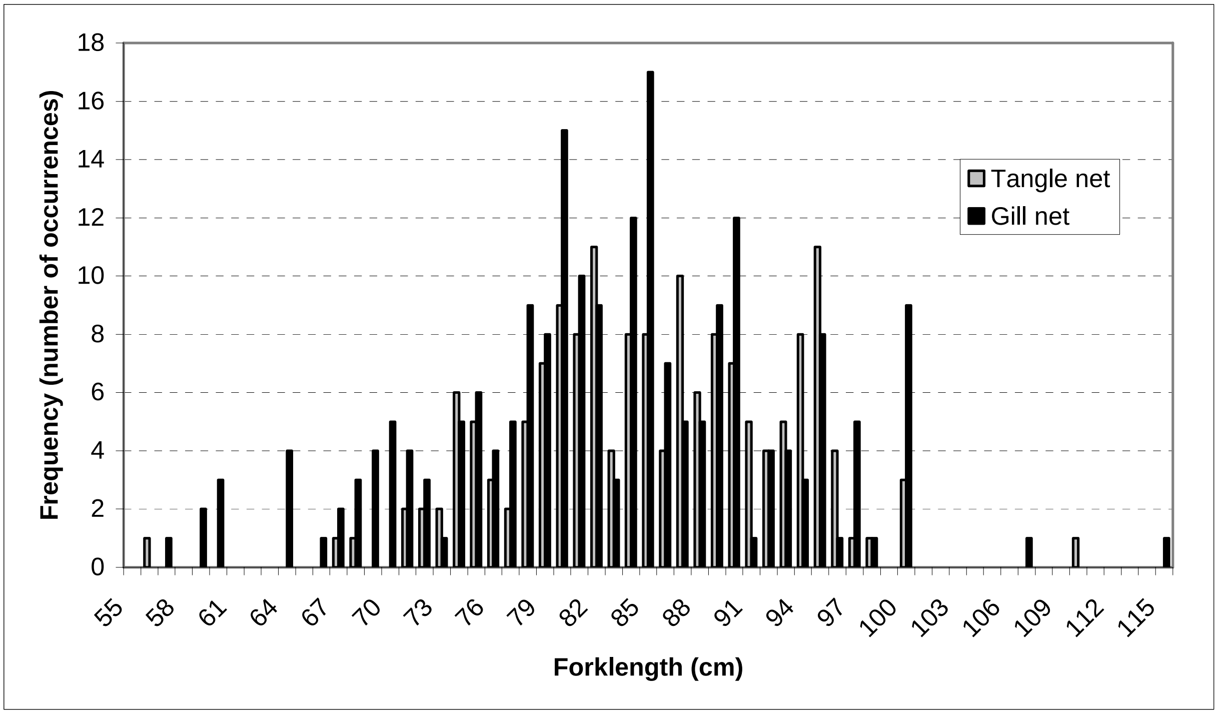

Figure 12. Histogram of forklength for Chinook salmon captured in tangle nets and gill nets.

The difference of catch in each net type for each day when the time the nets fished was the same was compared. We found that the gill net captured as many as about 4 fish more on 1 day and that across all days, the gill net captured about 1 more fish than the gill net (Figure 12). These results were significant, with the catch being greater in the gill net than the tangle net $(0.01<P(T_{-}=2)<0.02)$.

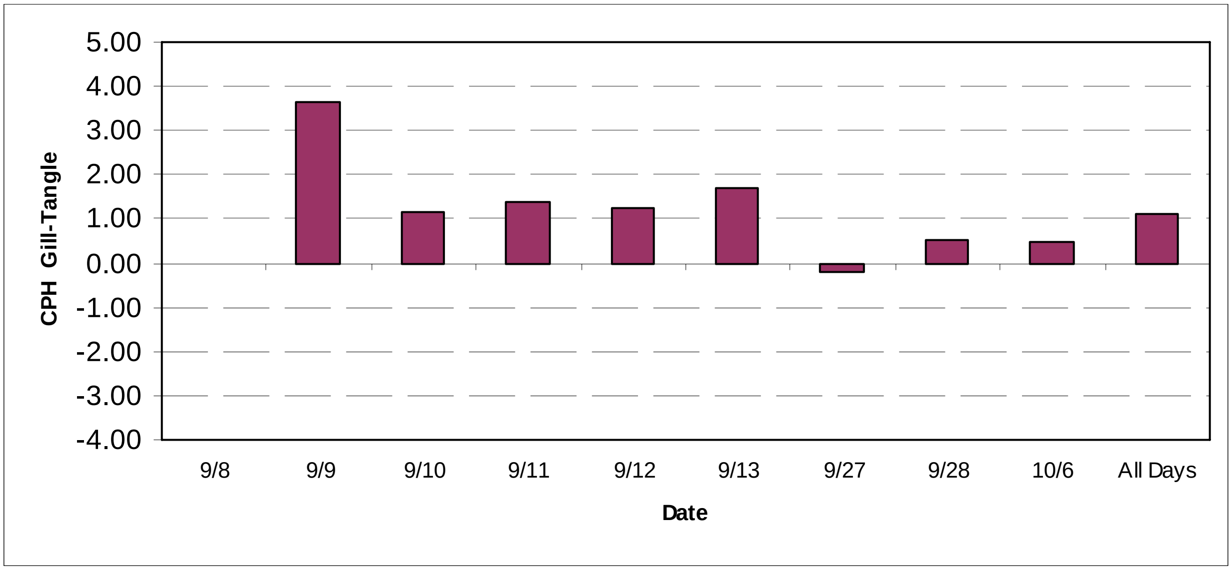

Figure 13. Catch per hour (CPH) for Chinook salmon adults captured during the 2003 Willapa test fishery using 5.75" and 3.5" nets during the 2003 Willapa test fishery. The bars reflect the difference in catch between the two nets by day fished, with bars >0 representing days when more fish were captured by the gill net and bars <0 representing days when more fish were captured by the tangle net.

Chi-square tests were used to evaluate the capture method of Chinook in the tangle net and gill net (Table 25). The results were significant ($P(\chi^2_3 > 81.7862) < 0.001$), with a higher than expected number of fish in the tangle net captured by tangling and a higher than expected number of fish in the gill net captured by gilling, mouth clamping and wedging. For the analysis, the rolled and unknown categories were not used.

Table 25. Number and percent of Chinook caught in the tangle net by capture type during the 2003 Willapa test fishery.

	Tangle net		Gill net	
Capture method	n	Percent	n	Percent
Gilled	2	1.2	30	14.0
Mouth Clamp	16	9.7	54	25.2
Rolled	0	0	0	0.0
Tangled	147	89.1	97	45.3
Wedged	0	0	31	14.5
Unknown	0	0	2	1.0
Total	165	100	214	100

We attempted to revive all Chinook to condition 1 or 2 by placing them in a revival box or placing a tube of flowing freshwater in their mouth while they were in a partially filled tote of water. Similar to the coho, the revival box was not as helpful as expected, likely because of the number of fish that needed to be revived. Because so many fish were in lethargic condition at capture, fish could not always be revived to excellent condition prior to release. We evaluated the condition at capture by gear type, the condition at release, and the recapture of fish by condition. Using a chi square test of homogeneity, we found that Chinook condition immediately following capture (Table 26) was significantly different between the nets ($P(\chi^2_3 > 25.59) < 0.0001$). More fish captured by the tangle net were in excellent condition (1) and more fish caught in the gill net were in lethargic and poor condition (3 and 5) than expected. For this analysis, condition 2 was not included and conditions 5 and 6 were pooled.

Table 26. Condition immediately assigned to Chinook adults upon their arrival in the boat during the 2003 Willapa test fishery.

Condition at capture	Tangle net		Gill net	
	N	Percent	n	Percent
1	103	62.8	90	42.1
2	0	0.0	1	0.5
3	51	31.1	85	39.7
4	4	2.4	2	0.9
5	5	3.1	34	15.9
6	1	0.6	2	0.9
Total	164	100.0	214	100.0

Because we attempted to revive fish to condition 1 or 2 before releasing them, we also evaluated condition at release (

Table 27). A chi square test of homogeneity was used to evaluate the condition at release by gear type and the results were significantly different (P(χ_3^2 > 236.81) < 0.0001), with more Chinook than expected released from the tangle net in condition 1 and more fish than expected released from the gill net in conditions 3, 4, and 5. For this analysis, condition 2 was not used.

Table 27. Final condition assigned to Chinook adults during the 2003 Willapa test fishery.

Condition at release	Tangle net N	Tangle net Percent	Gill net n	Gill net Percent
1	99	64.3	86	49.1
2	0	0.0	1	0.6
3	48	31.2	78	44.6
4	4	2.6	1	0.6
5	3	1.9	9	5.1
Total	154	100.0	175	100.0

A three dimensional chi-square test was used to evaluate the independence of tag recoveries by condition and gear type (Table 28). Because of limited data, only conditions 1 and 3 were evaluated. The results were significant (P(χ^2_3 > 10.5823)=0.0317), with more Chinook recovered that were released from the tangle net in condition 1.

Table 28. Condition assigned to coho adults at their capture in the gill net and their recovery by condition.

Recovered by release condition	Recovered 1	Recovered 2	Recovered 3	Recovered 4	Recovered 5	Not recovered 1	Not recovered 2	Not recovered 3	Not recovered 4	Not recovered 5
Tangle net	7	0	7	0	0	92	0	41	4	3
Gill net	7	0	4	0	0	79	1	74	1	9
Total	14	2	11	0	0	171	1	115	5	12

Not all fish that were captured and released were tagged. The number of Chinook released with tags is shown in Table 29.

Table 29. Adult Chinook tagged and released by net type during the 2003 Willapa test fishery.

Gear	Released Tags
Tangle net	154
Gill net	175

About eighty-six percent of the Chinook captured in the tangle net by tangling were recovered (Table 30). In contrast, the recovery of Chinook that had been captured in the gill net was spread fairly evenly between fish captured by gilling, mouth clamp, and tangling (Table 30). Although the number of Chinook recovered by capture type was noted for each gear (Table 30), statistical tests were not run because of limited data.

Table 30. Number of Chinook recovered by net type following their capture and release from the 2003 Willapa test fishery.

Capture method	Tangle net		Gill net	
	n	Percent	n	Percent
Gilled	0	0.0	3	27.3
Mouth Clamp	2	14.3	4	36.4
Rolled	0	0.0	0	0.0
Tangled	12	85.7	3	27.3
Wedged	0	0.0	1	9.0
Unknown	0	0.0	0	0.0
Total	14	100	11	100

As with the coho, we did not observe a difference in survival differences by water temperature (Table 31). However, there was little data for this analysis.

Table 31. Survival of Chinook captured in the tangle net and the gill net by water temperature during the 2003 Willapa test fishery.

Temperature	Tangle net				Gill net			
	No. caught	No. lived	No. died	Survival (%)	No. caught	No. lived	No. died	Survival (%)
14	0	0	0	NA	0	0	0	NA
15	6	6	0	100.0	8	8	0	100.0
16	4	4	0	100.0	8	8	0	100.0
17	14	13	1	92.9	27	24	3	88.9
18	23	22	1	95.7	45	34	11	75.6
19	3	3	0	100.0	2	2	0	100.0
Unknown	114	110	4	96.5	124	106	18	85.5
Total	164	158	6	96.3	214	182	32	85.1

Most tag recoveries for Chinook were from fish released from the tangle and gill nets (

Table 32). Of the fish that returned to hatcheries, most of the Chinook returned to the Forks Creek Hatchery (Table 33). The differences for recoveries between tangle net and gill net released fish versus purse seine and sport gear released fish may reflect that the different fishing locations held different subpopulations of Chinook.

Table 32. Recovery of Chinook adults by gear type for the 2003 Willapa test fishery.

Net type	Tagged and released	Recovered	Percent recovered	Percent S.E.
Tangle net	158	14	8.86	0.051
Gill net	182	11	6.04	0.031
Sport	9	0	0.00	----
Modified purse seine	20	1	0.05	0.238

Table 33. Recovery locations and number of Chinook salmon by tag group for the 2003 Willapa Test Fishery.

Recovery Location	Tangle net	Gill net	Sport	Purse seine	Total
Forks Creek Hatchery	3	4	0	0	7
Naselle Hatchery	1	0	0	0	1
Nemah Hatchery	1	1	0	1	2
Fisheries and spawning grounds	10	6	0	0	16
Total	15	11	0	1	26

Evaluation

Objective 1: Compare the number and condition of coho salmon caught in tangle nets and conventional gill nets.

The tangle net is a potential substitute for a conventional gill net with the intention of lowering impacts to non-target stocks and species. Before deciding to implement this gear, managers need to know that it is useful for catching the target species and that the impacts on non-target animals really are lower than the gears already in use. Two previous investigations in the study area had mixed results so in this study we hoped to clarify if tangle nets are suitable for a coho selective fishery in an estuary.

We found that a coho selective fishery that includes tangle nets, shorter soak times, careful handling techniques, and a revival box will catch adult coho that are about 2 cm smaller on average compared to a fishery that uses gill nets under the same conditions. The biological and economic significance of this difference seems negligible. The catch efficiency for the tangle net and gill net will be the same but coho captured by the tangle net will be more apt to be captured by tangling and in better condition at capture and release. Coho captured in the tangle nets will usually be captured around the jaw and face, and suffer less body trauma than fish captured in the gill net. Correspondingly, coho captured by the tangle net will be captured by becoming entangled in the net while coho captured in the gill net will be captured by being gilled or wedged in the net. As a result of these differences, fish captured using selective fishing methods may provide a more marketable product, equal in quality to fish captured by trolling. Because the tangle net could be a way to improve the value of fish, its use merits consideration by the industry.

During the test fishery, soak periods were lowered from the planned 20 to 25 minutes to an average of about 19 minutes to ensure that fish were captured in good condition and survived their immediate capture at high rates. This adjustment occurred because during the first few days, the capture rate of fish was high, the water temperatures were warm, and fish were in less vigorous condition at capture than expected.

We were limited to test fishing with the gill and tangle nets when the commercial fishery was not occurring. This meant that we fished before and after the peak return of coho to the Willapa Basin. We fished with the assumption that the same results would occur if we had fished at the peak of the coho return. Had we fished at the peak of the return it is likely that even more fish would have been captured, exacerbating the problem of large volumes of fish that needed to be revived.

We received support to replicate this objective (Objective 1) in 2004, but unfortunately this did not occur. The previous year (2003), Saltonstall-Kennedy Program funds enabled us to pay fishermen to fish during a test fishery and so all captured fish became part of the study. During 2004, there were not funds to pay the fishermen and so we consequently requested of managers that observers be placed on boats during the actual fishery so that all released fish could be evaluated and tagged. The judgment was made by the agency that there was not enough room for observers. Consequently, the remaining funding went into further refining and analyzing the project.

Objective 2: Using coho captured in a modified purse seine as a control, estimate and compare the immediate and long-term survival of coho caught in the tangle net, the conventional gill net, and with hook and line.

The gears we tested are intended to provide access to hatchery fish while protecting non-target species and stocks. The premise of live capture selective harvest is that the released fish do survive at a high rate and are therefore afforded protection. To estimate the mortality associated with the capture and release from any gear, a control was required so that natural mortality could be separated from the test fishery mortality. We developed estimation methods described in the Approach Section of this report that were based on the presence of a control.

We used a modified purse seine for the control because it was expected to incur minimal mortality on the captured fish. As expected, coho salmon captured in this gear were captured and released in excellent condition with little to no visible marks or descaling, and an immediate survival of 100%. The only visible damage observed in fish captured in this gear was an occasional small tear to one or more fins. These results make the use of a purse seine for a control or a selective fishing gear quite promising.

Previous studies (Vander Haegen et al., 2004) found that post-release survival can be very different from immediate survival, so post release survival estimates are crucial for allocating the effects of selective fishing gears. The modified purse seine did not provide the control we hoped for, making post-release and total survival estimates unavailable for this study.

The purse seine fisher and crew had experience purse seining in Alaska and gill net fishing in the Willapa River. However, because there is not a purse seine fishery in the Willapa, the fisher brought his vessel down from Alaska. The rough weather encountered as he traveled from Alaska to Willapa Bay both delayed and shortened the purse seine test fishery. As a result the test fishery captured fewer fish than planned. Another problem was the location that this gear fished. The purse seine vessel fished further out in Willapa Bay, where the channel was deep and wide enough to fish with this gear and where it would not interfere with the sport fishery. Coho released from the purse seine gear returned in even numbers to all three hatcheries but most coho released from tangle nets and gill nets returned to the Forks Creek Hatchery. We hypothesize that the purse seine captured more or different populations of coho because of the location fished; this could also explain why the recovery rate for purse seine captured fish was not higher than for the tangle net and gill net captured fish. As a result of these problems, we conclude that a purse seine cannot be used as a control to evaluate survival for a commercial coho fishery in the Willapa Basin. Because recovery dates were collected for recovered tags, a survival estimation method that may be more suitable is Continuous Sampling as considered by Gulland (1995), Chapman (1961), and Paulik (1963). Too few fish were captured in the sport test fishery to speculate about the usefulness of a purse seine for estimating sport captured fish survival in the Willapa Basin.

Because the purse seine was not a suitable control for the net gears, we compared the relative survival for the tangle net and gill net captured coho. Based on the study results, tangle nets are a more suitable choice for many reasons but whether increased survival is imparted is not clear. Although coho captured in the tangle net were in better condition at capture and at release than coho captured in the gill net and coho captured in excellent condition (Condition 1) were more apt to be recovered. However, this did not translate to a significant gain in immediate or long-term survival (
Table 10 and Table 13). The lack of significance for post release survival could be the result of low detection probabilities confounding any detectable differences in survival between the two groups. It is also possible that environmental stressors masked the survival advantages imparted by the tangle net. For instance, we observed that many fish needed to be revived, and typically more than there was room for in the revival box. This situation was also the case for the previous two years of study in the Willapa Basin and contrasts sharply with the spring Chinook test fisheries in the Columbia River, where fish revived quickly and many did not require the revival box (Vander Haegen et al., 2004; Ashbrook et al., 2004). Biologic factors that could explain why salmon were more sensitive in this environment include stress from low dissolved oxygen as a result of warmer water temperatures, that fish were undergoing physiologic transformation, and the relatively short time period prior to spawning. Certainly the Columbia River study holds many differences. Among them, fishing location, this study was done in an estuary while the Columbia study was done in freshwater, time of year, and species (Columbia study used spring Chinook).

As occurred previously, the two-chambered revival boxes used for lethargic fish were effective for recovering coho. Farrell et al. (2001a) also found these types of boxes effective; although we were unable to achieve the 93.5% recovery of coho captured in gill nets in poor condition (Condition 5) that they observed. The reason for this difference is unclear, but may be because of the physiologic factors mentioned earlier. Because a true physiological recovery requires much longer than the time we held fish, Farrell et al. (2001b) have noted that the post-release survival of any captured fish could probably be improved by holding fish for as long as possible, especially if the fish was brought on board in very poor condition, or by holding the fish in a cage alongside the vessel to promote active swimming during recovery. For the Willapa Basin, because so many fish were in lethargic condition and the water was warm, it is doubtful these methods could be employed.

Stream surveys were generally unsuccessful at recovering tags. High water events precluded surveys during some critical times and this compounded the difficulty in recovering coho carcasses. The tags we recovered mainly at the Forks Creek Hatchery are clearly a minimal estimate of the survival, and are most applicable to hatchery fish.

In a selective fishery, a fish released by one fisher may be recaptured by another, and this could result in additional mortality if capture effects are multiplicative. We tried to evaluate the effects of multiple recaptures on the short-term survival of coho salmon, but in spite of having the tangle and gill net fishers near each other, the recapture rate was negligible. This is encouraging because it indicates that most fish do not undergo multiple captures. No difference was observed in coho survival by skipper for immediate survival although a difference was observed for post-release recovery, indicating that differences in handling can have long-term survival effects on released coho.

<u>Objective 3: Enumerate bycatch and compare the immediate mortality of untargeted salmon stocks and species (bycatch) captured in the tangle net, the conventional gill net, and with hook and line using the modified purse seine as a control.</u>

It is important to document the effects these gears have on non-target stocks and species. For example, many crabs were captured by the purse seine in some areas. Using a gear that may be friendlier to one species is not acceptable if the negative impacts are simply transferred to another species.

As expected, the sport gear captured the least amount of bycatch. The purse seine captured the most bycatch. Of the commercial gear, the tangle net captured more species and numbers of bycatch than the gill net. Further, the tangle net captured jack coho and Chinook while the gill net did not capture any of these smaller sized fish. Nonetheless, bycatch were typically released alive and in good condition.

The most commonly captured salmonids were adult chum and Chinook that were captured by the tangle net and gill net gears. All chum were captured and released in excellent condition and survived their immediate capture. The adult Chinook captured by the tangle net survived their immediate capture (96%) better than those that were captured by the gill net (85%).

Objective 4: Compare the egg-to-fry mortality and abnormality rate of the progeny for coho released from the tangle net, the gill net and hook and line gears that return to a hatchery.

This objective was developed to consider the effects of capture and release on spawning success. A premise of selective fishing is that released fish successfully reproduce to contribute to rebuilding the weak stocks that need protection. Although there exists speculation that the physiological stress resulting from capture could negatively affect reproduction and gamete health, this is the first study we are aware of that evaluates the progeny of salmon captured in selective and standard fishing gear. This evaluation consisted of testing if fertilization occurred and if it did, at what stage, if any, the embryo died.

Because this study is difficult to do for naturally spawning fish, we evaluated the progeny of fish that returned to the Forks Creek Hatchery. Survival differences were significant for the three- and five- treatment models at the eyed egg to fry life stage. A multi-comparison test performed on the three treatment model showed that the progeny of coho captured by the tangle net survived equally to the control coho and that both of these groups survived at an approximately 5% higher rate than the progeny of coho captured by the gill net. Whether this result is biologically significant is questionable, especially in hatcheries where typically more fish can be collected to mitigate for lower survival rates. But the significant result is interesting and indicates the need for further work at evaluating progeny survival as well as the physiologic mechanisms that result in greater mortality. For example, it may be that some females or males may not be as fertile. Further, one hypothesis is that the gonadotropin cascade may have been affected as a result of stress due to capture. Should this study be repeated, we recommend that abnormality evaluation also be done at the egg stage. This can be performed by applying Stockard's solution to the eggs that do not eye up, and then using a microscope to examine if fertilization occurred and if it did not, at what stage the embryo died.

Because a survival difference was observed for the progeny of gill net captured fish that were reared in a hatchery, there may also be a difference for coho salmon that spawn naturally. Because greater energy expenditure is required to choose, defend, and build a redd, adult and progeny survival could be further reduced for naturally spawning fish. Released fish that attempt to spawn naturally may continue to be affected by capture – they may have difficulty competing with other spawning fish, or gamete quality may be decreased. We consequently recommend further studies to investigate the effects of capture and release on spawning, and to estimate the post-release survival rates for fish captured and released from fishing gears that will spawn naturally.

Objective 5: Estimate the hooking mortality rate for coho captured in an estuary. Compare this rate with the value currently used by fish managers and with other ocean and freshwater hooking mortality studies.

Currently fish managers use agreed-to values for modeling runs and setting sport fisheries because there is insufficient information to estimate a statistically valid mortality rate. This value may not reflect the actual mortality of released fish. By estimating the long -term survival of fish captured by hook and line relative to a control, we hoped to recommend to fish managers whether they should lower or raise their mortality value.

Initially we planned to use a charter vessel for the sport fishing component of the 2003 Willapa test fishery. Because we did not receive any bids for a charter vessel we instead used agency sport boats and asked agency and local Willapa fishers to assist with the study. To provide incentive to the local fishers, we offered entry into a raffle drawing for a cash prize to those sport fishers who provided us with fish for this study. (Agency employees did not qualify to enter the raffle drawing). The agency anglers provided a summary of their experiences and suggest that in the future, the sport test fishery begin earlier, additional work be done to enlist the support of local fishers and fishing clubs, and care be taken to ensure bait quality. An oil spill in the area and the early movement of coho up the rivers may have impeded our ability to capture coho. Even with these changes and considerations, based on previous years' harvest data (Tim Flint, WDFW, personal communication) it is unlikely that we would capture enough coho using sport gear to evaluate reproductive success.

Objective 6: Compare the number and condition of Chinook salmon bycatch caught in the coho test fisheries.

We also collected data for fall Chinook bycatch during 2003. This was done because during the 2001 Willapa study we had observed that fall Chinook salmon captured in the tangle net had a significantly better immediate survival than fall Chinook salmon captured in the gill net (Vander Haegen et al., 2002). Further, Chinook are ESA listed and the bycatch of this species can consequently impede coho fisheries. Should Chinook survival improve as a result of using the tangle net, shorter soak times, careful handling techniques, and a revival box, the use of this gear in place of the standard gill net could increase the opportunity for coho fisheries. We were able to evaluate the Chinook data through a no-cost time extension with funds remaining from the 2003 study.

We found that a Chinook selective fishery that uses 8.9 cm (3.5") tangle nets, shorter soak times, careful handling techniques, and a revival box will catch adult Chinook that are about 2 cm smaller on average compared to a fishery that uses gill nets under the same conditions. The biological and economic significance of this difference seems negligible. The catch efficiency for the tangle net and gill net will be the same but Chinook captured by the tangle net will be more apt to be captured by tangling and in better condition at capture and release. Chinook captured in the tangle nets will usually be captured around the jaw and face, and suffer less body trauma than fish captured in the gill net. Correspondingly, coho captured by the tangle net will be captured by becoming entangled in the net while coho captured in the gill net will be captured by being gilled, mouth clamped, or wedged in the net. As a result of these differences, fish captured using tangle nets may provide a more marketable product, equal in quality to fish captured by trolling. As mentioned earlier, we did not detect a difference between the tangle net and gill net for Chinook post release survival. However, the recovery of Chinook captured in the tangle net by condition was significantly different than for Chinook captured by the gill net, showing that there are differences in post release survival between the two gears. Because the immediate survival was greater and the tangle net could be a way to improve the economic value of fish, its use merits consideration by fish managers and the industry.

Based on the condition at capture and method of capture results, a net that is appropriate for a tangle net coho fishery will also act as a tangle net for fall Chinook bycatch. Similarly, a net that acts as a gill net for a coho fishery will also act as a gill net for fall Chinook bycatch.

These results contrast sharply with a similar evaluation of the post-release survival of spring Chinook salmon on the Columbia River (Vander Haegen et al. 2004). In that study, spring Chinook captured and released from tangle nets did not differ in immediate survival from gill net captured fish but did survive at significantly higher rates following their release than Chinook released from gill nets. Different species are known to have different responses to the same stressors (Schreck et al. 2001), and so may not respond to 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. Another possibility is that environmental stressors may override and mask survival benefits provided by the tangle net. In our study, the estuarine environment was likely unfavorable to capture and release because the water was relatively warm during the coho migration. Fishing in better conditions (e.g. cooler water, fewer predators) would most likely increase survival, although we do not know the magnitude of the difference. On the Columbia River, spring Chinook salmon were captured after they had migrated about 140 miles upstream, and were presumably habituated to the river environment. In contrast, coho salmon captured in the Willapa Basin were undergoing a physiological transition between salt and freshwater and spawned soon after, and these factors may have assisted in making the coho more susceptible to capture mortality.

Another consideration for the differences between the Columbia River spring Chinook study and this one is the statistical power related to the study design and the confounding between survival and tag detection probabilities. In this study survival differences between fish released from each gear type were estimated using mark-recapture methods of jaw tagged fish with sample sizes on the order of approximately 170 fish for each net type where the recovery of jaw tags was dependent on sampling rates in either commercial or sport fisheries, hatcheries, or on the spawning grounds. The number of recovered jaw tags represents a joint probability of detection and survival. Detection probabilities of jaw tags are unknown and likely to be much less than one. Both of these factors (low sample sizes and a survival probability that is confounded by tag recovery rates) complicates the interpretation of study results.

Power to detect a difference: comparison of Willapa and Columbia studies

For this study, we did not detect a difference between the long-term survival of coho or Chinook captured by the tangle net and the gill net. However, a power analysis shows that because of limited Chinook data it is not possible to be certain that there was or was not an actual difference.

To date, WDFW personnel have conducted several studies to evaluate the usefulness of different gear types in reducing the release mortality of non-targeted stocks in commercial selective fisheries. A three-year study in the Columbia River found statistically significant differences in long-term survival among fish released from a tangle net versus those caught and released from gill nets. This study found no statistically significant differences in long term survival among fish caught and released from tangle versus gill nets. An evaluation of statistical power showed the Columbia River study was able to detect much smaller differences in survival between tangle nets and gill nets than the Willapa bay study. Therefore, although the differences in outcomes might be interpreted as related to the type of environment or species (freshwater vs. estuarine), they could also be attributable to the disparities in power related to the study design. Consequently, a difference in survival that could be easily detected with the Columbia River study design, but not the Willapa Bay study design, would yield the outcome we observed in the Willapa Basin. Two key issues must be considered when interpreting the combined results of the Willapa Bay and Columbia River studies and are

1. Sample sizes, and therefore power, in the Willapa Bay study were much lower than in the Columbia River study.
2. In studies such as this one in Willapa Bay study, inestimable detection probabilities confound the detectable true long-term survival differences, complicating the interpretation of power of the study.

In each study, long-term survival was estimated by the marking and recapture of fish released from both net types. Recovery of a tag is a function of both survival and detection probabilities. In the 2003 Columbia River study, released adult fish were tagged using PIT tags. The infrastructure of the Columbia River hydro system allows for almost 100% detection of adult fish as they migrate upstream through the dams. Subsequently, the number of recovered tags reflects actual survival. Further, approximately 1,100 fish were tagged in the Columbia River study.

Willapa Bay study survival differences between fish released from each gear type were estimated using mark-recapture methods of jaw tagged fish with sample sizes on the order of 170 fish for each net type. Recovery of jaw tags is dependent upon sampling rates in either commercial or sport fisheries, hatcheries, or on the spawning grounds. The number of recovered jaw tags represents a joint probability of detection and survival. The detection probabilities of jaw tags are unknown and likely to be much less than one.

To illustrate the confounding influences of detection probabilities on survival estimates and the effects of sample sizes on allowable inferences, one of us (Ryding) performed a simulation study to compare the detectable differences between the Columbia River type and Willapa Bay type studies for several Type II error rates. Results of the simulation exercise are presented in the table. The expected number of recoveries for gear type *i*, t_i, out of n_i tagged fish is as follows,

$$E\left(t_i\right) = n_i S_i p \text{ ,}$$

where S_i = long-term survival of fish caught in net type *i* and,

p = tag-specific detection probability.

Note that the recovery rate of a tag is $S_i p$ the joint survival and detection probability. For PIT tags in the Columbia River, the proportion of observed tags out of n_i at a dam is an estimate of survival to that point because p is approximately equal to one. Observing 400 tags out of 1100, approximately the number recovered and released in 2003, gives a survival estimate of 0.364 (36.4%; Table 1). In the Willapa Bay study, approximately 15 jaw tags were recovered, giving a recovery rate $\left(Sp\right)$ of 0.088 (8.8%). However, long-term survival of jaw tagged fish could range from a low of 8.8% for $p = 1$ to 100% for $p = 0.088$. Table 1 gives values of S_1 under several different detection rates of jaw tags.

Estimates of relative survival between two groups of fish, as measured by S_2/S_1, are not confounded by detection probabilities provided that detections rates are the same for both groups of fish (those caught in tangle nets and those caught in gill nets). For example, if the relative recovery rate of tags between two groups of fish is 90%, then the relative survival ratio is also 0.90 if $p_1 = p_2 = p$ because,

$$0.90 = \frac{t_2/n_2}{t_1/n_1}$$

$$0.90 = \frac{S_2 p_2}{S_1 p_1}$$

$$0.90 = \frac{S_2}{S_1}.$$

Hence, a ratio of the proportions of tag recoveries between two groups would accurately reflect relative survival probabilities.

However, power and Type II error rate calculations for proportions are based on effect size or the difference between two proportions, e.g., $S_1 - S_2$, rather than the ratio. Under the assumption of equal detection probabilities the difference in relative recovery rates is expressed as follows,

$$\frac{t_1}{n_1} - \frac{t_2}{n_2} = S_1 p - S_2 p$$

$$\frac{t_1}{n_1} - \frac{t_2}{n_2} = p\left(S_1 - S_2\right)$$

In this case, detection probabilities confound true differences in survival. Low detection probabilities reduce the power, i.e. in order to be detected the differences in survival must be much larger than if the detection probabilities were higher.

One way to illustrate power is through detectable differences. For a given alpha level, the greater the power in a study, the smaller the difference (or effect size) that can be detected. In the table below, effect size in absolute difference and related detectable differences as a ratio are listed for several values of power and detection probabilities for a the Willapa Bay type study. The other parameters in the simulation were taken to reflect the values similar to those estimated in the Willapa Bay and Columbia River studies. As the probability of detecting an effect size when it actually exists, power increases with effect sizes (differences in survival), but is inversely proportional to the ratio of relative recoveries. This is because as the ratio gets closer to one, the effect size gets closer to zero and, subsequently, power decreases.

When tag recovery probabilities are small, differences in survival would have to be quite large to be detected by a hypothesis test. In the Willapa Bay study, there were approximately 170-tagged fish released from each net type and 15 were recovered from one net type ($t_1 = 15$). If 7 or 8 tags were recovered in the other group, for example, the effect size could be anywhere from 45% ($S_1 - S_2 = 0.45$) for $p = 0.1$ or 4.4% when $p = 1$ (Table 34). Furthermore, the probability of detecting a difference of 0.45 if one exists is 90% for $p = .1$ but only 50% for tag recovery probabilities greater than 30%. The low tag rates coupled with a lack of information on detection probabilities makes interpretation of not rejecting the null hypothesis very difficult. Because of the lower power, the results of the long-term survival analysis of the Willapa Bay study should be interpreted with caution, particularly when compared with those from the more powerful Columbia River study.

Table 34. Comparison of the expected power between the Willapa Bay study (2003) and a Columbia River study.

	Willapa Bay – fall Chinook				Columbia River study – spring Chinook
Tag Type	Jaw				PIT
Sample Sizes n_1 and n_2	170				1100
Tag Recoveries	15				400
Reporting Rate (p)	Unknown				100%
Proportion of recovered tags $S_1 p$	$\frac{15}{170} = 0.088$				$\frac{400}{1100} = 0.364$
Assumed reporting rates - p	p 0.10	0.30	0.50	1.0	$p \approx 1.0$
Survival – S_1 under assumed $p's$	0.882	0.294	0.176	0.088	$S_1 = 0.364$
Power - $(1-\beta)$	Detectable Differences *Ratio:* $R = \frac{S_2}{S_1}$ *(Effect size:* $S_1 - S_2$*)* *Expected* t_2				Detectable Differences *Ratio:* $R = \frac{S_2}{S_1}$ *(Effect size:* $S_1 - S_2$*)*
90%	*0.49* *(0.45)* *7*	*0.25* *(0.221)* *4*	*0.22* *(0.138)* *3*	*0.20* *(0.071)* *3*	*0.84* *(0.058)*
70%	*0.63* *(0.335)* *9*	*0.41* *(0.174)* *6*	*0.39* *(0.109)* *6*	*0.37* *(0.056)* *6*	*0.88* *(0.044)*
50%	*0.73* *(0.238)* *11*	*0.54* *(0.135)* *8*	*0.52* *(0.085)* *8*	*0.50* *(0.044)* *8*	*0.91* *(0.033)*

Comparison with previous Willapa and Columbia studies

The results of this study and two previous years of comparing tangle and gill nets (Table 35) have not shown that tangle nets provide a significant post release survival improvement in coho or fall Chinook when using modified fishing and handling techniques. This could be a result of low statistical power and so we recommend future studies that use tags with greater detection probabilities. During the same year of this study (2003), a similar study was done in the lower Columbia River that compared detections between jaw and PIT tags. That study found that PIT tags were superior for providing point estimates of survival with tight confidence intervals. Unlike the Columbia River, the Willapa River does not have multiple dams that can be outfitted with PIT tag detectors. Nonetheless, PIT tag detection technology advances may make it feasible to install detection receivers along the Willapa River and at hatcheries where salmon return. Further, handheld PIT tag readers could be provided to spawning survey crews and fishery observers.

This study showed that fall Chinook captured in a coho- sized tangle net have an immediate survival that is higher than fall Chinook captured in a coho-sized gill net. Compared to previous studies for spring Chinook (Vander Haegen et al., 2004; Ashbrook et al., 2004), coho and fall Chinook salmon in this study did not revive as quickly when placed in the revival box. Further, more coho and fall Chinook needed reviving than could fit in the revival box. This situation suggests that in a commercial selective fishery, the mark ratio of hatchery to wild fish is even more important than it is for a spring Chinook freshwater fishery. If the fishery is occurring in an area where there are many wild fish that will need to be revived, a selective fishery may not be a good choice regardless of whether the tangle net provides an improvement in survival.

Table 35. Summary of results for coho and Chinook salmon captured during the 2000, 2001, and 2003 Willapa test fisheries. The first year, 2001, was a feasibility study so there is no data for some categories.

Species	Category	2000	2001	2003
Coho	Immediate survival	80% tangle net 75% gill net	>88% and no detected difference between tangle net and gill net	>88% and no detected difference between tangle net and gill net
	Long-term survival	No data	No detected difference between tangle net and gill net	No detected difference between tangle net and gill net
	Catch efficiency	No data	Higher for tangle net	No detected difference between tangle net and gill net
	Size	No data	Tangle net fish smaller	Tangle net fish smaller
	Condition at capture	Better condition in tangle net	No detected difference between tangle net and gill net	Better condition in tangle net
	Capture method	No data	Tangle net by tangling and mouth clamp Gill net by wedging and gilling	Tangle net by tangling Gill net by wedging and gilling
Chinook	Immediate survival	91% tangle net 88% gill net	97.3% tangle net 83.2% gill net	96.3% tangle net 85.0% gill net
	Long-term survival	No data	No detected difference between tangle net and gill net	No detected difference between tangle net and gill net
	Catch efficiency	No data	Higher for tangle net	No detected difference between tangle net and gill net
	Size	No data	No detected difference between tangle net and gill net	Tangle net fish smaller
	Condition at capture	Better condition in tangle net	Better condition in tangle net	Better condition in tangle net
	Capture method	No data	Tangle net by tangling Gill net by gilling	Tangle net by tangling Gill net by wedging, gilling, and mouth clamp.

Dissemination of project results

We have shared the project results with fishers and managers for the region where the study occurred. We will also share the results other management agencies and interested parties (e.g. Fisheries and Oceans Canada, the Oregon Department of Fish and Wildlife, the Columbia River Intertribal Fisheries Commission, the Confederated Colville Tribes, etc.) through making this report available on our website. Funding from this project enabled further development of this website. Oral presentations have been given to interested parties and this has also provided a forum for promoting discussion about selective fishing. We will submit an article to a peer-reviewed journal that considers this research together with the two previous years when tangle nets and gill nets were evaluated in the Willapa River. This study provided educational opportunity by supporting the education and providing the research topic toward a Master's Degree in Fisheries Science for one of us (Ashbrook). Methods were developed to estimate immediate, post-release and total survival when a control is available. This information was presented at the 2004 World Fisheries Congress and a paper submitted (Ashbrook et al., in press).

Literature Cited

Ashbrook, C.E., J.R. Skalski, J.D. Dixon, K.W. Hassel, and E.A. Schwartz. 2007. *Estimating bycatch survival in a mark-selective fishery*. Fourth World Fisheries Congress Publication. American Fisheries Society.

Ashbrook, C.E., A. Hoffman, K.W. Yi, J.D. Dixon, and E.A. Schwartz. 2004. 2002: Evaluate Live Capture Selective Harvest Methods. WDFW Report. 32 p.

Box, and Cox 1964. An analysis of transformations. Journal of the Royal Statistical Society Series B –Statistical Methodology 26: 211-252.

Farrell, A.P., P. Gallaugher, C. Clarke, N. DeLury, H. Kreiberg, W. Parkhouse and R. Routledge. 2000. Physiological status of coho salmon (*Oncorhynchus kisutch*) captured in commercial non-retention fisheries. Canadian Journal of Fisheries and Aquatic Science 57:1668-1678.

Farrell, A.P., P.E. Gallaugher, J. Fraser, D. Pike, P. Bowering, A.K.M. Hadwin, W. Parkhouse and R. Routledge. 2001(a). Successful recovery of the physiological status of coho salmon on board a commercial gillnet vessel by means of a newly designed box. Canadian Journal of Fisheries and Aquatic Science 58:1932-1946.

Farrell, A.P., P.E. Gallaugher, and R. Routledge. 2001(b). Rapid recovery of exhausted adult coho salmon after commercial capture by troll fishing. Canadian Journal of Fisheries and Aquatic Science 58:2319-2324.

Fisher, R.A. 1956. Statistical methods and scientific inference. Hefner Press. 180 p.

Gallinat, M.P., H.H. Ngu and J.D. Shively. 1997. Short-term survival of lake trout released from commercial gill nets in Lake Superior. North American Journal of Fisheries Management 17:136-140.

Hudson, 1971. Interval estimation from the likelihood function. Journal of the Royal Statistical Society, Series B 33:256-262.

Kalbfleisch and Sprott 1970. Application of likelihood methods. Journal of the Royal Statistical Society, Series B 32:175-208.

Nelder, J.A. and R.W.M. Wedderburn. 1972. Generalized Linear Models. Journal of the Royal Statistical Society, Series A (General). 135 (2):370-384.

McCullagh, P. and J.A. Nelder. 1989. Generalized Linear Models, 2nd ed. Chapman and Hall, New York, NY. 511 p.

Muoneke, M.I. and W.M. Childress. 1994. Hooking mortality: A review for recreational fisheries. Reviews in Fisheries Science. 2:123-156.

Schreck, C.B., W. Contreras-Sanchez and M.P. Fitzpatrick. 2001. Effects of stress on fish reproduction, gamete quality and progeny. Aquaculture 197:3-24.

Schroder, S. and J. Ames. 2004. Summer chum salmon conservation initiative: an implementation plan to recover summer chum salmon in the Hood Canal and Strait of Juan de Fuca Region. Supplemental report no.6. 33 p.

Vander Haegen, G.E., K.W. Yi, C.E. Ashbrook, E.W. White, and L.L. LeClair. 2002. Evaluate Live Capture Selective Harvest Methods. WDFW Report #FPT-02-01. 35 p. http://www.wa.gov/wdfw/fish/commercial/selective/livecapture.htm

Vander Haegen, G.E., C.E. Ashbrook, K.W. Yi, and J.F. Dixon. 2004. Survival of spring Chinook salmon captured and released in a selective commercial fishery using gill nets and tangle nets. Fisheries Bulletin 68: 123-133.

Zar, J.H. 1999. Biostatistical analysis, fourth edition. Prentice Hall. Upper Saddle River, New Jersey. 663 p.

Egg to eyed egg survival

Three treatment model

ANOVA table for arcsine-square root transform method**,** three-treatment model

Group	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	2	41.671	20.8357	0.4947	0.6156
Residuals	25	1053.040	42.1216	----	----

ANODEV table for seven-treatment model, GLM analysis

Group	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	2723.188	----	----	----
Treatment	2	85.3186	42.6593	0.4043	0.6721
Residual	25	2637.870	105.515	----	----

Five Treatment Model

ANOVA table for arcsine-square root transform method**,** five-treatment model

Group	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	4	81.367	20.3417	0.4617	0.763
Residuals	23	1013.345	44.0585	----	----

ANODEV table for three-treatment model, GLM analysis

Group	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	2723.188			
Treatment	4	203.3039	50.826	0.4639	0.8277
Residual	23	2519.885	109.5602		

Seven Treatment Model

ANOVA table for arcsine-square root transform method**,** seven-treatment model.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	6	201.4385	33.5731	0.7893	0.5883
Residuals	21	893.2733	42.5368	----	----

ANODEV table for seven-treatment model, GLM analysis

	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	2723.188	----	----	----
Treatment	6	493.9437	82.32395	0.7755	0.598
Residual	21	2229.245	106.1545	----	----

Eyed egg to fry survival

Seven Treatment model

One-way ANOVA results, Seven treatment model. The 2 survival values > 1 transformed to 1. (For 2 observations #eggs - # fry = -1; that is, 1 more fry counted than number of eggs.)

Group	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	6	41.6669	6.9445	2.3797	0.0653
Residuals	21	61.2836	2.9183	----	----

ANODEV table for seven-treatment model, GLM analysis (corresponds to Table 7)

Group	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	160.4180	----	----	----
Treatment	6	62.63316	10.4387	2.2418	0.0791
Residual	21	97.7849	4.6564	----	----

Five Treatment model

One-way ANOVA results, five treatment model. The 2 survival values > 1 transformed to 1. (For 2 observations #eggs - # fry = -1; that is, 1 more fry counted than number of eggs.)

Group	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	4	39.6584	9.9146	3.6029	0.0202
Residuals	23	63.2922	2.7518	----	----

ANODEV table for five-treatment model, GLM analysis (corresponds to Table 11).

Group	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	160.4180	----	----	----
Treatment	4	58.9887	14.7472	3.3441	0.0269
Residual	23	101.4293	4.410	----	----

Three treatment model

One-way ANOVA, three-treatment model. The 2 survival values > 1 transformed to 1. (For 2 observations #eggs - # fry = -1, that is, 1 more fry counted than number of eggs.)

Group	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	2	39.3847	19.6924	7.7449	0.0024
Residuals	25	63.5658	2.5426	----	----

ANODEV table for five-treatment model, GLM analysis (corresponds to Table 15).

Group	Df	Deviance	Deviance/Df	F Value	Pr(F)
Null	27	160.4180	----	----	----
Treatment	2	57.3883	28.6942	6.9626	0.0039
Residual	21	103.0297	4.1212	----	----

Fry stage to abnormality proportions

Seven treatment model

ANOVA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	6	1.9664	0.3277	0.7325	0.6289
Residuals	21	9.3960	0.4474	----	----

ANOVDEV

	Df	Deviance	Pr(F)
Null	27	39.7286	----
Treatment	6	7.1046	0.6075
Residual	21	32.6240	----

	Df	Deviance	Resid. Df	Resid. Dev	Pr(Chi)
NULL	27	39.7286	----	----	----
Treatment	6	7.1046	21	32.6240	0.3113

Dispersion Parameter for Binomial family taken to be 1.669

ANODEV – F-test – P(F) = 0.6075

Five treatment model

ANOVA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	4	0.8122	0.2030	0.4427	0.7765
Residuals	23	10.5502	0.4587	-----	----

ANODEV

	Df	Pr(F)
Null	27	----
Treatment	4	0.5239
Residual	23	----

	Df	Deviance	Resid. Df	Resid. Dev	Pr(Chi)
NULL	27	39.72860	----	----	----
Treatment	4	4.974356	23	34.75424	0.2899389

Dispersion Parameter for Binomial family taken to be 1.5775

Three treatment model

ANOVA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Treatment	2	0.4534	0.2267	0.5195	0.6011
Residuals	25	10.9090	0.4364	----	----

ANODEV

	Df	Pr(F)
Null	27	----
Treatment	2	0.2718
Residual	25	----

	Df	Deviance	Resid. Df	Resid. Dev	Pr(Chi)
NULL	27	39.72860	----	----	----
Treatment	2	3.931809	25	35.79679	0.1400292

Dispersion Parameter for Binomial family taken to be 1.6694