2001 Annual Project Report

I. **Project Title:** *Impacts of Size Selective Gillnet Fisheries on Puget Sound Coho Salmon Populations*
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IAC Grant No.: *01-047N*

II. Abstract:

Reduction in size of mature fish has economic, genetic and ecological implications leading to declines in fishery income, population productivity and viability. Selective removal of larger individuals prior to spawning can result in the non-random removal of their genes from the next generation. To the extent that larger size is heritable, removing larger individuals from the breeding population will result in a response: smaller fish produced in the next generation. The magnitude of the response depends on the habitability of the traits and the size of the selection differential – the differences between the trait's distribution prior to selection and after selection.

Using WDFW's historical CWT database we estimated the size selectivity of terminal Puget Sound and Coastal gillnet fisheries for four hatchery (1980-1999) and two wild (1978-1994) populations by comparing length data from coded-wire tagged recoveries collected in terminal fisheries to recoveries from the spawning areas (trap or hatchery rack). Two of the hatchery populations we examined have historically been managed at relatively high exploitation rates in terminal gillnet fisheries: Voights and Purdy. These two populations showed large selection differences (mean catch length-mean escapement length), the greatest number of statistically significant positive selection differences indicating selective removal of larger fish in the catch, and had the steepest rates of decline in length and fecundity over time. The two hatchery populations managed on a less intense exploitation basis: Wallace and Bingham, exhibited no significant selection differences indicating larger fish were not being selectively removed by the gillnet fishery and showed no significant declining trend in length over time. Wallace hatchery did show a significant decline in fecundity over time (-24 eggs/year), but the rate of decline was significantly shallower than the Voights (-42 eggs/year) and Purdy (-34 eggs/year) populations (ANCOVA; $p<0.05$). Bingham showed no significant decline in fecundity over time. The Big Beef Creek and Deschutes River wild populations, which experienced high exploitation rates, had some of the largest positive selection differences and exhibited rates of decline in length similar to the Voights and Purdy populations. However, only one of the three wild length trends was statistically significant due at least in part to low sample sizes.

In this study size selective fisheries that on average remove larger fish from the pre-spawning population were found to contribute to the rate of decline in body size and fecundity. The greater the size selective fishery's exploitation rate, the greater the rate of decline in length and fecundity. Management actions regarding the intensity of any size selective fishery must consider the consequences of those actions on the population's long-term health, particularly on populations at genetic or demographic risk.

III. Executive Summary:

Reduction in size of mature fish has economic, genetic and ecological implications leading to declines in fishery income, population productivity and viability. Selective removal of larger individuals prior to spawning can result in the non-random removal of their genes from the next generation. To the extent that larger size is heritable, removing larger individuals from the breeding population will result in a response: smaller fish produced in the next generation. The magnitude of the response depends on the habitability of the traits and the size of the selection differential – the differences between the trait's distribution prior to selection and after selection. While there are a number of potential factors that could also contribute to a temporal trend in body size such as large scale climate changes, oceanic decadal oscillations or carrying capacity constraints (Beamish, et al. 1999; Bigler and Helle 1994), such factors should effect the coho populations we studied in a similar fashion because they are geographically similarly distributed (Table 1) and share identical life history patterns. Thus, between population differences in rates of decline should not be related to these large scale factors, but to population specific factors.

Using WDFW's historical CWT database we estimated the size selectivity of terminal Puget Sound and Coastal gillnet fisheries for four hatchery (1980-1999) and two wild (1978-1994) populations by comparing length data from coded-wire tagged recoveries collected in terminal fisheries to recoveries from the spawning areas (trap or hatchery rack). Two of the hatchery populations we examined have historically been managed at relatively high exploitation rates in terminal gillnet fisheries: Voights and Purdy. These two populations showed large selection differences (mean catch length-mean escapement length), the greatest number of statistically significant positive selection differences indicating selective removal of larger fish in the catch, and had the steepest rates of decline in length and fecundity over time. The two hatchery populations managed on a less intense exploitation basis: Wallace and Bingham, exhibited no significant selection differences indicating larger fish were not being selectively removed by the gillnet fishery and showed no significant declining trend in length over time. Wallace hatchery did show a significant decline in fecundity over time (-24 eggs/year), but the rate of decline was significantly shallower than the Voights (-42 eggs/year) and Purdy (-34 eggs/year) populations (ANCOVA; $p<0.05$). Bingham showed no significant decline in fecundity over time. The Big Beef Creek and Deschutes River wild populations, which experienced high exploitation rates, had some of the largest positive selection differences and exhibited rates of decline in length similar to the Voights and Purdy populations. However, only one of the three wild length trends was statistically significant due at least in part to low sample sizes.

In this study size selective fisheries that on average remove larger fish from the pre-spawning population were found to contribute to the rate of decline in body size and fecundity. The greater the size selective fishery's exploitation rate, the greater the rate of decline in length and fecundity. Management actions regarding the intensity of any size selective fishery must consider the consequences of those actions on the population's long-term health, particularly on populations at genetic or demographic risk.

IV. **Purpose:**

Reduction in size of mature fish has economic, genetic and ecological implications leading to declines in fishery income, population productivity and viability. The coded-wire tagging (CWT) database offers a unique opportunity to measure the magnitude of size selectivity of terminal area coho gillnet fisheries over the past 20 years and to estimate population specific trends in size over time. In addition, hatcheries have collected mean fecundity data over the past 40 years. Fecundity is directly related to the fitness (reproductive success) of the females and, because it is significantly correlated with female size, can serve as a surrogate for size, allowing temporal trends to be examined over a longer time frame. Selective removal of larger individuals prior to spawning will result in the non-random removal of their genes from the next generation. To the extent that larger size is heritable, removing larger individuals from the breeding population will result in a response: smaller fish being produced in the next generation. The magnitude of the response depends on the habitability of the traits and the size of the selection differential – the differences between the trait's distribution prior to selection and after selection. While there are a number of potential factors that could contribute to a temporal trend in body size such as large scale climate changes, oceanic decadal oscillations or carrying capacity constraints (Beamish, et al. 1999; Bigler and Helle 1994), such factors should effect the coho populations we studied in a similar fashion because they are geographically similarly distributed (Table 1) and share identical life history patterns. Thus, between-population differences in rates of decline should not be related to these large scale factors common across all group, but to population specific factors. There are distinct differences in how the populations are managed in terms of terminal area gillnet fishery exploitation rates. If size selective fisheries are contributing to the rate of decline in body size and fecundity, then management actions regarding such selective fisheries need to consider those consequences.

While the actual trait being directly selected for in a gillnet fishery is girth, girth is positively correlated with length and serves as a surrogate for girth in these analyses. For example, fork length explained 73 to 90% of the variation in girth in five Puget Sound coho hatchery populations sampled in 1996 (R. Eldrich, WDFW, unpublished data). It was necessary to substitute fork length for girth in these analyses because fork length is collected routinely in the CWT sampling program, while girth is not.

Objectives of the project:

1. Estimate historical size selectivity of terminal Puget Sound and Coastal area gillnet fisheries.
2. Estimate the rates of decline in body size of the coho populations based on CWT recoveries and fecundity (mean female reproductive output).
3. Compare the rates of decline in size and fecundity over time of hatchery coho populations experiencing different intensities of size selection.
4. Describe the demographic and genetic impacts of the documented trends in body size reduction.

V. Approach:

Detailed description of the work that was performed.

Obj. 1. **Estimate historical size selectivity of terminal Puget Sound and Coastal area gillnet fisheries.**

Using WDFW's historical CWT database we estimated the size selectivity of terminal Puget Sound and Coastal gillnet fisheries for four hatchery (1980-1999) and 2 wild (1978-1994) populations by comparing coded-wire tagged recoveries from the terminal fishery to recoveries from the spawning areas (trap or hatchery rack). The four hatchery populations were: Wallace River Hatchery (central Puget Sound), Voights Creek Hatchery (south Puget Sound), Purdy Creek Hatchery (Hood Canal), Bingham Creek Hatchery (Coastal). The two wild populations were Big Beef Creek Wild (Hood Canal) and Deschutes River Wild (South Puget Sound). ANOVA was used to make statistical comparisons between fishery and spawning area fork lengths by sex.

Obj. 2. **Estimate the rates of decline in body size of the coho populations based on CWT recoveries and fecundity (mean female reproductive output).**

We estimated the sex specific rates of decline in size over time of coho spawning populations based on trends in annual mean length estimated from coded-wire tag recoveries and mean fecundity from four hatcheries over the past 40 years. Simple linear regression was used to estimate the rates of change over time.

Obj. 3. **Compare the rates of decline in size and fecundity over time of hatchery coho populations experiencing different intensities of size selection.**
Using the results from Obj. 2 we compared, using ANCOVA, the temporal trends in size of coho populations experiencing different intensities of size selection. Our goal being to determine if the trends in size of populations experiencing higher rates of gillnet fishery exploitation and size selection were statistically different from populations exploited at lower size selectivity and fishing intensity.

Obj. 4**. Describe the demographic and genetic impacts of the documented trends in body size reduction.**
Given the results of Obj.3., discuss and describe their demographic and genetic impacts and the management concerns they raise.

Project management: List individuals and/or organizations actually performing the work and how it was done. Separately funded agencies working on the same project should submit one report.

Curtis Knudsen, Oncorh Consulting – Coordinated with WDFW CWT database and hatchery personnel and assembled the CWT and fecundity data. Performed the regression and ANCOV analyses and report preparation. Presented the study results at the IAC Meeting in Feb. 2001. Senior author of the manuscript for peer-review.
Steve Phelps, WDFW – Contributed significantly to the study design and scope. Drafted an early manuscript.
Craig Busack, WDFW – Contributed efforts toward Objective 4 and final study design.

VI. **Findings:**

Actual accomplishments and findings by objective.

1.) Estimate historical size selectivity of terminal Puget Sound and Coastal area gillnet fisheries.

Length data from the WDFW CWT database representing adult coho caught in the terminal area gillnet fisheries and recovered at hatchery/trap sites from 1980 to 1999 was requested and received. We then estimated size selectivity: the differences in mean fork length between terminal area gillnet catch and fish from the same CWT groups returning to spawn, by sex. The initial estimates of the selection difference (mean catch length – mean escapement length) are summarized in Figure 1. A positive value indicates that the fishery selectively removes larger fish on average allowing smaller fish to reproduce. A negative value indicates a fishery that is size selective for smaller fish on average. For Voight's Creek Hatchery males and females, 93% and 67% of the selection differences (n=14 and 15), respectively, were positive and significant (ANOVA; $\alpha=0.05$). Purdy Creek Hatchery recoveries resulted in 67% of male and 50% of female selection differences (n=12 and 12) being significantly positive. Thus, both of these hatcheries were found to have size selective terminal area gillnet fisheries that on average removed significantly larger fish from the breeding population. There were no statistically significant positive selection differences in either Wallace River (n=9 and 9) or Bingham Creek (n=5 and 5). Bingham Creek males did have significant negative selection differences in 40% of the comparisons and indicated that smaller male coho were being selectively removed from the fishery.

Ultimately, we would like to estimate the parameters in the equation: $h^2 = R^*(SD)^{-1}$

where h^2 is heiratability, R is the population's response in the next generation to selection, and SD is the selection differential.

However, we found that the selection difference estimated from the CWT catch and escapement data is not equivalent to *SD*. The selection difference is biased and always over estimates *SD*, whether the differential is negative or positive.

2.) Estimate the rates of decline in body size of coho populations based on CWT recoveries and fecundity.

Mean annual length and fecundity, for years with available data, were calculated for 1978-1999 and 1960-1999, respectively. Temporal trends in mean length and fecundity were estimated as the slopes from the linear regression analyses. Trends in fork length are given in Table 1 and for fecundity in Table 2. Voights and Purdy Creek hatchery male and female coho all demonstrated statistically significant declines in fork length of approximately -0.4 cm/year ($p<0.05$). The Wallace and Bingham Creek populations did not show any significant declining trend, and Bingham Creek males actually exhibited a significant positive trend of 0.3 cm/year. For fecundity Voights, Purdy and Wallace populations exhibited significant ($p<0.01$) declining trends of -42, -34 and -24 eggs/year, respectively. Bingham Creek was essentially flat, declining at a non-significant ($p=0.80$) -1 egg/year.

The wild populations, Big Beef Cr. and Deschutes R., declined in length at rates of –0.3 to –0.4 cm/year, respectively. These are comparable to the rates exhibited by the hatchery populations experiencing the same high exploitation rates. However, in only one case, Big Beef males, was the declining trend found to be statistically significant. One reason for this is that there were fewer numbers of years with CWT representing the wild populations and thus less power in the test.

3.) Compare the rates of decline in size and fecundity over time of hatchery coho populations experiencing different intensities of size selection.

There are distinct differences in the way these populations have been managed in terms of terminal area gillnet exploitation rates. Tables 3 gives mean terminal gillnet exploitation rates for three of the four hatcheries from 1987-1991. Voights' exploitation rate is over twice the Wallace rate and is almost 50% greater than Purdy. On average 86% of the Voights adults entering the terminal gillnet fishery are removed in a non-random way (Fig. 1). In comparison to Voights, Wallace River fish passing through the terminal gillnet fishery were removed at only a 38% rate. Based on the percentage of all Bingham CWTs taken in the gillnet fishery (13%) and assuming an escapement proportion similar to Wallace, Bingham Cr. terminal area gillnet exploitation rates are likely to be at or below the relatively low

Wallace rates. Thus, the Voights gillnet fishery has the capacity to exert a much greater selectivity response, by removing a much greater proportion of the potential spawners.

The two wild populations are located geographically near the high harvest rate terminal areas of Hood Canal and south Puget Sound and thus experience those relatively high levels of exploitation.

The two hatchery populations that have historically been managed at relatively high exploitation rates in terminal gillnet fisheries: Voights and Purdy, showed large positive selection differences, the greatest number of statistically significant positive selection differences, and had the steepest rates of decline in length and fecundity. The two hatchery populations that were managed at less intense exploitation rates: Wallace and Bingham, exhibited no significant positive selection differences and no significant declining trends in length over time. Wallace hatchery did show a significant decline in fecundity over time (Table 2), but the rate of decline was significantly shallower than Voights and Purdy populations (ANCOVA; $p<0.05$). Bingham showed no significant trend in fecundity over time.

4.) Describe the demographic and genetic impacts of the documented trends in body size reduction.

A method was developed to "back calculate" a population's original size distribution prior to terminal area size selective gillnet fisheries. This method uses a population's catch and escapement length frequencies, combining them using a weighting factor based on the terminal fishery exploitation rate, H. This method should produce a less biased estimate of SD.

Estimating SD from harvest and escapement size distributions.

$\overline{L}_{preh}$ is the mean length of the population Pre-harvest (prior to the fishery).

$\overline{L}_{esc}$ is the mean length of the population Escapement (after the fishery).

$$SD = \overline{L}_{preh} - \overline{L}_{esc}$$

The escapement mean can be calculated from escapement data. To calculate the preharvest mean, the preharvest distribution must be synthesized from harvest and escapement distributions. We have samples representing the length distributions of both subpopulations. The preharvest distribution can be synthesized by appropriately weighting these two distributions. The preharvest population is then simply the sum of the harvest and escapement subpopulations. Thus, the preharvest length frequency is calculated as follows:

$$f_{i,preh} = f_{i,harv}H + f_{i,esc}(1-H)$$

Where $f_{i,preh}$ is the frequency of the i_{th} preharvest length class, $f_{i,harv}$ is the frequency of the i_{th} harvest length class, H is the exploitation rate (number harvested/total number entering the fishery), and $f_{i,esc}$ is the frequency of the i_{th} escapement length class. Finally, the preharvest mean length is calculated as:

$$\overline{L}_{preh} = \sum f_{i,preh} \times L_{i,preh}\,.$$

Once we have calculated *SD* values we can calculate h^2 values based on $h^2 = R^*(SD)^{-1}$, where *R,* the per generation response, is estimated from the slopes of the temporal trends. We can then compare the realized h^2 values to those from the published literature.

If significant problems developed which resulted in less than satisfactory or negative results, they should be discussed.

Description of need, if any, for additional work.

Obj. 4 is not completed yet. A draft manuscript for peer review has been started, but will need to incorporate Obj. 4 results into the final draft.

VII. **Evaluation:**

Describe the extent to which the project goals and objectives were attained.
This description should address the following:

Were the goals and objectives attained? How? If not, why?
No, not all objectives were completed. Objectives 1-3 were completed. Only Obj. 4 remains to be completed and the final manuscript can then be completed. The contract runs through Sept. 2001 and both Craig Busack and Curtis Knudsen are currently working on Obj. 4.

Were modifications made to the goals and objectives? If so, explain.
No changes in goals and objectives have been made.

Dissemination of project results – explain how the project results have been, or will be, disseminated.
A presentation was made at the IAC workshop in Feb. 2001. A manuscript for submission to a peer-reviewed journal is being drafted.

Citations:

Beamish, R, D. Noakes, G. McFarlane, L. Klyashtorin, V. Ivanov, and K. Kurashov. 1999. The regime concept and natural trends in the production of Pacific salmon. Can. J. Fish Aquat. Sci. 56:516-526.

Bigler, B. and J. Helle. 1994. Decreasing size of north Pacific salmon (Oncorhynchus sp.): Possible causes and consequences. Document submitted to the Annual N. Pac. Anad. Fish Com.

Fuss, H. and C. Ashbrook. 1996. Hatchery operation plans and performance summaries. Annual Report. Assessment and Development Program, WDFW.

Weitkamp, L., T. Wainwright, G. Bryant, G. Milner, D. Teel, R. Kope, and R. Waple. 1995. Status of coho salmon from Washington, Oregon, and California. NOAA Technical Memorandum, NMFS-NWFSC-24.

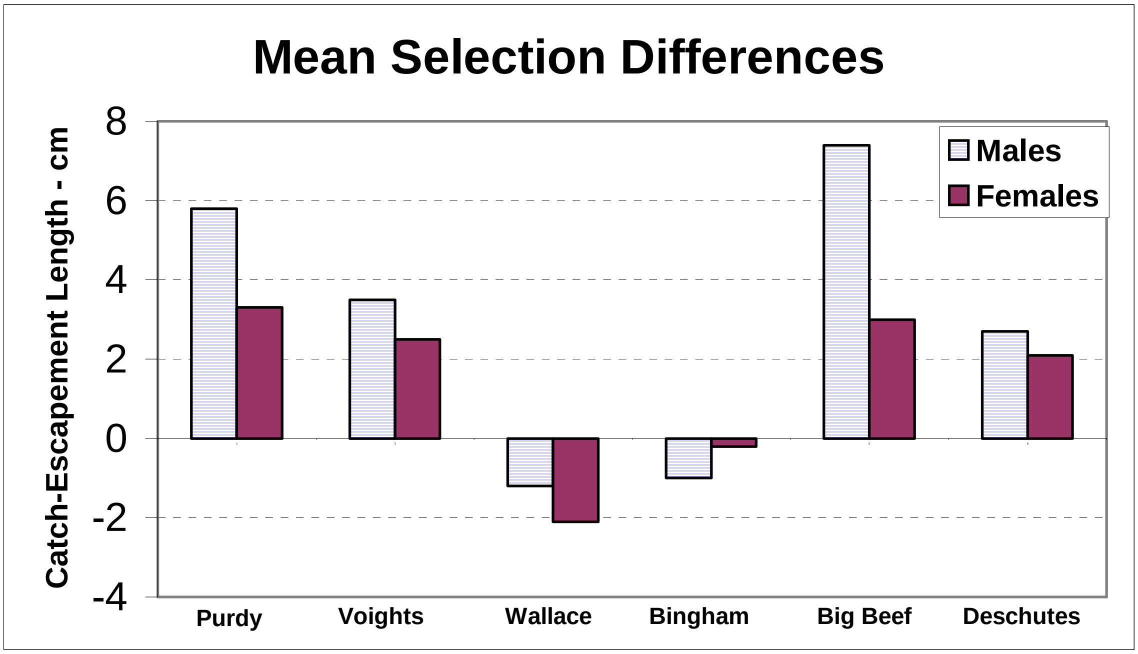

Figure 1. The average selection difference (mean catch length-mean escapement length) over all years by population. A positive value indicates a population experiencing selective removal of larger fish by the fishery.

Table1. The percentage of CWT recoveries by marine area from 1971 to 1989. The similarity in geographic distribution for the 4 populations indicates that they share common migration and rearing areas within the same marine areas. (Taken from Appendix Table C6, Weitkamp, et al. (1995).)

Hatchery	Area of interception				
	Alaska	BC	Wash	Oregon	Calif
Wallace R.	0.0	57.6	40.6	1.7	0.0
Purdy Cr.	0.0	39.2	59.1	1.6	0.0
Voights Cr.	0.0	50.7	47.9	1.4	0.0
Bingham Cr.	0.4	44.0	52.7	2.8	0.1

Table 2. Temporal trends (slopes) in length from 1978 to 1999 for six coho populations by sex estimate by simple linear regression. Significant trends (α=0.05) are indicated with an asterisk (*). H and W indicate hatchery and wild populations, respectively.

	Male trend (cm/year)	Female trend (cm/year)
Big Beef (W)	-0.32*	-0.27
Deschutes (W)	-0.26	-0.36
Bingham (H)	+0.32*	+0.13
Wallace (H)	0.00	-0.13
Purdy (H)	-0.44*	-0.37*
Voights (H)	-0.38*	-0.40*

Table 2. Temporal trends in mean annual fecundity at 4 hatchery populations from 1960 to 1999. Significant (α<0.01) trends are indicated by an asterisk (*).

	Fecundity trend (eggs/year)
Bingham Creek	- 1.3
Wallace River	-23.8*
Purdy Creek	-33.5*
Voights Creek	-42.1*

Table 3. Mean gillnet exploitation rates estimated as the ratio of the percentage of the total number of CWT recoveries taken in the gillnet fishery to the percentage in the escapement (taken from Fuss and Ashbrook (1996)).

	Terminal Gill Net %	Escapement %	Gill Net Exploit. Rate (TGN/E)
Voights H	54.4	9.2	85.5
Purdy H	32.4	23.1	58.4
Wallace H	17.4	27.9	38.4
Bingham H	13.0	N.A.	N.A.