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# Estimating the Abundance of Juvenile Coho Salmon in the Strait of Georgia by Means of Surface Trawls

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*Abstract.*—A fixed survey design with a randomized depth component and a large rope trawl that fished surface waters at a speed of approximately 5 knots was used to estimate the abundance of juvenile coho salmon *Oncorhynchus kisutch* in the Strait of Georgia. The estimates of 4.2 million juveniles in September 1996, 3.0 million in September 1997, and 3.0 million in September 1998 were minimal because the catchability of the net was probably lower than that used in the analysis. In 1997, by using hatchery-marking percentages, we estimated that 3.4 million wild coho salmon smolts entered the Strait of Georgia from Canadian rivers. The estimates of juvenile abundance made in September 1997 were considerably larger than the estimated total returns in 1998, indicating that the marine mortality in fall and winter is an important component of the total marine mortality determining the final strength of the brood year. The use of surveys for estimating juvenile coho salmon abundance is a contribution to the understanding of the processes that regulate salmon abundance naturally and can potentially provide management information well in advance of any fishery.

One method of assessing the abundance of stocks has been to find ways of collecting informative data, independently from a fishery. For some species, fishery-independent data come from standardized trawl surveys (Wilkins et al. 1998). 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 (Ware and McFarlane 1995). A problem with surveys is that the capability of the gear to capture fish (catchability) is difficult to quantify. Catchability is often assumed to be constant and fish directly in front of the net opening are often assumed to be captured. Despite these limitations, surveys are a standard assessment tool for many species (Doubleday and Rivard 1981). Pacific salmon stocks are a notable exception, 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) to conduct high seas surveys in which trawls with openings of approximately 50 × 50 m are used. The Russian trawl-based assessments are used to adjust earlier forecasts of adult returns based on estimates of the number of spawning females (female escapements). We propose that for some salmon species, such as coho salmon *Oncorhynchus kisutch*, routine standardized surveys of total juvenile abundance can improve management by providing advanced warning of changing impacts of the marine environment on distribution and abundance, as well as the relative abundance of hatchery and wild (meaning nonhatchery production instead of genetically distinct wild fish) stocks.

## Methods

*Trawl specifications*.—The research vessel *W. E. Ricker* was used on all cruises except for 19–27 September 1997, when it was necessary to use the fishing vessel *Frosti.* We compared the catch per unit effort (CPUE) of the two vessels for coho salmon at depths from the surface to 45 m. The $\log_e$-transformed CPUE were not significantly different ($t$-test: $N = 112$, $P > 0.05$), so the data from the two vessels were combined. The fishing gear used on both vessels was a model 250/350/14 midwater rope trawl (Cantrawl Pacific Ltd., Richmond, British Columbia). When fished to design specifications the rope trawl has an opening 21 m deep by 64.5 m wide. However, the opening was smaller (about 14 m deep by 30 m wide) in our surveys because a towing speed of about 5 knots was used to catch salmon. The front end was 54 m long with large meshes that ranged from less

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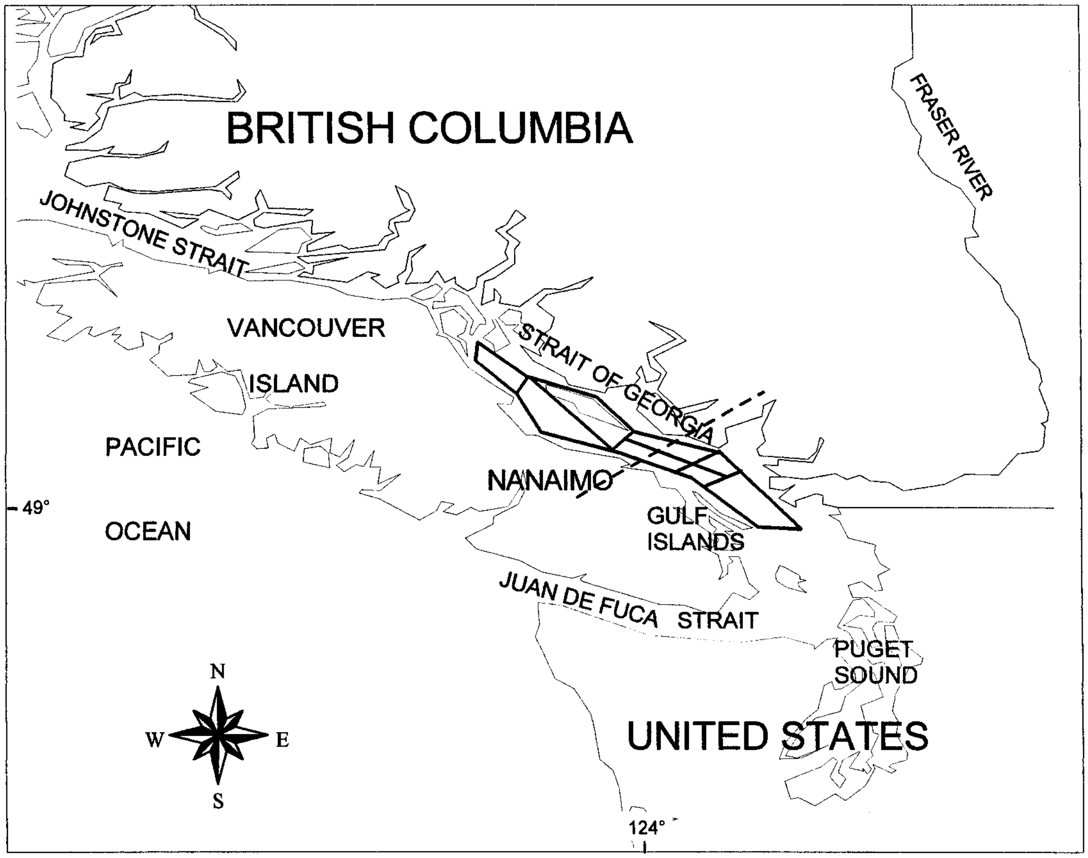


FIGURE 1.—The trawl survey sampling design used to estimate coho salmon abundance in the Strait of Georgia, British Columbia, in September 1996–1998. The track of the survey is shown as a solid line; the dotted line separates the north and south regions.

than 2.0 m to more than 3.8 m in width. The intermediate section of the net contained meshes ranging from 1.6 m to 20 cm. The cod end meshes were 10 cm with a 1-cm liner in the last 7.6 m of the cod end. The net was held open with model-P USA Jet Doors that could be fished 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 was 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 3.5 m, thus the net fished just below the surface. We measured the net opening (height and width) using 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 in late summer 1996 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 most efficient survey was to fish continuously along a tract, provided that the design did not introduce a significant sampling bias.

The actual survey area of 5,899 km$^2$ encompassed 93% of the total area of the Strait of Georgia (Thomson 1994) and excluded the Gulf Islands area (Figure 1) because it was difficult to fish in its confined waters. The survey design allows for the identification of seasonal and interannual changes in distribution that can be accommodated in future survey designs. The survey design enabled all species of Pacific salmon to be studied.

TABLE 1.—Mean catch (percentages of the total standardized catch) of ocean age-0 coho salmon standardized to 1 h for each 15-m strata for 1996–1998 and the mean for those years.

| Stratum (m) | 1996 | 1997 | 1998 | Mean |
|---|---|---|---|---|
| 0–15 | 94.5 (71) | 60.3 (55) | 47.3 (59) | 67.4 (63) |
| 16–30 | 19.1 (14) | 22.5 (21) | 23.4 (29) | 21.7 (20) |
| 31–45 | 12.1 (9) | 21.5 (20) | 8.0 (10) | 13.9 (13) |
| >45 | 6.9 (5) | 4.7 (4) | 1.3 (2) | 4.3 (4) |

Because chinook salmon *O. tshawytscha* tend to be deeper than coho salmon, a series of depth strata were fished.

Surveys were conducted in the Strait of Georgia during 9–20 September 1996, 8–27 September 1997, and 8–16 September 1998. In 1997, fishing depths were stratified according to catches observed in earlier surveys. In general, density of juvenile salmon was greatest in the top 45 m, the largest catch occurring in the top 15 m in all years (Table 1), although depth distributions varied somewhat among years. Catches deeper than 45 m accounted for 5% or less of the total catch. We therefore estimated coho salmon abundance at depths of 0–45 m within the Strait of Georgia. This was chosen as a probable habitat for ocean-age-0 coho salmon because for all three survey years the standardized catch for 0–45-m sets was at least 90% of the total standardized catch.

Each trawl set encompassed approximately 15 m of depth, strata being 0–15 m, 16–30 m, and 31–45 m. Each day we attempted to complete four sets at 0–15 m, three sets at 16–30 m, and one set at a deeper strata (31–45, 46–60, or 61–75 m) and one set >76 m. Except for the first set of the day (at the surface) and one set deeper than 75 m, the sequence of sets at the selected depths varied randomly each day. The 1996 and 1997 surveys of the Strait of Georgia were completed within 8–10 d, averaged eight 1-h sets per day, and had a minimum target of 50 fishing sets per survey. In 1998, we shortened the sets to 30 min to reduce the possibility of large catches of juvenile coho salmon because managers, who had closed fisheries to protect wild coho salmon, had expressed concerns. Fishing operations were generally conducted 7 d/week between 0600 and 1800 hours.

*Size and condition*.—Estimates of size and condition are included in this report because, in association with abundance estimates, they define the health of the juvenile population in their first marine year. Differences in mean fork lengths and mean weights were compared between years by analysis of variance (ANOVA). Condition factors (weight/length$^3$ $\times$ $10^2$) were calculated for a subsample of fish that were weighed at sea. All fish could not be weighed because catches were too large or ocean conditions were too rough. Differences in mean condition were tested using the Kruskal–Wallis nonparamentric ANOVA because condition factors in 1996 and 1997 were not normally distributed.

*Abundance estimates*.—Abundance of ocean-age-0 coho salmon within the Strait of Georgia was estimated using the volume fished between the surface and 45-m depth. We assumed that catchability of the net was constant and that all juveniles in front of the net opening were captured. However, all fish in front of the net opening were probably not captured, so our catch was probably less than the number of fish in the front of the net and our abundance estimates were probably low.

A preliminary assessment of standardized catch data indicated that coho salmon were not evenly distributed but were more abundant in the northern region. To meet the assumption of even distribution and to reduce sampling variance, we divided the Strait of Georgia into north and south regions and estimated abundance for each region. We divided the north–south regions by a line from the mouth of the Fraser River westward to Nanaimo (Figure 1) to account for possible ecological differences. 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 1981) and is largely confined to the surface waters of the south.

An estimate of coho salmon abundance in the entire Strait of Georgia was constructed as a stratified random sampling estimate. The north and south regions were treated separately and abundance in each area was estimated as a stratified random sampling estimate:

$$C_h = N_h\bar{c}_h = (V_h/\bar{v}_h)\bar{c}_h; \qquad (1)$$

$C_h$ = estimated number of coho salmon in stratum $h$;

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

$V_h$ = the volume of estimated coho salmon habitat in stratum $h$, where the north stratum volume = 167.86 km$^3$ and the south stratum volume = 97.52 km$^3$;

$\bar{v}_h$ = the average sample volume in stratum $h$; and

$N_h = V_h/\bar{v}_h$ or the total number of possible 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 number of coho salmon sampled within that region. A ratio estimate is appropriate when the variance of the sampling volume is large, which is not the case in this study. Our stratified random sampling allows a simpler calculation of variance for the Strait of Georgia abundance estimate, as follows:

$$\mathrm{var}(C_s) = \sum_h N_h(N_h - n_h)\frac{S_{ch}^2}{n_h}; \qquad (2)$$

$C_s$ = the estimate of coho salmon 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 salmon sample variance;

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

$c_h$ = the number of coho salmon sampled in stratum $h$; and

$n_h$ = the number of samples taken in the $h$th stratum.

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

$$C_s \pm 2\sqrt{\mathrm{var}(C_s)} \qquad (3)$$

The upper and lower bounds are plus and minus two standard deviations of the mean, but are not true 95% confidence intervals based on the normal distribution. Although the confidence bounds do not necessarily cover the true population estimate with a prescribed probability, they do describe the variability of the samples collected in the surveys. We rounded off all abundance estimates and confidence intervals to the nearest 1,000 coho salmon.

We used a randomization procedure to assess the effect of sample size on the abundance estimate and sample variance within each stratum. Because the September 1997 cruise provided the most samples per stratum ($N$ = 57 in the north and $N$ = 37 in the south) we used this cruise as the database from which random samples were drawn. For each stratum, a sample of size $s$ was selected randomly, with replacement, to produce an estimate of coho salmon abundance. This was repeated 1,000 times.

TABLE 2.—Abundance estimates for coho salmon in the north and south regions in Strait of Georgia in September 1996–1998 for a habitat depth of 0–45 m.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| North | | | |
| Number of sets | 39 | 57 | 43 |
| Abundance | 3,700,000 | 2,600,000 | 2,227,000 |
| South | | | |
| Number of sets | 13 | 37 | 32 |
| Abundance | 489,000 | 378,000 | 810,000 |
| Strait of Georgia | | | |
| Number of sets | 52 | 94 | 75 |
| Abundance | 4,189,000 | 2,978,000 | 3,037,000 |
| Upper interval | 5,881,000 | 4,261,000 | 4,407,000 |
| Lower interval | 2,498,000 | 1,693,000 | 1,667,000 |

The number of samples per cruise in the north ranged 17–57, so we drew random samples of $s$ = 20, 30, 40, and 50. The number of samples per cruise in the south ranged 10–37, so we drew random samples of $s$ = 10, 20, and 30. For each stratum, the resulting distributions of 1,000 abundance estimates per sample size were compared using a Kruskal–Wallis one-way nonparametric ANOVA, because the distributions were not normally distributed and transformations did not improve normality.

*Hatchery marked coho salmom*.—In 1997, 49.6% of Canadian hatchery-reared coho salmon entering the Strait of Georgia as smolts were marked by removal of the left pelvic fin, and a small fraction of these fish were also marked by removal of the adipose fin and insertion of a coded wire tag (CWT). Hatcheries in the USA released 70% of all the coho salmon smolts that entered Puget Sound, 17% of which were marked by removal of the adipose fin (Bill Tweit, Washington Department of Fish and Wildlife, personal communication). Thus, in 1997 hatchery-reared coho salmon released from U.S. hatcheries into Puget Sound could be distinguished from those released from Canadian hatcheries into the Strait of Georgia by the missing left pelvic fin. Numbers of hatchery and wild coho salmon were estimated for 1997 using these marks in conjunction with daily growth patterns in the otolith microstructure, as described by Zhang and Beamish (1994) and Zhang et al. (1995).

## Results

In all years, we estimated a larger abundance of juvenile coho salmon in the north region than in the south (Table 2), which is a reflection of the larger volume of the north. The abundance of coho salmon in the Strait of Georgia was highest in 1996

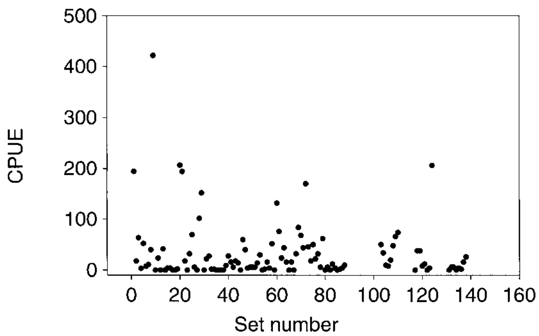


FIGURE 2.—Catch per unit effort (CPUE; number/h) of coho salmon in relation to set number for a survey in the Strait of Georgia, British Columbia, during September 1997. The set numbers represent systematically changing locations.

and lowest in 1997. The small increase in abundance in 1998 compared with 1997 reflects nearly a doubling in abundance of coho salmon in the south region and a small (9%) decrease in the north region (Table 2). Despite these differences, the estimates for the 3 years were not significantly different (ANOVA: $P = 0.27$).

The average CPUE of coho salmon was unrelated to station number (Kruskal–Wallis one-way ANOVA: $P = 0.25$; Figure 2). The station numbers represent systematically changing locations, so there is no relationship between density and location. The assumption of randomness in the sampling location appears valid and indicates that the estimates are not biased by the sampling design.

The sample size in each stratum was adequate for estimating abundance of coho salmon (Kruskal–Wallis one-way ANOVA: $P = 0.15$). For the north, abundance estimates of coho salmon for sample sizes of 20, 30, 40, and 50 were not significantly different. In the south, abundance estimates of coho salmon for sample sizes of 10, 20, and 30 were also not significantly different. Mean lengths of coho salmon were shorter in 1997 and 1998 than in 1996 (ANOVA: df = 5,724, $P < 0.01$). Condition factors of coho salmon were significantly lower in 1997 than in 1996 (ANOVA: df = 1909, $P < 0.01$) but were similar in 1996 and 1998 (Table 3).

### *Hatchery and Wild Coho Salmon*

Experimental fishing surveys in Puget Sound in the USA in June and July 1997 caught 1,696 ocean-age-0 coho salmon, of which 280 (17%) had a missing adipose fin (17.8% of these fish also had a CWT). Because all coho salmon missing an adipose fin (with or without a CWT) from U. S. hatcheries were from Puget Sound, it was possible to separate Puget Sound coho salmon in the catches in the Strait of Georgia. The number of marked Puget Sound coho salmon captured in the Strait of Georgia was expanded by the marked percentage observed in Puget Sound (17%). This produced an estimate of 14% for the Puget Sound ocean-age-0 coho salmon caught in the Strait of Georgia in 1997. Using this estimate, the number of Canadian-origin coho salmon in the Strait of Georgia in 1997 was estimated to be about 2.6 million, of which about 75% (76.6% using the marks, 72.5% using otolith microstructure) was estimated to be from Canadian hatcheries. The abundance of wild (i.e., nonhatchery production, not necessarily genetically distinct wild fish) coho salmon was estimated to be 0.7 million (25% of 2.6 million) in September 1997. Assuming a similar survival rate for wild and hatchery coho salmon from ocean entry to September, 25% of the coho salmon smolts entering in spring would also be of wild origin. Beamish et al. (1998) estimated that 10.1 million smolts were released from hatcheries into the Strait of Georgia in 1997. This indicates that the total number of smolts entering the Strait of Georgia from all Canadian sources was 13.5 million, of which 3.4 million were of wild origin.

## Discussion

The survey design described herein provides a method for estimating the abundance of ocean-age-0 coho. Using track lines, we are able to sample much of the Strait of Georgia along randomly selected depths of a grid pattern. Preliminary sur-

TABLE 3.—Mean ± SD (number of fish sampled) lengths, weights, and condition factors (CF = [weight/length$^3$] × $10^{-2}$) of ocean-age-0 coho salmon sampled in all September surveys and at all depths.

| Measurement | 1996 | 1997 | 1998 |
|---|---|---|---|
| Length (mm) | 251 ± 25 (2,185) | 243 ± 22 (2,277) | 244 ± 29 (1,251) |
| Weight (g) | 168 ± 64 (173) | 176 ± 57 (809) | 179 ± 73 (851) |
| CF | 1.21 ± 0.09 (173) | 1.16 ± 0.10 (809) | 1.22 ± 0.20 (851) |
| Total catch | 2,571 | 2,277 | 1,326 |
| Total sets | 62 | 112 | 92 |

veys allowed for the identification of different distributions between the north and south regions and indicated the need to stratify estimates to reduce sample variability. The number of sets that we were able to fish was sufficient to provide reproducible estimates of abundance. Our randomized survey procedure in September 1997 showed that mean abundance did not change significantly for varying sample sizes. The absence of a trend in CPUE with location also indicates that our samples were taken at random. While the survey is statistically sound, its most important feature is the capacity to provide early estimates of year-class abundance and biological information (e.g., condition) for the coho salmon population that may be used to predict marine survival and returns of Pacific salmon. Estimates of the total number of smolts entering the Strait of Georgia can be estimated using marked hatchery releases as a method of estimating wild smolt production. Escapement can also be estimated from fecundity and egg-to-smolt survival rates.

We provided minimal 1996–1998 abundance estimates for coho salmon in September of their first marine that suggest the final brood-year returns were determined in the fall and winter. We estimated that 13.5 million coho salmon smolts entered the Strait of Georgia in 1997. Our estimate of 3.0 million juvenile coho salmon, 2.6 million of which were of Canadian origin, indicates that at least 19% of smolts entering salt water in the spring survived until September. In 1998, there was virtually no fishing for coho salmon in the Strait of Georgia. Thus, the 315,000 coho salmon adults that returned in 1998 (Holtby et al. 1999) were subjected to only natural mortality and represented 7.4% and 18.6% of the upper and lower abundance estimates (4.261 and 1.693 million) of coho salmon from our survey. This indicates that natural mortality after the September survey ranged from 81.4% to 92.6%, which would have a major effect on brood-year strength. The total return of 364,000 coho salmon in 1997, including removals from fishing (Holtby et al. 1999), was slightly more than in 1998 but was consistent with the abundance estimate of 4.189 million in 1996 and 2.978 million in 1997. The 1997 and 1998 survey abundance estimates were virtually identical. If condition is also a factor in the rate of mortality after September, the better condition in 1998 than in 1997 may a 1999 return larger than the 1998 return.

There are about 970 coho salmon stocks in British Columbia (Aro and Shepard 1967) that are distributed throughout the rivers and streams of the province in a manner that makes coho salmon the most widely distributed of the Pacific salmon species in British Columbia (Milne 1964). An accurate assessment of the number of spawning coho salmon in these stocks is not possible, but Milne (1964) reported that, of the approximately 2.6 million coho salmon that spawn in British Columbia rivers, less than 10% are from the 10 most abundant stocks. Slaney et al. (1996) report 2,594 coho salmon stocks in British Columbia and the Yukon, which is the largest number of stocks of any of the species of Pacific salmon in British Columbia. Clearly, the aggregates in the ocean result from the production of a large number of stocks. These individual stocks are fished as aggregate stocks and, until recently, at relatively high exploitation rates of 65–80% (Department of Fisheries and Oceans, South Coast Division, Nanaimo, British Columbia, unpublished report, 1992). In a recent study of exploitation rates of coho salmon from nine streams, Labelle et al. (1997) determined an average exploitation rate of 80% each year and rates as high as 96% for some stocks.

One approach to assess the health of a stock and the impact of fishing has been to assess trends in abundance, including escapements, of selected stocks as an indication of general trends of associated stocks (Labelle et al. 1997; Simpson et al. 1997). These studies of selected stocks provide valuable information for management, but it is not known if a small number of key stocks or streams can reliably represent the dynamics of large aggregates of stocks and reliably forecast smolt production (Bradford et al. 1997; Labelle et al. 1997). Estimates of abundance of wild stocks in the ocean could be used to assess general trends in abundance. At a time when wild coho salmon abundance is at low levels, the abundance of aggregates of large numbers of stocks, compared with past trends, can provide information about the potential impact of fishing before fishing begins. Mortality during autumn and winter may also have implications for management strategies attempting to restore and rebuild wild coho salmon stocks. For example, in ocean conditions that are less favorable for coho, the appropriate management approach may not be to introduce more juvenile coho salmon but to structure hatchery releases to optimize summer and autumn growth rates.

The usefulness of our survey design will be proven if estimated abundance is a reliable indicator of final returns. Surveys of juvenile salmon in the marine environment are new, and there is much to learn about the efficiency of the sample design. Still, these initial surveys provide an excellent database upon which to design future surveys. These surveys also provide information on abundance of juvenile chum and chinook salmon that remain in the Strait of Georgia in late fall. Estimates of abundance are also available for pink and sockeye salmon, although their residence time is shorter. We recognize that the existing time series is short, but we believe that these surveys will provide useful data for the management of salmon fisheries in the Strait of Georgia, particularly for coho salmon.

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