Fisheries and Oceans Canada — Pêches et Océans Canada

Science — Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2003/107

Not to be cited without permission of the authors *

Document de recherche 2003/107

Ne pas citer sans autorisation des auteurs *

Analyses of juvenile surveys for recruitment prediction in the Strait of Georgia.

Analyses de relevés du hareng juvénile pour prédire le recrutement dans le détroit de Georgia.

D. E. Hay, J .F. Schweigert, M. Thompson, C.W. Haegele and P. Midgley

Fisheries and Oceans Canada
Science Branch
Nanaimo, British Columbia V9T 6N7

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at::

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed)

Canada

ABSTRACT

We estimated annual variation in the relative abundance of juvenile herring from purse seine surveys conducted from 1991 to 1999 in the Strait of Georgia. The objective was to evaluate the predictive capability of the surveys to estimate the relative size of the recruiting year class before it enters the fishery at age 3. In some years, a substantial part of the fished population (20-50%) consists of herring that recruit in the same year. Therefore such predictive capability would be useful as ancillary information for determining total allowable catches for the fishery. Purse seine surveys were made throughout the Strait of Georgia in September and October. Sets were made at ten fixed transects, each with about five fixed sampling stations that varied in depth and distance from shore. Juvenile herring in their first year of life (about 5-6 months of age) were the most common species captured, followed by age-1+ herring. Juvenile herring abundance changed significantly among years, but there were also significant inter-annual differences in abundance among different regions of the Strait of Georgia. For each year of the survey, we compared the numbers and weight of age-0+ juvenile herring catches with the number of age-3 recruits, of the same cohort, estimated independently 3 years later, from age-structured analyses used for the annual assessments. There are several alternate ways to consider these comparisons, each differing in the estimate of the annual juvenile abundance. In general however, all comparisons show a positive but variable relationship, with the juvenile index accounting for less than 50% of the variability in the recruitment index. The most aberrant data point, in an otherwise convincing regression of seven points, is the exceptionally abundant 1999 cohort, that recruited as age 3 herring in 2002. This was the second largest cohort seen since the 1954 cohort, which was only marginally greater. The troubling aspect of these juvenile surveys, therefore, is that they were unable to anticipate this exceptionally large cohort. At best, we would have anticipated only moderately good recruitment. However, we anticipate that additional data will allow further refinement and understanding of the predictive utility of the approach, as well as factors contributing to the variation. With further data collection and analyses we suggest that the results of the survey could become a key indicator of potential recruitment in the Strait of Georgia. Such a prediction could be made nearly two years prior to the recruitment and we comment on the potential of this approach for future use by management. We conclude the paper with a brief discussion of biotic factors that might have contributed to the strong 1999 cohort.

RÉSUMÉ

Nous avons estimé les variations annuelles de l'abondance du hareng juvénile grâce à des relevés à la senne coulissante effectués de 1991 à 1999 dans le détroit de Georgia. Nous avions comme objectif d'évaluer la capacité des relevés à permettre la prédiction de la taille relative d'une classe d'âge avant qu'elle soit recrutée à la pêche à l'âge de trois ans. Dans certaines années, une bonne partie de la population pêchée (de 20 à 50 %) est constituée de harengs recrutés la même année. Une telle capacité de prédiction offrirait donc de l'information supplémentaire utile pour déterminer le total autorisé des captures. Les relevés à la senne coulissante ont été effectués dans l'ensemble du détroit de Georgia en septembre et en octobre. Les mouillages de senne ont été effectués sur dix transects fixes comprenant chacun environ cinq stations d'échantillonnage fixes qui variaient quant à leur profondeur et à leur distance de la côte. La classe d'âge la plus abondante dans les captures était le hareng juvénile 0+ (âgé d'environ 5-6 mois), suivi du hareng 1+. L'abondance du hareng juvénile a varié significativement d'une année à l'autre, mais il y avait aussi des différences interannuelles significatives entre différentes régions du détroit de Georgia. Pour chaque année du relevé, nous avons comparé l'abondance et le poids des prises de harengs juvéniles 0+ à l'abondance des recrues de 3 ans de la même cohorte estimée trois ans plus tard, de façon indépendante, à partir des analyses par structure d'âge utilisées dans les évaluations annuelles. Il y a plusieurs façons d'effectuer ces comparaisons, chacune différant quant à l'estimation de l'abondance annuelle des juvéniles. Mais, en général, toutes les comparaisons montrent que la relation est positive mais variable et que moins de 50 % de la variabilité de l'indice de recrutement est attribuable à l'indice d'abondance des juvéniles. Une régression effectuée sur sept points de données est très convaincante si l'on ne tient pas compte du point aberrant que constitue la cohorte exceptionnellement forte de 1999 qui a été recrutée à l'âge de 3 ans en 2002. Il s'agissait de la deuxième plus forte cohorte observée depuis celle de 1954, qui était à peine plus forte. Ainsi, ce qui est troublant avec ces relevés des juvéniles, c'est qu'ils n'ont pas permis de prévoir cette cohorte exceptionnellement forte. Au mieux, nous n'aurions prévu qu'un recrutement modérément bon. Toutefois, nous prévoyons que des données supplémentaires permettront d'améliorer et de mieux comprendre la capacité de prédiction de la méthode et les facteurs qui contribuent à la variation. Nous croyons qu'avec davantage de collecte et d'analyses de données, les résultats du relevé pourraient constituer un indicateur important du recrutement potentiel dans le détroit de Georgia, et ce, presque deux ans avant le recrutement. Nous commentons le potentiel de cette démarche pour son utilisation par les gestionnaires et concluons par une brève discussion des facteurs biotiques qui pourraient avoir contribué à la forte cohorte de 1999.

INTRODUCTION

In British Columbia, most herring join the sexually maturing population at age-3, so the number of age-3 fish is an approximate estimate of recruitment (Hay and McCarter 1999). In some years, this age group represents as much as 50 percent of the population. Current stock assessment methods (Schweigert et al. 1997) estimate the numbers and biomass of fish *after* they have joined the spawning stock. However, they do not provide reliable estimates of recruitment of 3-year-olds *before* they join the adult component of the population. Previous attempts to predict recruitment examined a variety of environmental indicators in conjunction with population dynamics (Stocker and Noakes 1988, Schweigert and Noakes 1991) but the uncertainty associated with these procedures is high.

A different approach to recruitment prediction is the empirical estimation of the absolute or relative abundance of a cohort at an earlier life history stage. It is evident that the earliest life history stages are not useful as predictors or recruitment. For instance, each year, surveys of Pacific herring spawn deposition provide estimates of the numbers of eggs that could develop into the cohort recruiting in three years. It has long been recognized that this is not a reliable predictive measure of future recruitment, although spawn surveys provide an after-the-fact index of spawning stock size. Similarly, estimates of larval abundance are poor predictors of future abundance because of the substantial mortality that occurs at egg and larval stages. Surveys of older stages, such as the young of the year, offer some hope that surveys of juveniles may be related to the size of the recruiting year class and this approach has been attempted elsewhere (Koeller et al. 1986). This paper compares the estimated abundance of juvenile herring in the Strait of Georgia, with the independently-estimated abundance of the corresponding age 3-cohort, as estimated from an age-structured model. The predictive utility of these comparisons as a method of recruitment prediction is discussed. We briefly discuss this method in the context of the life history of herring, specifically their spatial variation and seasonal migrations that may limit, or confound, our attempts to predict future recruitment.

METHODS

Fishing methods and catch sorting

A purse seine net, 220 m long and 27 m deep, with marquisette webbing in the bunt that would retain fish > 3 cm (standard length), was fished from 11-12 m Fisheries and Oceans research vessels (Keta, Tahlok and Walker Rock). This net sampled an area of 3851 m^2. The fishing techniques, such as the velocity of pursing and drumming of the net, were as uniform as possible within and among cruises, although some variation occurred because of variation in wind and tidal currents.

Catches were landed, sorted by species, weighed and samples of herring and salmonids preserved in seawater formalin. In general, one transect was sampled per night and seine sets were completed about one hour apart, hence transects were generally sampled over a 4 hr period. The time between landing and preservation was 5-15 min and most fish were alive or recently dead at the time of preservation.

In the laboratory, fish were measured for standard length (mm) and total weight (gm).

The weight of the total catch for each species was estimated on board the vessel. This included estimating the total catch weight separately for each juvenile herring age group (age 0+, 1+ and 2+ herring). In practice it was not difficult to separate each size/age group of herring on deck, as the sizes are distinctly different. Some age 2+ herring, however, may have consisted of several age groups: from age-2+ and greater. Except for small catches, where counts of individuals could be made directly, the numbers of juveniles captured in each set was calculated by dividing the total catch weight by the age-specific mean weight of sub-samples from each set, as determined during post-cruise laboratory analysis at the Pacific Biological Station, Nanaimo. The maximal number of herring from each age class examined from each set was 200 fish (Haegele 1997).

Survey rationale, design, and data analysis

Ten transects were established at approximately equal intervals around the perimeter of the Strait of Georgia (Fig. 1). Transects were located in open coastal areas and channels. Open coast transects (numbers 1, 3, 5, 9, and 11) were perpendicular to shore with five stations approximately 1 km apart, and starting approximately 600 m from high water in about 15 m depth. Channel transects (numbers 2, 4, 6, 8, and 10) were established 'across channels', with the outer stations approximately 360 m from high water in 15 m depth. For each of these transects there was a mid-channel station, one station between each outer and mid-channel station, for a total of five stations. Channel stations were about 1 km apart. Each transect had three-five sampling stations that varied in depth (Table 1) with the most shallow varying from 5-10 m and the deepest being greater than 200 m (Table 2). A total of 427 sets were made, mainly in mid-September (Table 3). Two surveys were made in 1991, one in late August and early September and another in late September and early October. No survey occurred in 1995.

The original assessment of juvenile surveys (Hay et al. 1996, 1997) examined both catch weight and numbers of age-0+ and age-1+ juvenile herring, in spring and fall surveys, as potential predictors of herring recruitment. The analysis presented here focuses only on the estimate of the weight of age 0+ herring captured during the purse seine surveys. The catch weight was viewed as the most unbiased indicator of the relative abundance of juvenile herring. During the review of the set logs for these surveys, to include the time of set in the database, a few small, but un-resolvable errors were detected from several stations. These data were deleted from the dataset that had been used in the earlier analysis. Consequently, estimates of the means presented here may differ slightly from those reported previously. For simplicity, and to retain continuity with the earlier analyses only the data from the ‘core’ transects were included in this analysis.

Estimates of juvenile herring abundance from seine surveys

The estimates of 0 group catch weight for the transects and stations were analysed in two ways to determine their variability. First, the individual stations were treated as random samples from the distribution of all possible herring seine sets. This implies a random distribution determined by the mean and variance. In this instance, the variance was determined both analytically and by bootstrapping the individual stations. Secondly, to estimate the mean and variance of the data (again assuming an underlying normal distribution) the transects were treated as a first stage of a 'two-stage sampling design', with the stations within each transect treated as the second stage of sampling. The mean and variance for this analysis is estimated by:

$$\overline{y_i} = \sum_{j=1}^{m} \frac{y_{ij}}{m}$$ = sample mean per m stations in the i th transect

$$\overline{\overline{y}} = \sum_{i=1}^{n} \frac{y_i}{n}$$ = over-all sample mean per station across all n transects,

and the variance of $\overline{\overline{y}}$ is given by:

$$V(\overline{\overline{y}}) = \frac{S_1^{\ 2}}{n} + \frac{S_2^{\ 2}}{m}$$

where,

$$S_1^{\ 2} = \frac{\sum^{n} (\overline{y}_i - \overline{\overline{y}})^2}{n-1}, \qquad S_2^{\ 2} = \frac{\sum_i \sum_j (y_{ij} - \overline{y_i})^2}{n(m-1)}$$

The analyses were repeated for the data transformed to natural logarithms with 1 added to account for stations with zero catches. This analysis assumes an underlying lognormal distribution for the sampling data. A number of other distributions were examined for these data (Poisson, binomial, and negative binomial) but there was no evidence that they fit better than a simple normal or lognormal distribution. Recently, Schnute and Haigh (2003) have proposed a compound binomial-gamma distribution for these types of data. However, the moment estimator for the mean of this distribution is identical to that for the normal distribution presented here.

Estimates of recruit (age-3) abundance from annual assessments

The juvenile surveys that began in 1990 focussed on the age-0+ cohort that recruited as three-year-old herring in 1993. Therefore for each year the abundance of age-0+ herring in year *n* was compared to the estimated abundance of age three herring in year *n+3*. The estimated numbers of 3-year-old herring were taken from the published annual stock assessment documents (i.e. see Appendix Table 2.4 in Schweigert 2002). These numbers change slightly each year, as new data are added to the data set and model parameters are re-estimated. To assess the effects of the addition of new data to the model estimates of uncertainty in the number of age 3 recruits were calculated from the likelihood profiles for each year from 2002 (1999 year-class) back to 1994 (1991 year-class) by successively re-running the model and calculating the likelihood profile for each recruiting age-class independently. In addition, the likelihood profiles were also calculated retrospectively by removing the 2002 data, calculating the 95% confidence interval for the 1998 year-class, removing the 2001 data, and calculating the 95% confidence interval for the 1997 year-class, etc.

Forecasting models

The distribution of the juvenile survey data and the age-structured model estimates of the age-3 recruits suggested that a non-linear relationship is probable. Therefore, we fit linear models to the log transformed data for the 1991-1998 and 1991 to 1999 periods and used the resulting model to forecast age-3 recruits for each year of the time series. The recruitment forecasts were then cross referenced to the age structured model estimates of age-3 recruits from the 2002 assessment and assigned a poor, average, or good ranking. The rankings were then compared to the actual observed year-class sizes.

RESULTS

Sampling results

The ten key or 'core' transects were sampled consistently in early September over the ten years of the surveys except for 1991 when two surveys were conducted, just prior to, and following the sampling period of subsequent surveys. Consequently, data from both 1991 surveys were included in the analysis. During the 1997-1999 period only 3 stations were sampled on each transect. Catch weights for age-0+ herring varied between zero and a maximum of 1011 kg, median weights are also presented for comparison (Table 4). The spatial and temporal variation in catch weight, examined by ANOVA, was significant. Catches were lower at sampling stations with deeper depths (Table 5).

The untransformed catch data are not normally distributed. Most of the catches occur at the low end of the distribution, including a small number of zero catch stations in all years from 1991 to 2001 similar to a lognormal distribution (Fig. 2). Although log-transformed estimates of 0-group catches prior to 1997 are not clearly normal, catches from 1997 to present appear to be approximately normally distributed (Fig. 3).

Intra- and Inter-annual Variability

Recent discussions of preliminary analysis of juvenile catch data have raised questions about intra- and inter-annual variability and the most appropriate configuration of data to use as an index of juvenile abundance. For instance, we are aware that herring distributions are not static. Herring undergo strong diel changes in depth. This diel movement, combined with tidal action can result in rapid changes in vertical and horizontal distribution, even within the same day so small differences in timing of catches at each station could affect the results. We also are aware that catches may change with lunar periods (Tester 1938) and that the timing of cruises, relative to lunar and tidal periodicity, changes among years. Therefore, in theory, even with identical levels of herring abundance, catches at individual stations could vary substantially, within a 24-hr period, and among years. For this reason, we speculated that it may be preferable to pool catch data for each transect, and treat the transect as the smallest sampling unit instead of the station. To address this issue, we investigated two effects on the uncertainty in the individual juvenile survey estimates using bootstrapping and using two stage sampling. The results, when comparing the estimated mean 0-group abundance for simple random sampling versus a two-stage sampling, are nearly identical (Fig. 4, top panel). The variation around the means, however, is substantially different. The two-stage estimate of variance is much greater than the bootstrap estimate particularly for years 1997-1999, when only 3 stations were sampled along each transect. The large within-transect variation in these years results in a high estimated total variance.

Analysis of the extent of variation in the estimated age-3 recruits from age-structured analysis (Fig. 4, bottom panel) indicates that a relatively small change could occur in future estimates of age-3 recruits. Except for the 1993 cohort, however, the changes probably would not be significant. The status of the apparently exceptional 1999 year-class remains uncertain but it will probably not change substantially with the addition of new years of data. If we accept that estimates of age-3 recruits are unlikely to change substantially over time then it is reasonable to use these data as a basis for recruitment prediction from juvenile survey estimates.

Recruitment predictions and management implications

There is a trend for recruitment to increase and the index of juvenile abundance to increase (Fig. 5). Although the relationship may be approximately linear, the 1999 point (1999 juveniles versus age recruits in 2002) appears to be an outlier. The same pattern is seen when the juvenile abundance estimates are determined from a two-stage sampling design (Fig. 6). This may be indicative of a possible negative binomial distribution for the data of which the logarithmic is a special case.

Estimates of the mean weight of juvenile herring catches for each year are presented in Table 6 both for the untransformed and log transformed data with confidence bounds or estimated standard deviations. Corresponding estimates of the age-3 recruits from the 2002 assessment and from a retrospective analysis with 95% confidence limits are presented in Table 7.

In Figure 7 the log transformed estimates of the number of age-3 recruits and 0-group herring abundance are plotted together with the best fit linear relationship and the 95% confidence bounds on the line. The best fit relationship is:

$$\text{Ln(Age 3 No.)} = 7.7362 + 0.2308 \text{ Ln(wt. of 0 group herring)} \qquad (1)$$

The relationship is nearly significant (p = 0.058 with an r^2 of 47.6 percent. Although the relationship appears reasonable, the 1999 data point seems to be an outlier. The same best fit analysis, with the 1999 data point excluded, is significant at the 0.032 level with an r^2 of 63.48 percent:

$$\text{Ln(Age 3 No.)} = 7.7541 + 0.2094 \text{ Ln(wt of 0 group herring)} \qquad (2)$$

To investigate the management implications of these data, predictions of the estimated age-3 recruits were made from these two relationships and are presented in Table 8. The predictions were then compared against the age-structured model estimate of historical recruitment which were arrayed from highest to lowest, divided into thirds and ranked either as good, average, or poor. The ranking was done both for the entire data series and also for only the roe fishery period. The rankings for the two time periods are identical. The breakpoints between poor and average are 2800 and 2400 for the 1951-2002 and 1971-2002 periods, respectively. The breakpoints between average and good are 6100 and 6000, respectively. Although the predictions seem to be quite good, it should be noted that this is expected since the data were used to fit the model. A better test of the predictive accuracy would be achieved by bootstrapping or jack-knifing the data and then comparing the forecasts to the observed estimates. A true test will be to observe the predictions for the 2000 and 2001 year-classes.

DISCUSSION

Biological assumptions of juvenile surveys as predictors

Most purse seine sets captured age-0+ herring in all areas in the Strait of Georgia. The purse seine sets described in this report were 'set blind' or made without any reference to acoustical targets or other indications of the presence of herring. This corroborates earlier observations by Hourston (1957) and subsequent reports by Haegele (1995, 1997) that juvenile herring are ubiquitous in the Strait of Georgia. The surveys also confirm that juvenile herring distribution and density varied substantially. Total catch of age-0+ juveniles varied among sampling stations by several orders of magnitude - from zero to tens of thousands of fish - although there were few ‘zero’ catches. Sometimes other species, particularly juvenile salmonids, were abundant and may have displaced or reduced local herring densities.

A fundamental assumption for juvenile surveys, as a basis for forecasting recruitment, is that the sampling design provides an unbiased relative index of the abundance of juvenile herring. Clearly, there were geographic differences in catch size so there is a risk that inter-annual differences may be related more to annual differences in juvenile spatial distribution, than abundance. As there appear to be significant inter-annual changes in distribution of age-0+ juvenile herring, we cannot rule out this possibility that factors other than abundance will affect the estimates of catch size.

There is an *implicit* assumption about the time of migration of juveniles form the Strait of Georgia. The time of the migration of juvenile herring, from Georgia Strait, to elsewhere, has long been a debating point among local herring biologists. Some argued that herring left during their first summer - based on their direct observations of massive schools of small herring migrating seaward in the Strait of Juan de Fuca (L. Webb. pers. comm). Others noted that the presence of small herring taken for bait, and routinely found in salmon stomachs, was evidence of retention in the Strait. The juvenile surveys conducted throughout the summer (Haegele 1997) provide the best evidence that many herring over-winter in the Strait of Georgia and spend some of their second summer there. These same surveys, however, indicate that the abundance of herring declined towards the end of their second summer. Presumably, most migrated out of the Strait or to areas where they were not vulnerable to the seine gear.

Based on tagging data and offshore survey analyses, we assume that many herring from Georgia Strait migrate to the west coast of Vancouver Island where they feed offshore, and presumably, mix with herring from other locations, such as the west coast of Vancouver island, and spawning areas in American waters. We further assume that these herring return as spawning adults to the Strait of Georgia. There is now a substantial data base from herring tagging, and other studies that support this (Hay et al. 2001), but we cannot always be certain that all of the herring which originate in Georgia Strait return, or vice versa.

Quantitative analysis of juvenile and recruit data

The data collected from the seine sets was not normally distributed. A simple log transformation provided a reasonable approximation to a normal distribution. The non-normal distribution of fish catch data has been noted by many authors and a variety of assumptions about distributions have been proposed but no clear consensus is evident.

Estimates of variation in the data indicated a high degree of variability both within and between transects as determined by the two-stage analysis. Bootstrap estimates of variation also showed a high degree of inter-station variation with the coefficient of variation approaching 100 percent of the mean in many years. The estimated variation in the age-3 recruitment estimates from the age-structured analysis was substantially less than the variation in the sampling data. Interestingly, there was no evidence of substantial changes in these estimates over time.

Bivariate plots of un-transformed age-3 recruitment and juvenile herring data suggest a positive but weak relationship but with a high degree of uncertainty about the position of the 1997 and 1998 cohorts. Also, the 1999 cohort is an outlier relative to other surveys from other years. The two-stage analysis also raises some uncertainty about the 1991 data which is a composite of 2 separate surveys (one done slightly earlier, and another slightly later, than the survey times of other years. If the 1999 data point were excluded, the result is a positive association between the juvenile survey data and the age-3 recruitment estimates (Fig. 5 and 6). Transformation of these data (Fig. 7 and 8) indicates a more convincing relationship between these two variables which is significant at the 6% level for all 8 data points and significant at the 3% level without the 1999 data point. We also see that the relationship between these two variables is stable, even with the addition of the 1999 data point. The inclusion of the 1999 data point, while decreasing the significance of the fit to the data did not markedly change the model predictions of age-3 abundance or their ranking (good, average, poor) as shown in Table 8. The data available to date suggest that a positive relationship exists between juvenile herring abundance and resulting age-3 recruits to the fishery that should be confirmed with additional surveys. An outstanding question is why the 1999 year-class is an outlier to this function. At this point no obvious explanations are forthcoming but further investigation of these is warranted.

Implications for management

The results surveys indicate that the surveys have promise as approximate predictors of recruitment. The utility of the prediction would be to provide guidance, 1-2 years prior to the fishery, about the approximate size of the recruiting cohort: whether it will be poor, average, or good. The range of recruitment variation within each of these categories is broad, so some error is accounted for. Nevertheless, the results in Table 8 suggest that predictions could be correct 75% of the time (6 years out of 8). We recognize, however, that the data used to establish such a relationship are the same data used for the test so there is circularity in this analysis. There are alternate tests: a series of bootstrap or jack-knife analyses could be completed to assess the true predictive accuracy of this model. There are only eight data points at the present time, however, so we believe it is premature to recommend this model for fisheries management. Instead we propose to forecast recruitment for the incoming 2000 and 2001 year-classes to confirm its utility.

In this regard, the (natural) logarithm of the 2000 juvenile survey herring, based on the mean of the data from all stations is 6.76. Based on the relationship shown in Fig. 7, the corresponding estimate of age-3 recruits would be 9.30. On an arithmetic scale, this would be 1.09 billion (1,090,000,000) age-2 recruits. This is only about half the size of the estimated 1999 cohort, but still sufficient to be classified as 'good' recruitment.

The potential utility of the apparent relationship between the estimates of juvenile abundance (especially catch weight) and subsequent cohort size, would be for predicting the approximate size of the recruiting cohort (age-3). Presently, there are no reliable prediction methods available, but if there were, the benefits would be substantial, even if the prediction were accurate only to a 3-tiered range: poor, average or good. Reliable prediction of 'poor' recruitment would provide a risk averse method for adjusting annual catches. It also follows that there could be significant benefits to the fishery when good recruitment could be anticipated. Such a 3-tiered approach could be readily incorporated into the present stock assessment process.

Although the relationship between age-0+ juvenile abundance (catch weight) and estimated age-3 cohort numbers appears to be encouraging, we point out that the apparent relationship could change with future data. Probably the addition of a single strident data point, such as a year with very low juvenile abundance and good recruitment, or vice versa, could render the relationship to be meaningless as a predictive tool. Therefore, with cautious optimism we suggest that the surveys should continue. If they are indeed continued, and incorporated into the annual assessment process, frequent review and evaluation of the results would be warranted.

Biological implications of juvenile surveys

The basic biological assumption for conducting juvenile surveys is that the approximate strength of each year class is established at or prior to the time of the survey. The age of 'recruitment' at age-3 is approximately 1100 days, whereas the age-0+ herring surveyed in September were only about 150-200 days of age. Therefore, the young juveniles from September surveys have only lived about 20% of their lives between hatching and recruiting. It would be surprising if the trend towards large year-classes were rigidly fixed so early during the life history of herring in the Strait of Georgia. We have noted that, in comparisons of juvenile abundance with older recruits from the same cohort, the variance appears to increase with mean. Probably the biological potential for greater variance will occur in cohorts that have high initial abundance: that is, an apparently strong cohort at 120 days of age (age 0+) may, or may not, maintain its strength during the 1000 days, until it recruits. On the other hand, a very weak cohort at age 120 days, probably would have very little opportunity to develop into a strong cohort.

There also may be effects of large-scale changes in ocean climate and habitat on inter-annual variation in the survival of juveniles. For instance, there has been a recent, and geographically widespread decrease in the abundance of hake in waters offshore of the west coast of Vancouver Island (McFarlane et al. 2000). Juvenile herring are a common item in hake diets (Ware and McFarlane 1989). Therefore, with a sudden departure of hake, there may have been a sudden, and unprecedented opportunity for an increase in the survival of the 1999 herring cohort. Based on tagging studies, we know that herring migrate to, and from these offshore waters. This cohort would have been resident in offshore shelf waters in the spring and summers of 2000 and 2001. Remarkably, this is the same period when there was a substantial increase in the offshore abundance of another forage species (the eulachon *Thaleichthys pacificus*) (Hay and McCarter 2000, Hay et al, 2003). Perhaps the same conditions (reduction of hake predation?) that promoted the sudden increase in eulachon abundance has fostered the development of the strong 1999 herring cohort.

Conclusions

Surveys of age 0+ herring juveniles (six months of age) , made in the late summer and early fall of each year, may provide an useful but approximate estimate of future recruitment, in the form of a relative estimate of the size of the recruiting cohort (age-3 herring, 36 months of age), about 30 months after the survey.

The accuracy, precision and value of the surveys remain to be confirmed. The surveys were not able to anticipate the very strong 1999 cohort, that recruited in 2002. This strong 1999 cohort did not appear to have exceptionally strong abundance as juveniles. Rather it was about average. On the other hand, comparisons of juvenile abundance with subsequent recruitment appears to show evidence of positive covariance (r^2 ~ 50%) between the estimated levels of juvenile abundance and subsequent recruitment. Specifically, the years with low juvenile abundance may provide useful anticipation of future years of poor recruitment.

In addition to having potential for explicit utility for objective based management of herring, these surveys, if continued, and when considered relative to other biological analyses of herring, may contribute to increased understanding of factors affecting the strength and timing (or life history stages) of year class strength in Pacific herring.

Recommendations for research

Surveys of age-0+ juvenile herring should be continued for three more years, (2003-2006). At that time the basic design should be re-evaluated. Until then the surveys should follow the same format used in recent years. Specifically, they should cover the same basic ten transects, with 5 stations per transect. The associated field and laboratory analyses should continue, without change.

Relative to the present format of the surveys, some economies are possible. For instance, a survey of the ten core transects could be done in about two-weeks, rather than the longer time (three or four weeks) dedicated to the surveys in recent years. The annual reports describing the surveys could be presented in a concise report (10-20 pages) that is confined to the presentation of data. For each survey, a brief report describing the details of the survey (i.e. dates, times of sets on each station and transect, catch estimates, etc) should be prepared. The data would then go directly into a recently developed 'juvenile herring database' at the Pacific Biological Station.

Recommendations for management

The results from annual juvenile surveys could be incorporated into the main annual assessment document, relative to predictions of recruitment. Specifically, the results could be used to predict whether recruitment would be good, average or poor. The timing of the prediction, relative to the annual assessment report, is as follows. The surveys would be made in August of year n, when the juveniles would be about 6 months of age. The analysis and incorporation of the assessment report would be finalized in the fall of year n+1, (when the juveniles would be 18 months old). The assessment report would use the data to comment on anticipated recruitment in year N+3 or 18 months in advance of the time of the report. Therefore each annual assessment report would be able to use two past estimates of juvenile abundance, to comment on the probable recruitment in the next two subsequent years. If increased confidence in the predictive capacity of these juvenile surveys appears to be justified, they could develop into formal 'indicators' and reference points for decisions concerning herring stock assessments and other decisions about the resources.

REFERENCES

Haegele, C.W. 1995. Juvenile herring surveys (1990-1993) in the Strait of Georgia. pp 28-37. In D.E. Hay and P.B. McCarter. (eds.). Proceedings of the Seventh Pacific Coast Herring Workshop. Can. Tech. Rep. Fish. Aquat. Sci. 2060.

Haegele, C. W. 1997. The occurrence, abundance and food of juvenile herring and salmon in the Strait of Georgia, British Columbia in 1990 to 1994. Can. Man. Rep. Fish. Aquat. Sci. 2390: 124 pp.

Hay, D.E. and P.B. McCarter. 1999. Age of sexual maturation and recruitment in Pacific herring. Can. Stock Assessment Secretariat Research Document 99/175. 39 p.

Hay, D.E. and P.B. McCarter. 2000. Status of the eulachon *Thaleichthys pacificus* in Canada. Canadian Stock Assessment Research Document 2000/145. 92 p.

Hay, D.E., P.B. McCarter and K. Daniel. 2001. Pacific herring tagging from 1936-1992: a re-evaluation of homing based on additional data. Can. J. Fish. Aquat. Sci. 58: 1356-1370.

Hay, D.E., P.B. McCarter and J.F. Schweigert. 1996. Analyses of recruitment predictions in Georgia Strait - based on juvenile surveys. PSARC Working Paper H96-7. 9 pp.

Hay, D.E., P.B. McCarter, J.F. Schweigert and C.W Haegele. 1997. Analyses of juvenile surveys for recruitment prediction in Georgia Strait. PSARC Working Paper H97-4. 24 p.

Hay, D. E., K. West, D. Rutherford and D. Anderson. 2003. Indicators and reference points for management of Fraser river eulachon: a comparison and discussion with recommendations. PSARC Working Paper P2003-051. 48 p.

Hourston, A.S. 1957. Investigation of the juvenile herring stocks in the Strait of Georgia region, 1956. Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C. MS. Report No. BQ118: 59 p.

Koeller, P.A., P.C.F. Hurley, P. Perly and J.D. Neilson. 1986. Juvenile fish surveys on the Scotian Shelf: implications for year-class assessments. J. Cons. Explor. Mer, 43: 59-76.

McFarlane, G.A., J.R. King and R.J. Beamish. 2000. Have there been changes in climate? Ask the fish. Progress in Oceanography 47(2-4): 147-169

Schnute, J.T., and R. Haigh. 2003. A simulation model for designing groundfish trawl surveys. Can. J. Fish. Aquat. Sci. 60: 640-656.

Schweigert, J. 2002. Stock assessment for British Columbia herring in 2002 and forecasts of the potential catch in 2003. Can. Science Advisory Secretariat Res. Doc. 2002/110: 90p.

Schweigert, J.F., C. Fort and L. Hamer. 1997. Stock assessment for British Columbia herring in 1996 and forecasts of the potential catch in 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2173: 73p.

Schweigert, J.F. and D.J. Noakes. 1991. Forecasting Pacific herring (*Clupea harengus pallasi*) recruitment from spawner abundance and environmental information. Proc. Int. Herring. Symposium. Alaska Sea Grant Rep. 91-01: 373-387.

Stocker M., and D.J. Noakes. 1988. Evaluating forecasting procedures for predicting Pacific herring (*Clupea harengus pallasi*) recruitment in British Columbia. Can. J. Fish. Aquat. Sci. 45: 928-925.

Tester, A.L. 1938. Herring, the tide, and the moon. Fish. Res. Bd. Can. Prog. Rep. Pac. 38: 4 p.

Ware, D.M. and G.A. McFarlane. 1989. Fisheries production domains in the northeast Pacific Ocean. P. 359-379. *In* R.J. Beamish and G.A. McFarlane [ed.] Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Table 1. Summary of the transects and stations included in the analyses of 0+ herring catch.										
	Transects									
	1	2	3	4	5	6	8	9	10	11
1991	1,2,3,4	1,4,5	1,2,3,4,5	2,3,4,5		1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,4,5	1,2,3,4,5
1991	1,2,3,4,5	1,2,3,4,5		1,2,3,4,5			1,2,3,4			1,2,3,4,5
1992	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5		
1993	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
1994	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,2,3,4,5	
1996	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
1997	1,2,3	1,3,5	1,2,3	1,3,5	1,2,3	1,3,5	1,2,4	1,2,3	1,3,5	1,2,3
1998	1,2,3	1,3,5	1,2,3	3,5	1,2,3	1,3,5	1,2,3	1,2,3,5	1,2,3,5	1,2,3
1999	1,2,3	1,3,5	1,2,3	1,3,5	1,2,3	1,3,5	1,2,3	1,2,3	1,3,5	1,2,3
2000	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	2,3,5	1,2,3,4,5	1,2,3,4,5	1,2,3	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
2001	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3	1,2,3,4,5	1,2,3,4,5	1,2,3	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5

Table 2. Summary of the depth intervals and geographical co-ordinates for each of the key sampling locations. For each combination of transect and station, the first of the three numbers shows the depth interval (m) determined from bathymetry on CHS charts. The other numbers indicate the co-ordinates for each station (in decimal format).

	Station				
Transect	1	2	3	4	5
1	15-20	50-100	100-200	100-200	--
	49.224	49.233	49.237	49.237	--
	-123.94	-123.93	-123.92	-123.91	--
2	5-10	50-100	30-50	50-100	30-50
	49.042	49.048	49.056	49.060	49.066
	-123.75	-123.72	-123.72	-123.71	-123.70
3	5-10	30-50	50-100	100-200	50-100
	49.452	49.459	49.467	49.476	49.482
	-124.68	-124.67	-124.66	-124.66	-124.65
4	20-30	20-30	30-50	30-50	2-5
	49.593	49.601	49.598	49.598	49.602
	-124.87	-124.85	-124.85	-124.87	-124.83
5	15-20	50-100	50-100	--	--
	49.348	49.353	49.358	--	--
	-124.35	-124.34	-124.33	--	--
6	20-30	30-50	30-50	30-50	50-100
	48.855	48.862	48.867	48.873	48.877
	-123.43	-123.42	-123.42	-123.41	-123.41
8	30-50	50-100	15-20	30-50	--
	50.036	50.046	50.054	50.036	--
	-120-30	-125.02	-125.03	-120-30	--
9	20-30	100-200	100-200	100-200	50-100
	49.916	49.912	49.908	49.901	49.913
	-124.66	-124.67	-124.69	-124.67	-124.67
10	50-100	250.00	200-500	200-500	250.00
	49.670	49.662	49.651	49.642	49.642
	-124.20	-124.22	-124.24	-124.26	-124.28
11	30-50	100-200	100-200	20-30	250.00
	49.535	49.532	49.528	49.527	49.523
	-123.98	-123.99	-124.01	-124.04	-124.06

Table 3. Summary of mean date (day of the year) by year and transect. The first numbers show the sample size (*n* or numbers of stations) sampled on a transect for each year. The next number is the day of the year (DOY) shown as a mean. In non-leap years, September 1 is DOY 244, so most sampling occurred, during all years, in mid-September. Two surveys were made in 1991, one in late August and early September and another in late September and early October. No survey occurred in 1995.

		Transect										
Year		**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**All Transects**
1991	*n*	9	8	5	9	0	5	8	5	3	10	62
	DOY	262.0	266.0	231.0	260.0	--	239.0	261.50	235.0	236.0	263.50	254.36
1992	*n*	5	5	5	5	5	5	4	5	0	0	39
	DOY	258.0	261.0	265.0	263.0	264.0	260.0	268.0	269.0	--	--	263.50
1993	*n*	5	5	5	5	5	5	4	5	5	5	49
	DOY	266.0	257.0	260.0	261.0	259.0	256.0	262.0	263.0	264.0	265.0	261.28
1994	*n*	5	5	5	5	5	5	4	5	5	0	44
	DOY	259.0	258.0	263.0	264.0	262.0	257.0	265.0	266.0	267.0	--	262.98
1996	*n*	5	5	5	5	5	5	4	5	5	5	49
	DOY	259.0	260.0	264.0	265.0	263.0	261.0	266.0	267.0	268.0	269.0	264.33
1997	*n*	3	3	3	3	3	3	3	3	3	3	30
	DOY	264.0	256.0	262.0	263.0	261.0	257.0	264.0	265.0	266.0	267.0	262.50
1998	*n*	3	3	3	2	3	3	3	4	4	3	32
	DOY	262.0	259.0	274.0	273.0	276.0	260.0	271.0	269.0	266.0	264.0	267.23
1999	*n*	3	3	3	3	3	3	3	3	3	3	30
	DOY	264.0	263.0	270.0	271.0	269.0	265.0	273.0	274.0	276.0	277.0	270.20
2000	*n*	5	5	5	3	5	5	3	5	5	5	46
	DOY	267.0	261.0	269.0	270.0	268.0	263.0	276.0	275.0	286.0	287.0	272.44
2001	*n*	5	5	5	3	5	5	3	5	5	5	46
	DOY	252.0	254.0	262.0	263.0	259.0	255.0	265.0	267.0	269.0	270.0	261.72
All	*n*	48	47	44	44	39	44	39	45	38	39	427
	DOY	261.22	260.18	261.09	263.91	264.56	256.84	266.23	264.51	266.00	269.41	263.27

Table 4. Summary of catches *by weight* of age-0+ herring by year and transect. The first number refers to the total stations sampled on a transect for each year followed by the mean and median catch weight (g). Two surveys were made in 1991, one in late August and early September and another in late September and early October. No survey occurred in 1995.

	Transect										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**All Transects**
1991	9	8	5	9	0	5	8	5	3	10	62
	138	18599	233	10760	--	10166	26817	77126	15171	951	14455
	20	16233	12	10354	--	1000	1539	9200	9	300	794
1992	5	5	5	5	5	5	4	5	0	0	39
	0	6983	233	1887	103	31	832	26	--	--	1379
	0	8000	39	59	5	13	579	5	--	--	13
1993	5	5	5	5	5	5	4	5	5	5	49
	541	6247	19	12972	253	226	2497	0	499	0	2473
	57	5352	0	7814	0	22	1734	0	9	0	22
1994	5	5	5	5	5	5	4	5	5	0	44
	3	7265	13740	22743	28	142	66	353	18052	--	6780
	0	5993	7500	8000	0	158	71	84	12334	--	156
1996	5	5	5	5	5	5	4	5	5	5	49
	6415	20626	145	10193	429	29	27222	1	3450	1147	6980
	23	1219	103	6440	0	36	5092	0	1600	471	84
1997	3	3	3	3	3	3	3	3	3	3	30
	8355	50133	622	24028	415	19133	1430	39400	3058	7510	15409
	11400	25200	531	285	374	18100	1426	19000	4200	1203	3482
1998	3	3	3	3	3	3	3	4	4	3	32
	46403	35023	19586	1594	166478	6998	321	13511	4530	13733	30354
	56600	23769	18976	1594	0	8844	316	10421	517	12800	9000
1999	3	3	3	3	3	3	3	3	3	3	30
	233	25167	15669	1352	690	18733	177	1277	317	4478	6809
	0	4100	407	55	212	26700	171	1392	120	1700	821
2000	5	5	5	3	5	5	3	5	5	5	46
	8186	31620	5829	6100	758	151	1325	8840	13365	6393	9248
	38	17700	3300	5300	788	134	793	0	521	4100	1326
2001	5	5	5	3	5	5	3	5	5	5	46
	211940	16668	10133	1567	8319	952	223	1717	3773	250	29467
	8300	1552	6800	0	153	393	157	2100	1157	139	1369
All years	48	47	44	44	39	44	39	45	38	39	427
	31579	18914	5893	9958	20434	4388	8909	13698	6736	2855	12045
	34	9081	310	4700	16	190	594	241	940	739	545

Table 5. Summary of the mean catch weight (g) and standard deviation shown according to approximate depth interval.

Depth Interval	Count	Mean Catch Weight	Standard Deviation
2-5	10	1903	4104
5-10	21	3228	5920
10-25	11	11768	35480
15-20	19	2223	7935
20-30	44	3089	15443
30-50	101	1819	5155
50-100	100	784	1635
100-200	73	666	1764
200-300	23	410	1036
300-400	15	231	375
All	417	1722	8420

Table 6. Estimated mean juvenile herring catch weight and variance estimates from simple random and two-stage sampling analyses for the 1991 to 1999 year-classes.

Year class	Mean	Bootstrap 95% C.I. Lower	Bootstrap 95% C.I. Upper	Geometric Mean	Bootstrap 95% C.I. Lower	Bootstrap 95% C.I. Upper	Two-Stage Sampling Mean	Two-Stage Sampling Sdev	Two-Stage Sampling G-Mean	Two-Stage Sampling G-Sdev
1991	15388	5496	30361	6.408	5.561	7.235	17773	23434	6.3737	1.4056
1992	1273	498	2222	3.584	2.521	4.548	1262	1219	3.6586	1.3868
1993	2322	993	4990	3.689	2.586	4.767	2325	2439	3.7626	1.4679
1994	7089	3254	12027	5.338	4.174	6.384	6932	6745	5.3009	1.5011
1996	6552	1970	12835	4.604	3.548	5.592	6966	9832	4.6933	1.5889
1997	15409	7553	25455	7.772	6.821	8.635	15409	15537	7.7724	1.4512
1998	30354	9598	63364	7.516	6.269	8.770	30818	54998	7.5502	2.1092
1999	6809	2059	13467	6.104	5.013	7.165	6809	9522	6.1035	1.7282

Table 7. Estimates of the age-3 recruit abundance ($x10^{-5}$) from age-structured analysis from the 2002 assessment and calculated retrospectively from 1994 through 2002 with 95 percent confidence intervals calculated from likelihood profiles.

	Retrospective Assessment			2002 Assessment		
Year-class	No. Age 3	Lower C.I.	Upper C.I	No. Age 3	Lower C.I.	Upper C.I.
1991	8401	7026	9829	7154	6168	7474
1992	3921	3277	4590	3467	3133	3819
1993	10394	8674	12177	6708	6144	7342
1994	12330	10504	14191	10179	9290	11143
1996	5403	4522	6330	5847	5241	6494
1997	8046	6890	9362	10324	9062	11657
1998	11914	10123	13792	13196	11187	15300
1999	19095	16072	22269	19095	16072	22269

Table 8. Forecasts of the abundance of age-3 recruits ($x10^{-5}$) from regression models 1 and 2 and the associated observed and predicted recruitment (as good, average, or poor) for the 1991-1999 year-classes based on the historical time series from 1951-2002 and 1971-2002.

				1951-2002			1971-2002		
Year Class	Observed No Age 3	Pred(Age 3) Model 1.	Pred(Age 3) Model 2	Observed Status	Forecast Model 1	Forecast Model 2	Observed Status	Forecast Model 1	Forecast Model 2
1991	7154	8856	9970	Good	Good	Good	Good	Good	Good
1992	3467	5015	5328	Avg	Avg	Avg	Avg	Avg	Avg
1993	6708	5126	5457	Good	Avg	Avg	Good	Avg	Avg
1994	10179	7074	7784	Good	Good	Good	Good	Good	Good
1996	5847	6229	6765	Avg	Good	Good	Avg	Good	Good
1997	10324	11870	13770	Good	Good	Good	Good	Good	Good
1998	13196	11330	13082	Good	Good	Good	Good	Good	Good
1999	19095	8389	9368	Good	Good	Good	Good	Good	Good

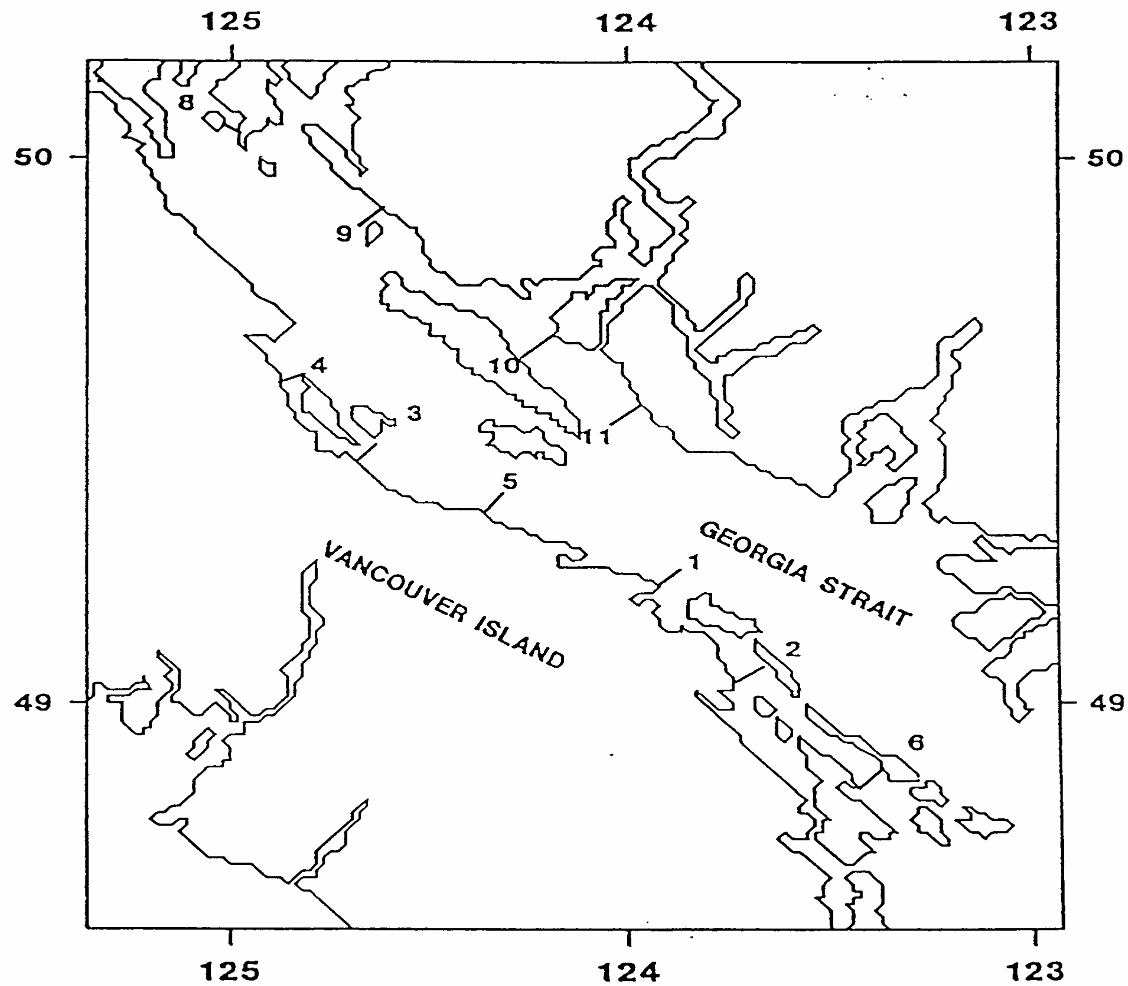

Fig. 1. Transect locations in the Strait of Georgia (from Haegele 1997).

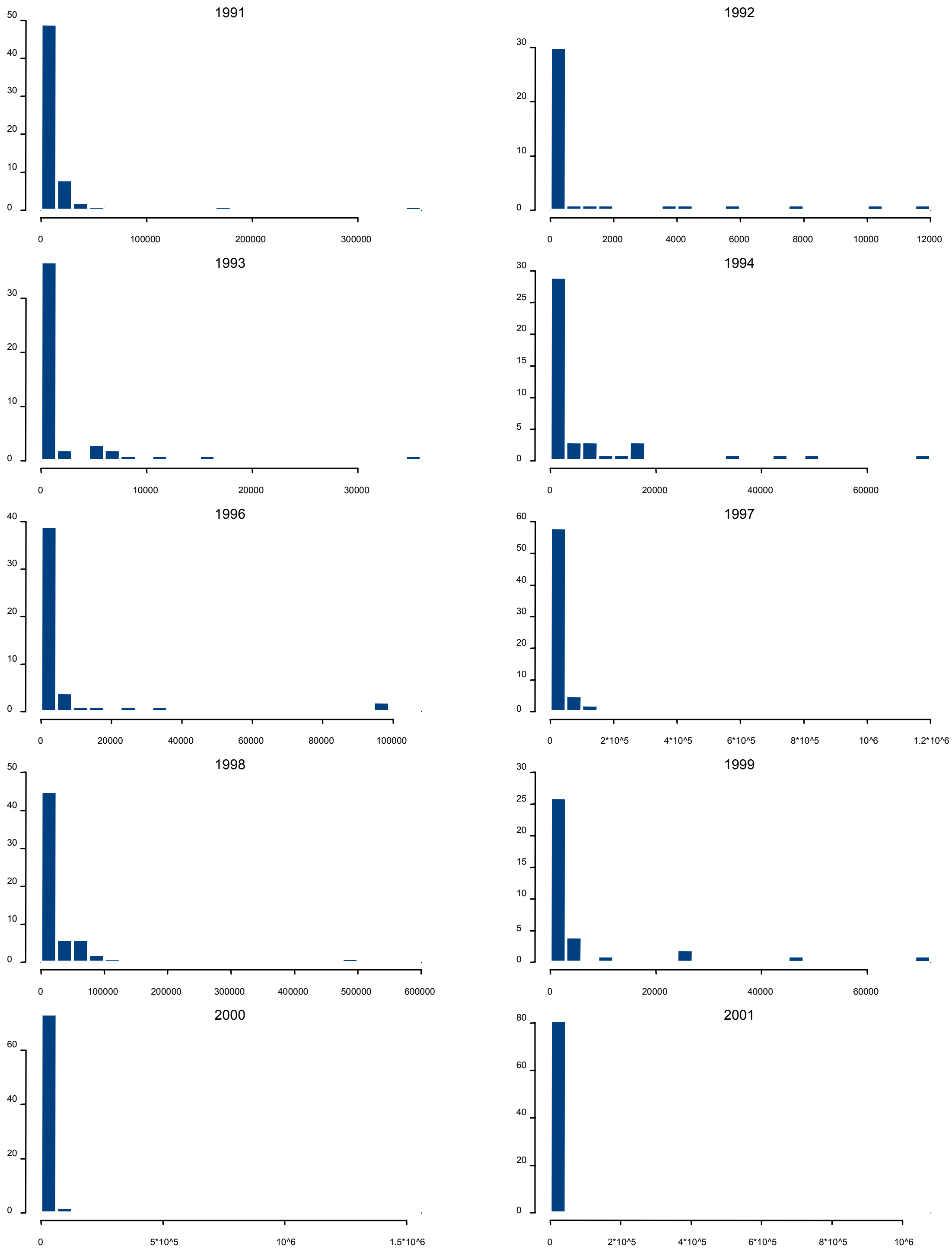

Figure 2. Frequency distribution of the catch weight data from the juvenile surveys for the core transects from the 1991 to 2001 surveys.

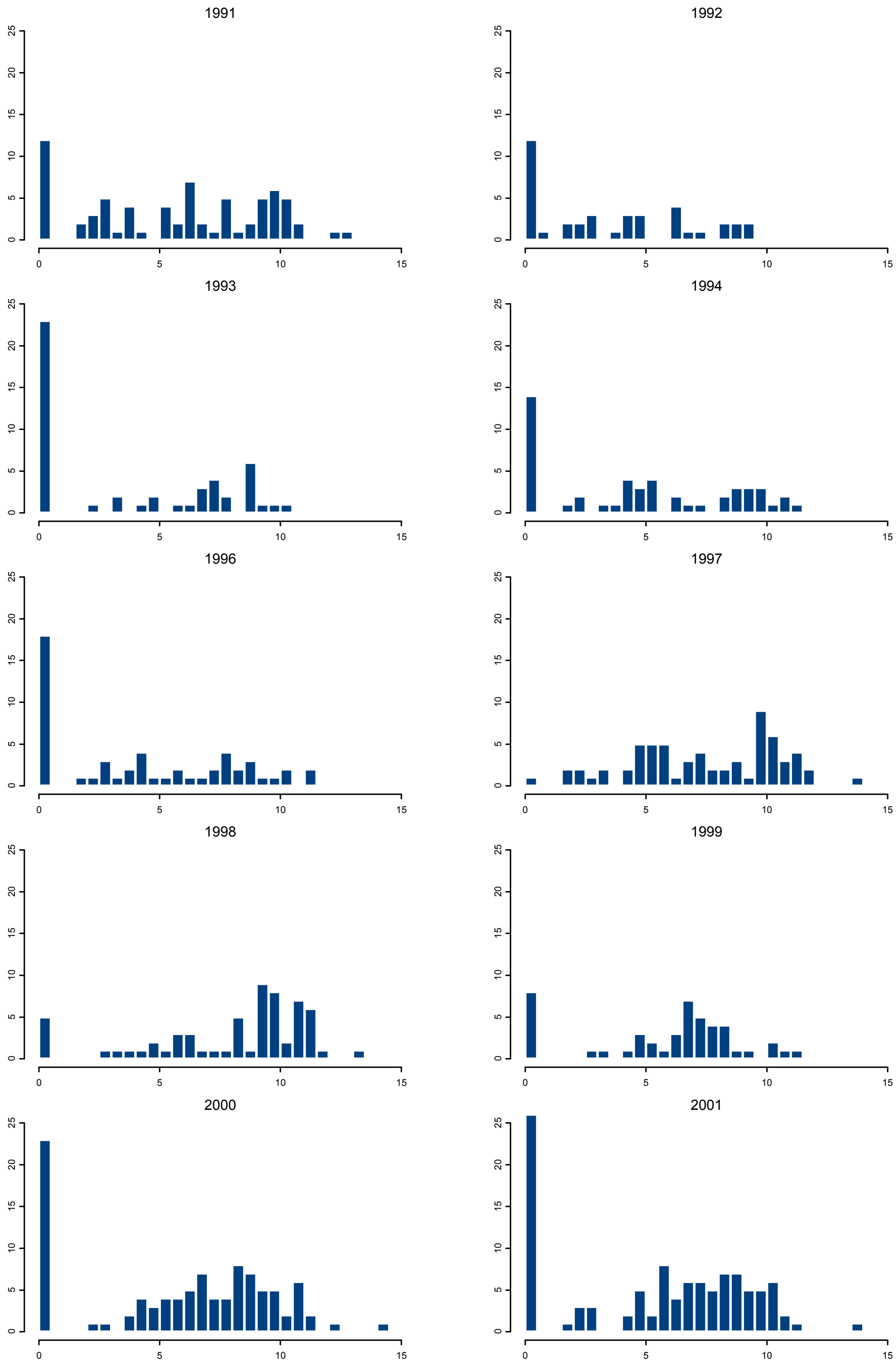

Figure 3. Frequency distribution of the log transformed juvenile survey data for the core transects from the 1991 to 2001 surveys.

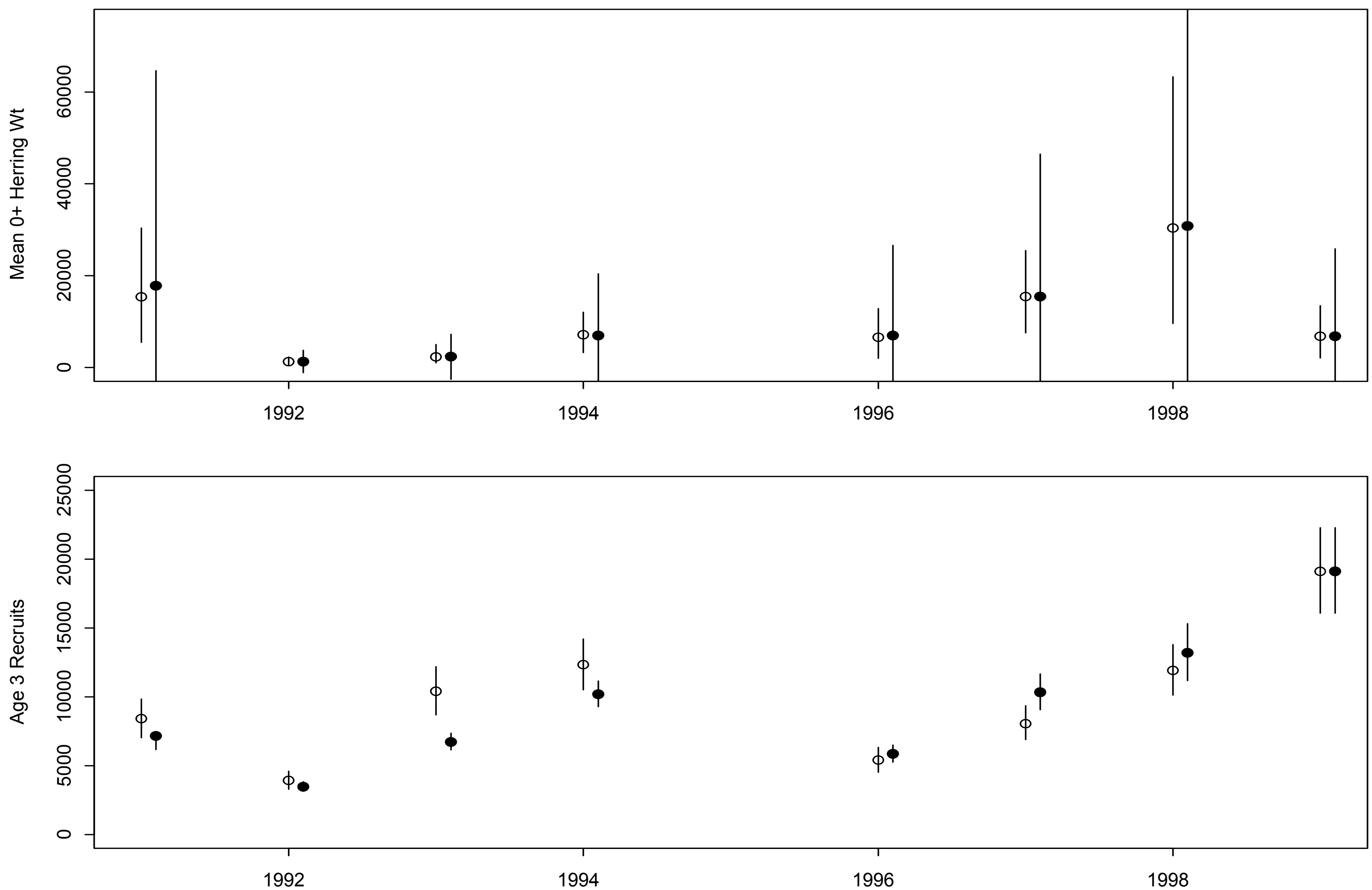

Figure 4. Juvenile abundance and subsequent number of age-3 recruits, shown according to the year of birth. Top panel shows mean juvenile herring catches and 95 percent confidence intervals from bootstrapping individual stations (open circles) and as estimated from 2-stage sampling (closed). Bottom panel shows the estimated age 3 recruit mean and 95 percent confidence intervals from age-structured analysis for 2002 (closed) and as calculated retrospectively (open) for the 1991 to 1999 year-classes.

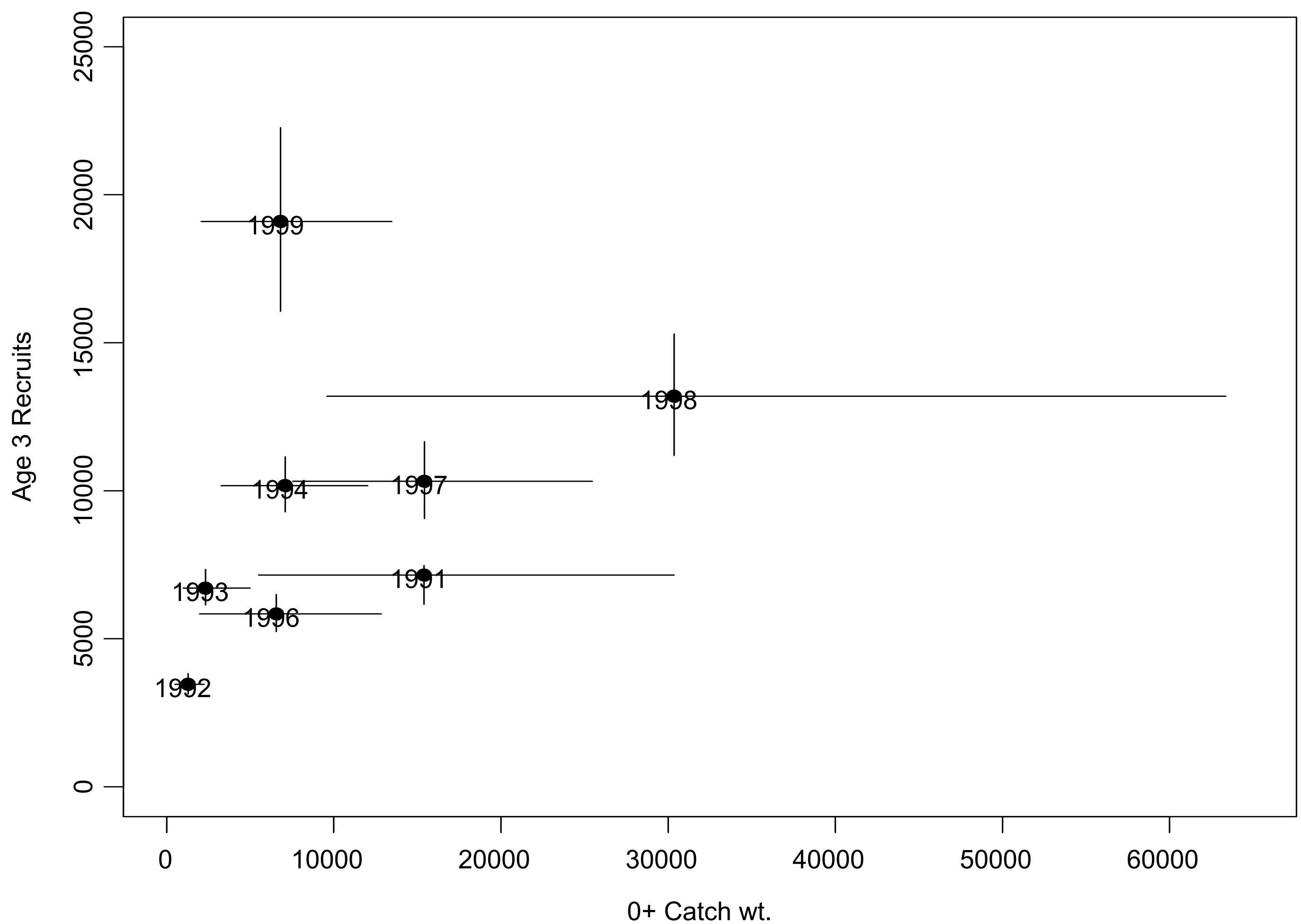

Figure 5. Plot of the juvenile herring abundance index with bootstrap 95% confidence limits versus the age structured model estimate of the abundance of age 3 recruits with estimated 95% confidence limits for the 1991 to 1999 year-classes.

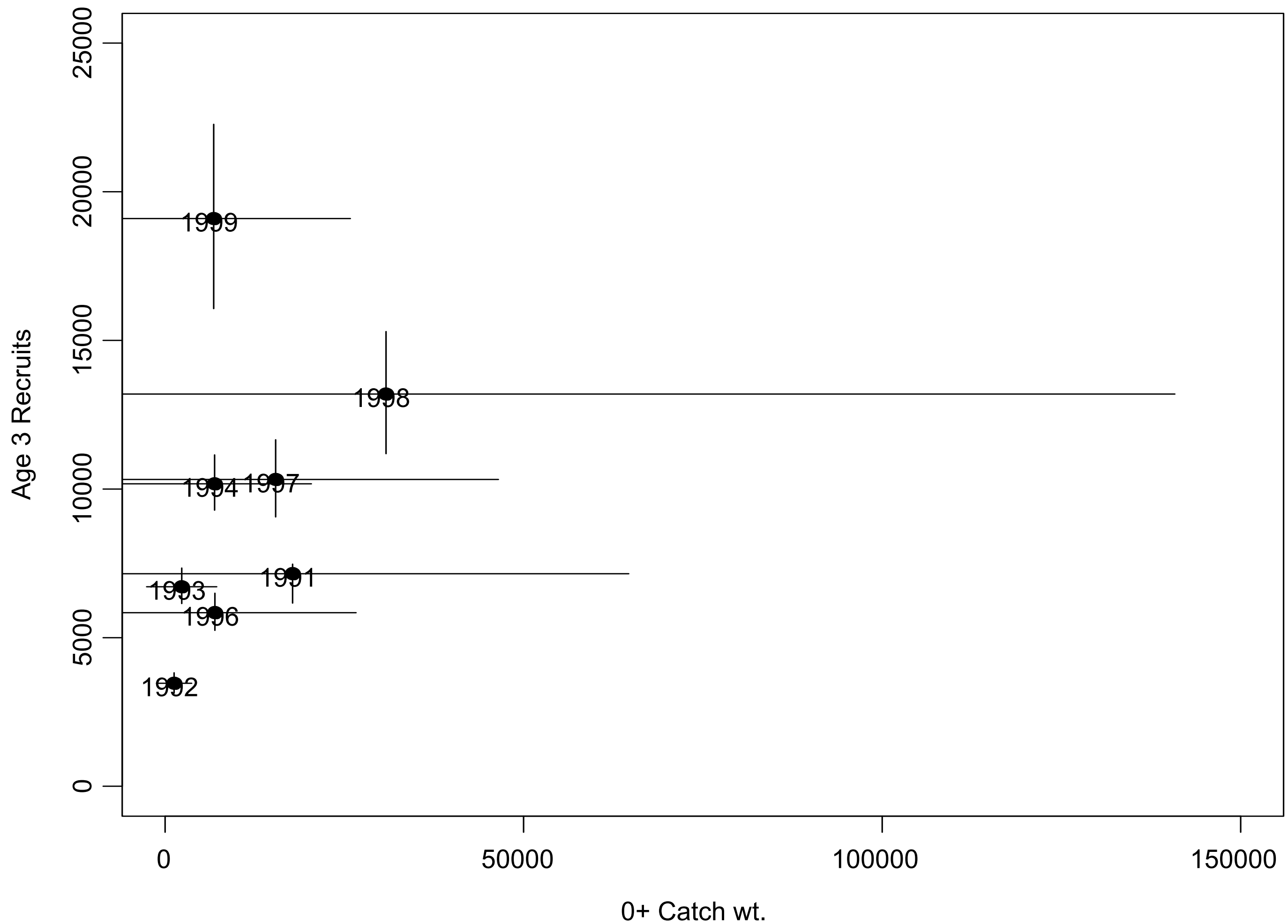

Figure 6. Plot of the juvenile herring abundance index with 95% confidence limits estimated from 2-stage sampling versus the age structured model estimate of the abundance of age 3 recruits with estimated 95% confidence limits for the 1991 to 1999 year-classes.

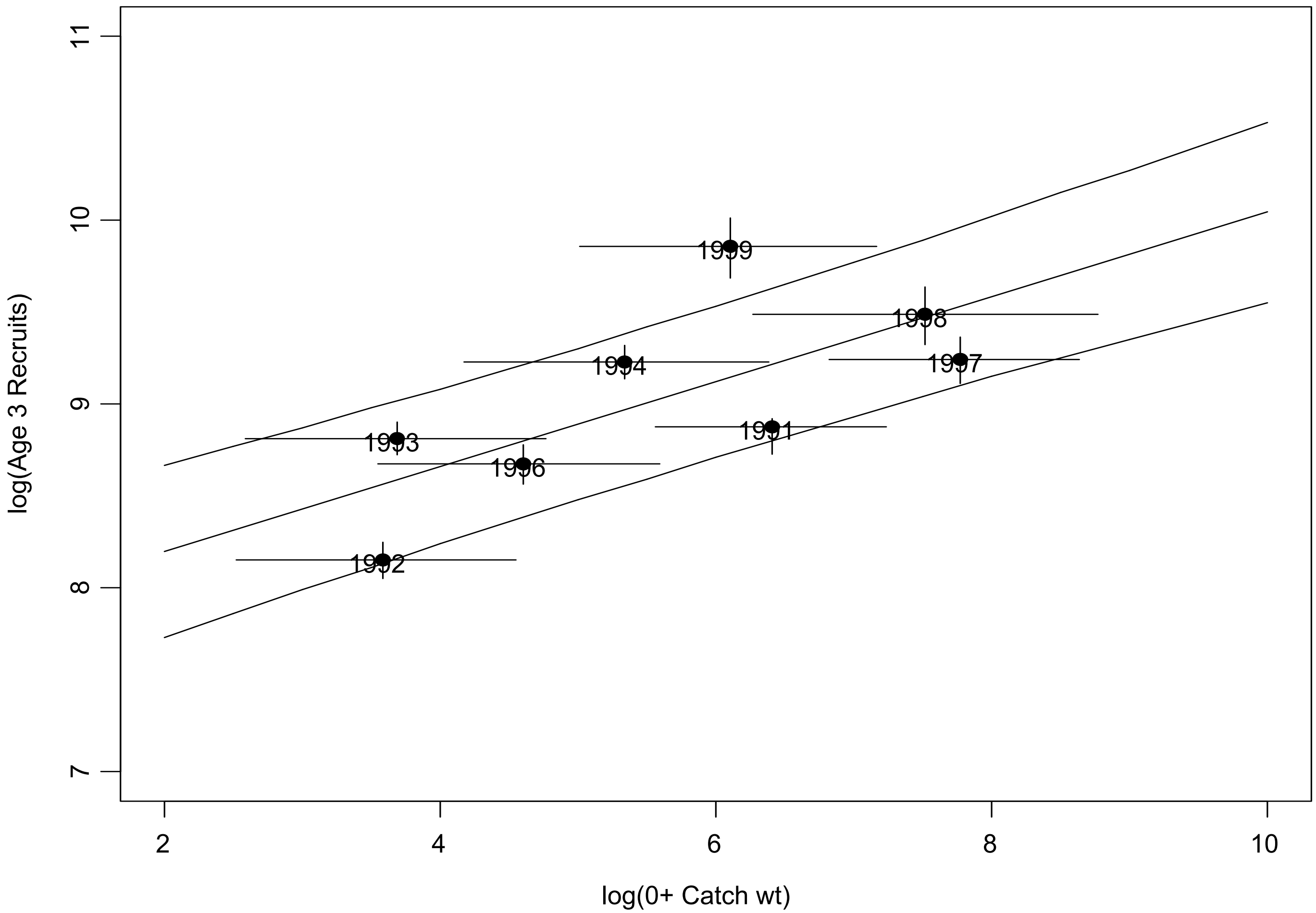

Figure 7. Plot of the log transformed estimates of juvenile herring catch with bootstrap 95% C.I. and age structured model estimates of the age 3 recruit abundance with 95% C.I. on each data point. The line represents the best fit to the data for the 1991-1999 year-classes with the 95% confidence bands.

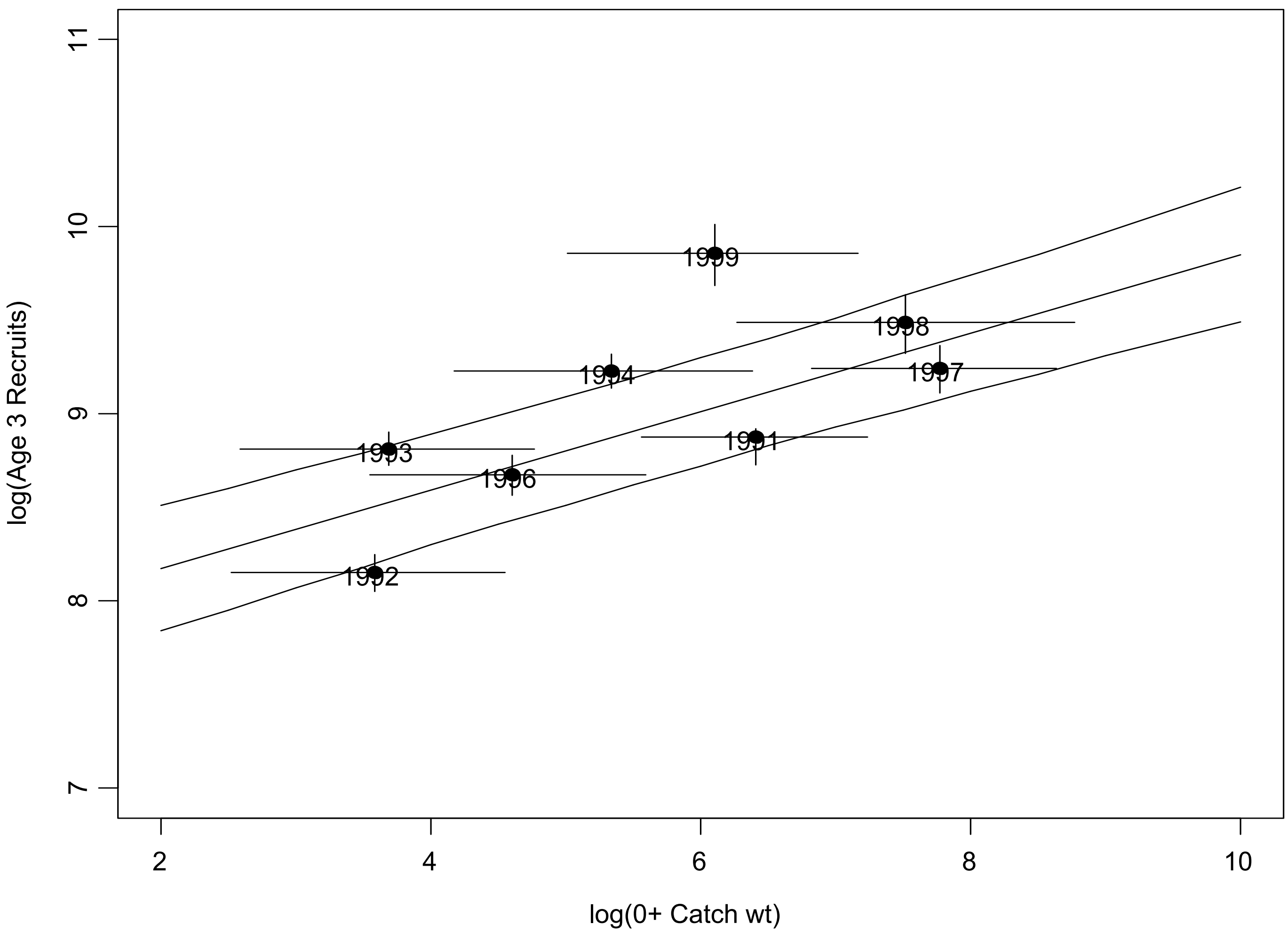

Figure 8. Plot of the log transformed estimates of juvenile herring catch with bootstrap 95% C.I. and age structured model estimates of the age 3 recruit abundance with 95% C.I. on each data point. The line represents the best fit to the data for the 1991-1998 cohorts (1999 excluded) with the 95% confidence bands.