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Estimating the relative abundance of juvenile coho salmon in the Strait of Georgia using trawls

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Abstract

A fixed survey design with a randomized depth component and a rope trawl fished at a speed of approximately 5 knots was used to establish the relative abundance of juvenile coho in the Strait of Georgia. The estimate of 3.6 million juvenile coho in September, 1996 was larger than the estimate of 2.8 million in September, 1997. The mean standardized catches in September 1997 were significantly smaller than in September 1996. These relative abundances were considered to be comparable among surveys as the catchability of the net was considered to be constant. The abundance estimates are probably higher as the catchability of the net was probably lower than used in this analysis. The minimal estimate of 3.6 million in September 1996 compares with an estimated total return of less than 500,000 in 1997. This indicates that the amount of fall/winter marine mortality is an important component of the total marine mortality that determines the final carrying capacity for the brood year. The use of surveys for juvenile coho can provide managers with measures of relative abundance, seasonal movement, and distribution and percentages of wild and hatchery fish up to a year in advance of any fishery.

Introduction

One method of assessing the abundance of stocks has been to find ways of collecting informative data, independently from information obtained from a fishery. For many species, fishery independent data come from standardized trawl surveys. These surveys frequently occur at the same time each year, in the same area and follow the same survey design. The stability of the survey design, the consistency of the statistical analysis and the general experience of both fishermen and biologists have shown that the surveys often provide useful indices of abundance. A problem with surveys is that the capability of the gear to capture fish (catchability) is difficult to quantify. In general, catchability is assumed to be constant and frequently all fish directly in front of the net opening are assumed to be captured. Despite these difficulties, surveys are a standard assessment tool for many species. A notable exception for North America is Pacific salmon stocks mainly because suitable gear has not been available to catch these near surface dwelling fishes. Prefishery salmon abundance surveys have been used in management by Russian scientists (Shuntov et al., 1988, 1993). Russian scientists conduct high seas surveys using several vessels that each fish rope trawls with openings of approximately 50m x 50m. The Russian trawl-based assessments are used to adjust forecasts based on estimates of the number of spawning females (escapements) and are an integral part in the management process. We believe that for some salmon species, such as coho, prefishery estimates of total abundance and relative abundance of hatchery and wild fishes will provide important management information, particularly when stock abundance and marine survival are low. Surveys are also useful to identify distribution changes. In this study, we use a smaller version of a standard midwater rope trawl (Beamish and Folkes, 1998). We present the result of these initial surveys to illustrate how these survey estimates of relative abundance can be used in management.

Methods

Trawl Specifications

The research vessel *W.E. Ricker* was used on all cruises except for September 19-27, 1997 when it was necessary to use the fishing vessel *Frosti* due to a mechanical failure of the *W. E. Ricker*. We compared the catch per unit effort (CPUE) of the two vessels for coho at depths from the surface to 45 m. A t-test for log_e transformed data did not show significant differences in CPUE (P=0.13) so the data from the two vessels were combined. The fishing gear used on both the *W.E. Ricker* and the *Frosti* was a model 250/350/14 midwater rope trawl built by Cantrawl Pacific Ltd., Richmond, B.C. When fished to design specifications the rope trawl has an opening of 21 m deep by 64.5 m wide. However the opening was smaller (approximately 14 m deep by 28 m wide) in our surveys because of the towing speed of approximately 5 knots used to catch salmon. The front end is 54 m long with large meshes that range from less than 2 m in width to over 3.8 m. The intermediate portion has meshes ranging from 1.6 m to 20 cm. The cod end has 10 cm meshes with a 1 cm liner in the last 7.6 m of the net. The net is held open with Model P USA Jet Doors that can be hooked up to fish at the surface or any depth. Door shoes weighing approximately 150 kg per door were removed during their use on the *Frosti.* The specified bridle length is 61 m, which we shortened to 30.5 m to fish the net at the surface. In addition, chains weighing approximately 200 kg apiece were attached at each delta plate joining the bridles to the warps. When the doors were at the surface, the headrope was between the surface and 3.5m, thus the net fished just below the surface. We were able to measure the net opening (height and width) by use of a backwards looking net sounder (Simrad FS3300). Data derived from the net sounder combined with bridge log data allowed us to calculate the volume of water sampled by estimating the average opening and measuring the distance trawled.

Survey Design and Sampling Dates

Preliminary surveys in the Strait of Georgia began in the late summer of 1996 and were used to study horizontal and vertical distribution of juvenile Pacific salmon. A fixed survey design, which is still experimental, was first used in September 1997 (Figure 1). The design provides full coverage of the Strait (including American waters) over a 10 day survey period. An alternative design would be to grid the Strait of Georgia with horizontal and vertical lines and then choose the intersections at random for sampling. This method would not insure that the stations would cover the Strait unless many strata were constructed and separately sampled to insure adequate coverage. It was felt that a more systematic design that covered the Strait would produce better results.

Figure 2 shows for the September 1997 survey, the average catch per unit volume plotted against station number. There is no relationship with station number and since the station numbers represent systematically changing locations there is not trend in density and location. It is believed therefore, that the assumptions of randomness in the sampling location is valid and no bias in the estimates due to sampling design is present.

The actual survey area of 5899km^2 is 93% of the published area of the Strait of Georgia (Thomson, 1994). Because it was difficult to fish in confined waters of the Gulf Islands area, we excluded this area from the survey. The survey design allows for the identification of seasonal and interannual changes in distribution so that they can be accommodated for in future survey designs. The surveys were designed so that all species of Pacific salmon could be studied. As chinook salmon tend to be deeper than coho, it was necessary to ensure that a series of depth strata were fished.

We report the results of five surveys in the Strait of Georgia: (i) late summer 1996 (September 9-20), (ii) late fall 1996 (November 4-15), (iii) early summer 1997 (June 17-July 11), (iv) late summer 1997 (September 8-27), and (v) early fall 1997 (October 17-November 1). In September and October of 1997, fishing depths were stratified according to densities observed in the preliminary surveys. In general, the density of juvenile salmon is greatest in the top 30 m, with few juveniles captured below 60m. However, the densities at deeper depths are difficult to measure as the net cannot be closed and theoretically could capture juveniles when it was lowered or brought back to the surface. We defined juvenile coho habitat depth by looking at the catch per unit effort (CPUE) at 15 m depth intervals and extending to the depth which had a CPUE that was at least 20% of the CPUE for all shallower depths. For example, if the CPUE from 30-45 m was greater than 20% of the CPUE from 0-30 m the habitat depth for that cruise would be defined as 0-45 m. If it was less than 20%, the habitat depth would be defined as 0-30 m. Generally, coho habitat depth was defined as 0 to 30 m, except for the September and October, 1997 cruises when it was 0 to 45 m.

Each day we attempted to complete four sets at 0 m to 15 m, three sets at 16 m to 30 m, and one set at one of the 31m to 45 m, 46 m to 60 m and 61 m to 75 m depth strata. Except for the first set of the day (which was at the surface) and one deep tow, the sequence of sets at the selected depths varied randomly each day. A survey of the Strait of Georgia was completed in 8-10 days with an average of 8 one hour sets per day and a minimum target of 60 fishing sets in one survey. Fishing operations were generally conducted 7 days a week between 06:00 and 18:00. This time restriction exists as a result of controls on the working hours of the deck crew.

Size and Condition

Differences in mean fork lengths in the September 1996 and 1997 surveys years were compared using a two sample t-test. Though not reported here, we did conduct a test survey using a beam trawl in September 1995 and used length data for comparison with 1996 and 1997. A condition factor (weight/length^3) was calculated for a sample of fish that were weighed at sea. We tested for differences in juvenile coho condition between September 1996 and September 1997 by a two sample t-test.

Abundance Estimates

Abundance estimates of ocean age 0 coho salmon within the Strait of Georgia were derived from an estimate of swept volume fished within (0m to 30m or 0m to 45m). The catchability of the net was assumed to be constant and that all juveniles in front of the net opening would be captured by the net. We believe that all fish in front of the net opening are not captured during a tow. Consequently, our catch is a smaller sample of the fish in the front of the net and our abundance estimates are probably minimal.

A preliminary assessment of standardized catch data indicated that coho were not evenly distributed, but were more abundant in the northern region. In order to meet the assumption of even distribution and to reduce sampling variance, the Strait of Georgia was divided into north and south regions that were used as separate areas for abundance estimates (Figure 1). The Strait of Georgia may differ ecologically in the north and south because the low salinity Fraser River plume plays a dominant role in the oceanography (Thomson 1985) and is largely confined to the surface waters of the south. In an attempt to recognize this possible ecological division, our regional boundary occurs above the mouth of the Fraser River and runs westward to the Nanaimo area (Figure 1).

For a whole Strait of Georgia estimate, a stratified random sampling estimate was constructed. Each region was treated separately and each abundance estimate was calculated as a stratified random sampling estimation:

$$C_h \;?\; N_h\overline{c_h} \;?\; \frac{V_h}{v_h}\bar{c}_h \qquad (1)$$

where,

C_h = the number of coho in stratum h

$\bar{c}_h$ = the average number of coho sampled in stratum h

V_h = the volume of estimated coho habitat in stratum h, where the north stratum volume (0-30 m) = 111.91 km^3 and the south stratum volume (0-30 m) = 65.01 km^3; the north stratum volume (0-45 m) = 167.86 km^3 and the south stratum volume (0-45 m) 97.52 km^3.

$\bar{v}_h$ = the average sample volume in the h^{th} stratum

v_{hi} = the volume of the i^{th} sample in the h^{th} stratum

v_h = the total sample volume in stratum h

$N_h = \frac{V_h}{\bar{v}_h}$ the total number of samples of size $\bar{v}_h$ in stratum h.

This estimate of abundance is similar to a ratio estimate where an abundance estimate is made for each sample, however here the abundance estimate for a whole stratum is based on the average sample volume and coho sampled within that region. A ratio estimate is most effective when the variance of the sampling volume is large, which is not the case in this study. Our stratified random sampling estimation allows for a more simple calculation of variance for the Strait of Georgia abundance estimate:

$$Var(C_S) = \sum_h N_h (N_h - n_h) \frac{S_{ch}^2}{n_h} \qquad (2)$$

where,

C_S=the estimate of coho for the Strait of Georgia

$S_{ch}^2 = \frac{\sum_i^{n_h} (c_{hi} - \bar{c}_h)^2}{(n_h - 1)}$ the h^{th} stratum coho sample variance

c_{hi} = the number of coho sampled in sample i in stratum h

c_h = the number of coho sampled in stratum h

n_h = the number of samples in the h^{th} stratum.

An interval estimate for the number of Strait of Georgia coho are estimated by:

$$C_S \pm 2\sqrt{Var(C_S)} \tag{3}$$

There are two models that could be assumed for the estimation procedure: (i) that the sampling was from an infinite population and the sample values could be modeled as values from a particular probability distribution such as the lognormal (the lognormal model might be chosen since the values are positive and skewed to the right) and (ii) to assume the sampling was from a finite population and finite population methods could be employed. The lognormal approach would have taken the logarithms of the catch per volume sampled and an estimate of the median catch per volume and its confidence bounds could have been calculated and expanded to the Strait of Georgia. To avoid trying to justify the lognormal distribution and to make the fewest assumptions, the finite population sampling method was chosen. The upper and lower bounds are plus and minus two standard deviations intervals and are not 0.95 confidence intervals used with the normal distribution. Although the confidence bounds do not necessarily cover the true population estimate with a prescribed probability, they do however, describe the variability of the samples collected in the surveys. All abundance estimates and confidence intervals were rounded off to the nearest 1,000.

We used a randomization procedure to assess the effect of sample size on the sample variance and the abundance estimate within each stratum. Since the September, 1997 cruise offered the most samples per stratum (n=57 in the north and n=37 in the south) we used this cruise as the data base from which random subsamples were selected. For each stratum, a subsample of size *s* was selected randomly with replacement and used to produce an abundance estimate. This was repeated for 1000 iterations. The number of samples per cruise in the north varied from 17 to 57, so we selected random subsamples of *s*=20, 30, 40 and 50. The number of samples per cruise in the south varied from 10 to 37, so we selected random subsamples of *s*=10, 20 and 30. For each stratum, the resulting distributions of 1000 abundance estimates per subsample were compared by a Kruskal-Wallis one-way nonparametric ANOVA since the distributions were not all normally distributed and transformations did not improve normality.

Hatchery Marked Coho

In 1997 only, approximately 60% of the coho salmon smolts released into the Strait of Georgia from British Columbia hatcheries had the left pelvic fin (LVC) removed (Beamish et al. 1998). As we caught these hatchery marked coho in our surveys, we were able to monitor the migration of juvenile coho out of the Strait of Georgia. In addition to sampling the Strait of Georgia, we also sampled the Juan de Fuca (which connects the Strait of Georgia to the open Pacific along the southcoast of Vancouver Island) in June/July 1997 and February/March 1998; areas along the West Coast of Vancouver Island in June/July 1997, October 1997 and February/March 1998; and in Puget Sound June/July and September 1997. The presence of hatchery marked coho in these areas provided information relating to the behaviour of coho.

Results

Catch Distribution

For the 5 survey cruises, the total catches of ocean age 0 coho ranged from 451 to 2571 and the catches standardized to one hour ranged from 9.6 to 53.2 (Table 1). Ocean age 1 catches are not reported but were extremely small and did not exceed 20 in any cruise. The low catches of ocean age 1 coho were considered representative of their actual abundance because virtually all ocean age 1 coho were outside of the Strait of Georgia (Beamish et al. 1998). The location of catches (Figure 3) shows that greatest densities are in the north.

Size and Condition

In September 1997, the mean length of coho was 244 mm (n=2402), which was significantly smaller (P?0.05) than the mean length of 251 mm (n=2186) in 1996. The condition factor of 1.164 x 10^{2} g · cm^{-3} for coho (n=173) in 1997 was also significantly (P?0.05) smaller than 1.215 x 10^{2} g · cm^{-3} for coho (n=911) in 1996. The length of coho caught in the beam trawl survey in September 1995 was 267 mm (n=524) and the condition was 1.255 x 10^{2} g · cm^{-3} (n=524).

Abundance Estimates

In general, we estimated a larger abundance of coho in the north region than in the south region (Table 2). This is both a reflection of the approximately double coho habitat volume of the north region compared to the south region and greater densities. As total abundance declined in 1996 and 1997 in October and November, the north and south abundance estimates were approximately equal. The abundance estimates for the north region exhibited large variance across sampling dates within a year. In both sampling years our north region coho estimates were greater earlier in the year (June and September) than later in the year (November and October respectively). The abundance estimates for the south region exhibited little variance across sampling dates within a year. The abundance estimate for June/July 1997 of 1,374,000 is lower than the September 1997 estimate because coho are probably entering salt water and moving from the shallow inshore areas into the deeper water where they are accessible to the survey. The coho abundance estimate made in September was lower in the north in 1997 than in 1996 (Table 2). The north region abundance estimates dropped approximately 24% while the south region abundance estimates, which were considerably smaller than the north, were approximately the same in both years.

Coho abundance estimates for the Strait of Georgia generally had narrow upper and lower confidence intervals, except for September of each year when the difference between abundance estimates in the north and south regions were very large (Table 2). In 1996, estimates of coho abundance in the Strait of Georgia decreased by approximately 80% from late summer (September) to late fall (November). In 1997, estimates of coho abundance in the Strait of Georgia increased by 52% from June to September, followed by a decrease of 67% in the October survey. Additionally, the abundance estimate of coho within the Strait of Georgia coho in September 1997 was 20% lower than the estimate for September of 1996. The mean standardized catches for all areas in September 1997 were significantly smaller (P=0.03) than in September 1996.

The Kruskal-Wallis one-way nonparametric ANOVAs on the abundance estimates derived from randomly selected subsamples in the north and the south were non-significant (P>0.05) indicating that the estimation of abundance is the same in all subsample sizes tested. For the north, there was no detectable difference in the distributions of abundance estimates for subsample sizes *s*=20, 30, 40 and 50. In the south, there was no detectable difference in the abundance estimate distributions for subsamples of size *s*=10, 20 and 30.

Movement of Hatchery Marked Coho

In June/July of 1997, the percentage of juvenile coho caught with the left ventral fin clipped (LVC) was 31% (Table 3). In all areas outside of the Strait of Georgia, no coho with a LVC were caught. By September, the percentage of LVC coho in the Strait of Georgia was approximately the same (30.2%). One coho with a LVC was found in Puget Sound. Because of the technical difficulties with the *W. E. Ricker*, we did not sample the Juan de Fuca Strait or off the West Coast Vancouver Island areas in September so we are unable to determine if coho migration to these areas occurred. However, the similar percentages of LVC coho in the Strait of Georgia in June/July and in September may indicate that there was no significant migration (or mortality) of coho out of the Strait of Georgia. The similar percentages does indicate that there was no selective migration of marked and unmarked fish. By October, the coho with a LVC in the Strait of Georgia were declining in percent (26.6%) and they began to show up off the West Coast of Vancouver Island (Table 3). By the February survey in 1998, virtually all juvenile coho had left the Strait of Georgia and the coho with a LVC were present in the Juan de Fuca Strait and off the West Coast of Vancouver Island areas.

Discussion

The June/July estimate in 1997 is probably lower than in September because large numbers of coho were still in areas that were not sampled by our net. The September samples appear to be a better index of abundance as coho were caught throughout the Strait of Georgia and the tagging information indicated that there was no selective movement of marked and unmarked coho out of the Strait of Georgia at this time. Our tagging and recapture data did not allow us to determine the amount of movement out of the Strait of Georgia in September. Because the percentage of hatchery fish in the Strait did not decline in September, we are estimating that the amount of movement was small. By November, coho abundance was reduced because of movement out of the Strait and possibly because of mortality.

We considered the abundance estimates to be minimal estimates because probably did not catch all fish directly in front of the net opening. In survey conducted by Russian scientists (Shuntov et al. 1988, 1993), the catchability of their gear was considered to be less than 0.5. However the net and fishing operations were different than in our survey. Thus we assumed a higher catchability to ensure that our abundance estimates were conservative. We also did not sample the Gulf Islands area and have not weighted the abundance estimates to include this area and several smaller areas excluded from the survey area. Including these areas and the coho deeper than our habitat depths would also increase the abundance estimates. There are other assumptions that may result in some overestimates of abundance such as our inclusion of near shore areas that may not contain coho juveniles, clumping distributions, or some herding effects of the warps. Despite these difficulties which are common to surveys, we feel that the surveys produce a useable index of abundance.

We are confident that our surveys are a random sample of the Strait of Georgia juvenile coho population. Our randomization procedure on the September 1997 survey illustrated that for varying sample sizes, the mean abundance estimate did not change significantly. Our look at catch per unit volume by location also confirms the randomness of our survey design.

We were not able to fish in Juan de Fuca Strait or off the West Coast in September 1997. By late October, 2.2% of the coho caught on the west coast of Vancouver Island had a left ventral fin clip. By February of 1998, the percentage increased to 6.5%. This indicates that movement out of the Strait of Georgia occurred after July, but we propose that much of the movement occurred after September as indicated by the low abundance in the Strait of Georgia in late October. The greater decline in population between September and November in 1996 than between September and October of 1997 may be the result of later fall survey dates in 1996, thus providing more time for the juvenile coho to migrate out of the Strait of Georgia.

An important observation is the relatively large abundances compared to the total returns. In 1996 our minimal estimate of 3.6 million ocean age 0 coho compares to the estimated total return of less than 500,000 coho in 1997. If, as we propose, 3.6 million is a minimal estimate, the actual abundance could be higher than 5 million if the catchability ranges between 0.5 and 1.0. Hatchery fish (US and Canadian) may represent approximately 77% (Beamish et al., 1998) of the coho smolts entering the Strait of Georgia. In 1996, Canadian hatcheries released approximately 8.5 million coho smolts into the Strait of Georgia. This means that the total juvenile coho abundance in 1996 could range from approximately 11 to 12 million individuals. Our estimates would indicate that by September of 1996 between about 35% (or higher depending on the actual catchability) of these coho were still present. This indicates that the fall/winter period is an important source of marine mortality in the regulation of brood year strength or carrying capacity. The possibility that fall/winter mortality is important has implications for management strategies attempting to restore and rebuild wild coho stocks, and should be highlighted so that the appropriate studies occur.

The declining mean size and condition is a concern as it indicates that ocean conditions not only remain less favorable for coho than in the past, but also that the impact may be worsening. The declining condition of coho may also be associated with the mechanisms causing the fall/winter mortality. The significantly lower mean standardized catch in September 1997 compared to September 1996 and the lower condition factors indicated that marine survival of juvenile coho stocks was less than in 1996. If the fall/winter mortality is as important as we propose (Beamish and Mankhen, 1998), and if the ocean environment in the winter of 1997/1998 was less favorable for coho than the winter of 1996/1997, the marine survival of Strait of Georgia coho in 1998 could be lower than in 1997.

These surveys currently supply an index of both abundance and condition of juvenile coho. The surveys can also be used to estimate the total “wild” smolt production. Wild as used here would mean non-hatchery production and would not imply that the coho are genetically distinct wild fish. The usefulness of the method will be proven if the index is an indicator of the final population size. The potential importance of these surveys cannot be overstated. Surveys for juvenile salmon in their marine environment are new and there is much to learn about the efficiency of the sample design. These initial surveys provide an excellent data base upon which to design future investigations. The important statistics are the variance of the catches, which range from 8235 in September 1996 to 60 in June 1996 and provide an excellent basis upon which to design future surveys. These surveys also provide abundance information for juvenile chum and chinook salmon that remain in the Strait of Georgia in the late fall. Indices of abundance are also available for pink and sockeye, although their resident time is shorter. We recognize that the existing time series is short, but we propose that these surveys provide useful data for the management of the Strait of Georgia salmon fisheries.

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Table 1: Total catch of juvenile coho (ocean age 0) and the average catch per hour (CPUE) from all depths.

Survey Date	Number of sets	Catch	Standardized catch/hour
September 09-20, 1996	62	2571	53.2
November 04-15, 1996	57	451	9.6
June 17-July 11 1997	69	523	13.6
September 08-27, 1997	112	2280	37.0
October 17-November 01,1997	58	625	11.4

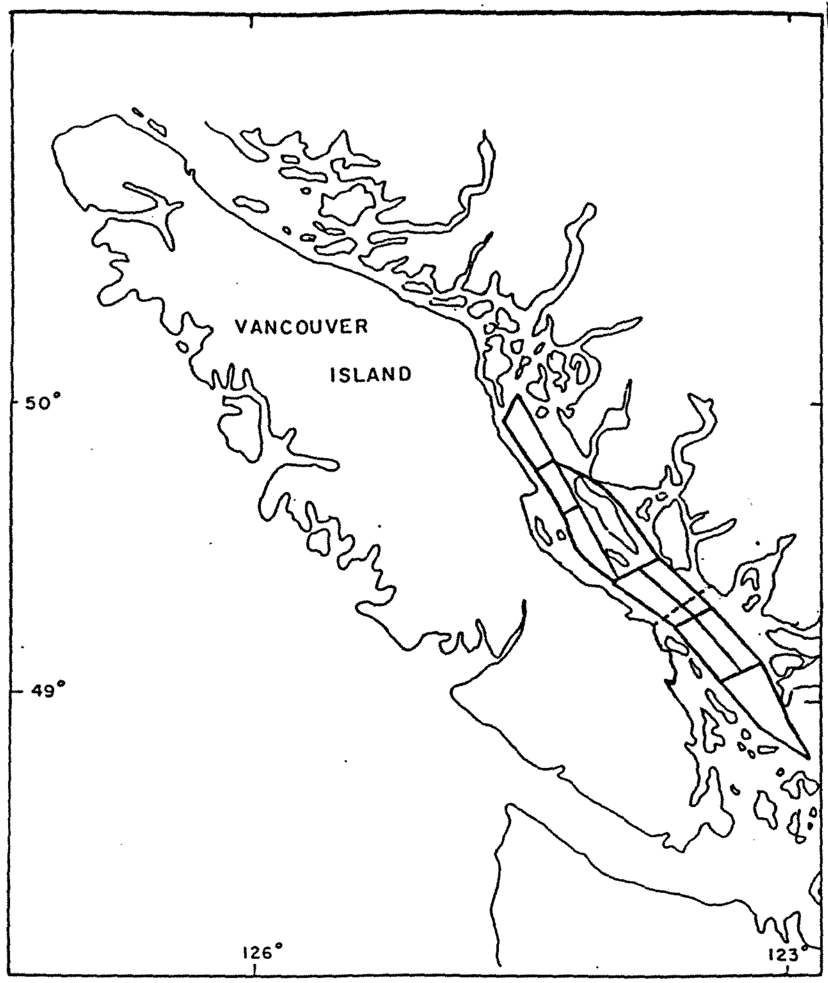
Table 2: Abundance estimates for coho in the north and south regions in Strait of Georgia and for the Strait of Georgia. Analysis based on tows in the top 30m during 1996 and June/July 1997, and the top 45m in September and October 1997.

	Sampling Date				
	Sept. 1996	Nov. 1996	June/July 1997	Sept. 1997	Oct./Nov. 1997
North					
Number of Tows	31	24	17	60	28
Abundance estimate	3,203,000	455,000	1,211,,000	2,451,000	658,000
South					
Number of Tows	11	10	28	36	20
Abundance estimate	363,000	295,000	163,000	389,000	284,000
Strait of Georgia					
Number of Tows	42	34	45	96	48
Abundance estimate	3,566,000	750,000	1,374,000	2, 840,000	942,000
Upper Interval	5,062,000	1,353,000	3,418,000	4,097,000	1,253,000
Lower Interval	2,070,000	340,000	330,000	1,583,000	631,000

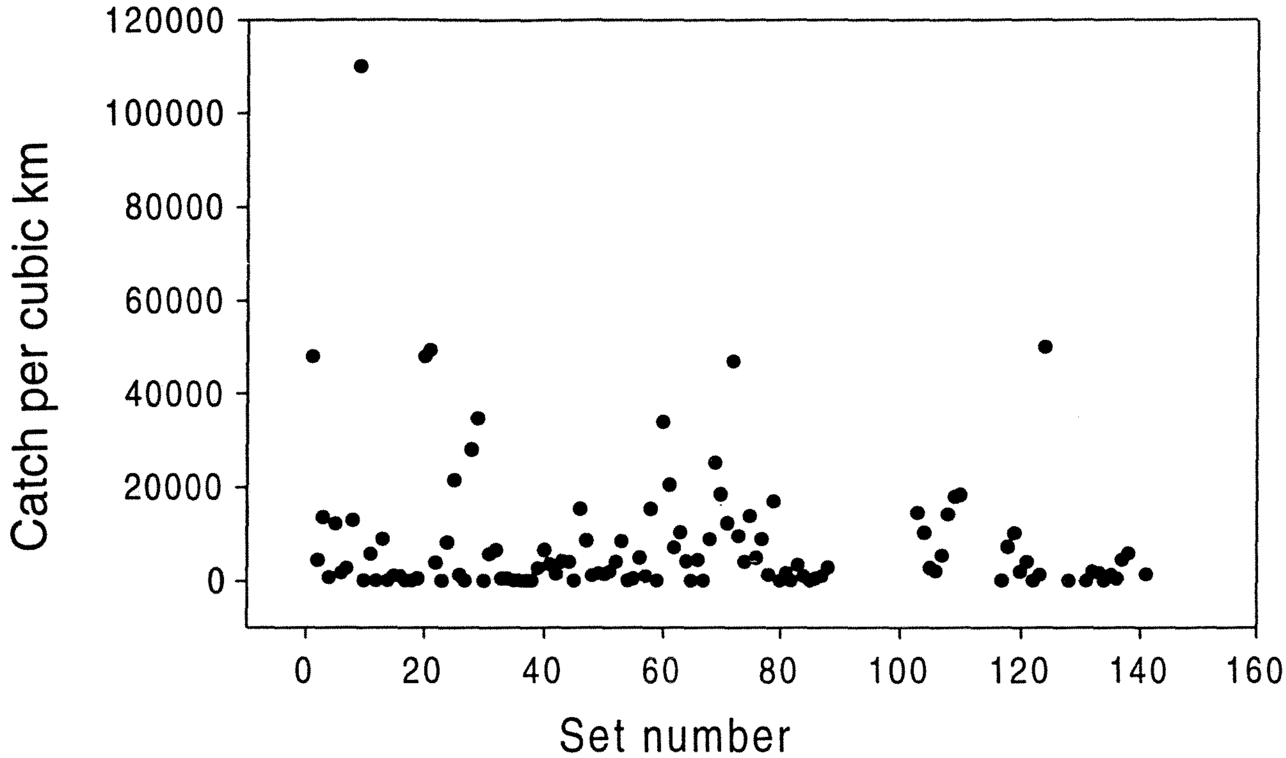
Table 3. Number of coho (*n*) and the percentage of left ventral fin clipped (LVC %) hatchery coho (LVC) caught in 1997 and 1998 surveys in the Strait of Georgia and the three areas outside of the Strait.

Survey Date	Strait of Georgia		Juan de Fuca		Puget Sound		West Coast	
	n	LVC %	*n*	LVC %	*n*	LVC %	*n*	LVC %
June 17 to July 10, 1997	523	31.0	226	0.0	1696	0.0	81	0.0
September 08-27, 1997	2280	30.2	-	-	69	1.4	-	-
October 17-30, 1997	625	26.6	-	-	-	-	685	2.2
February 10-23, 1998	1	0.0	478	6.1	-	-	960	6.5
March 04-07, 1998	14	7.1	121	1.65	-	-	538	4.5

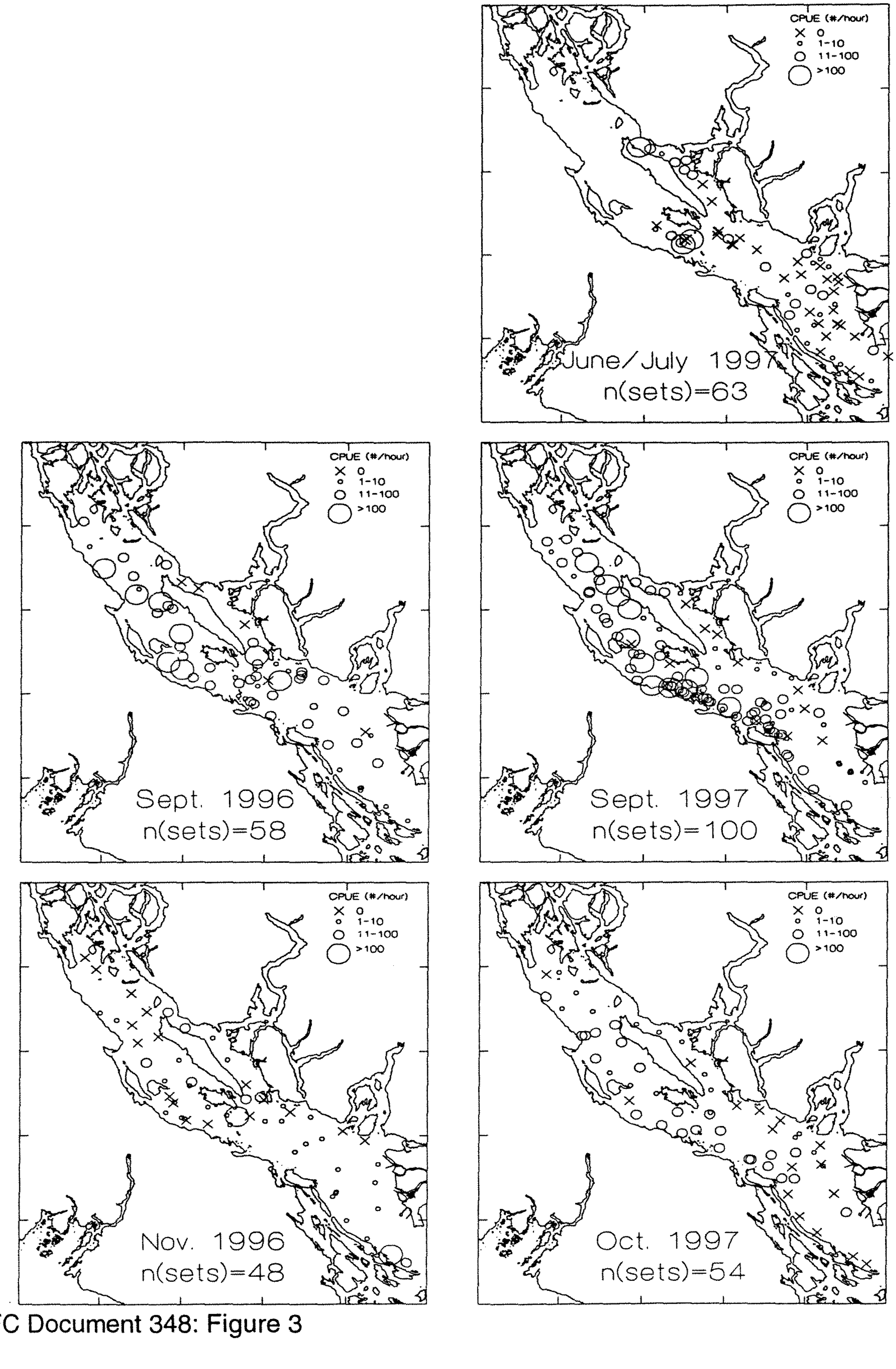
List of Figures



NPAFC Document 348: Figure 1



NPAFC Document 348: Figure 2



NPAFC Document 348: Figure 3