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# A retrospective analysis of escapement model performance using different adult survival rate estimates

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## Abstract

Test fishing data, catch data and spawning biomass estimates for the west coast Vancouver Island herring stock were used to compare how three different methods of estimating apparent adult survival rate affect the performance of the escapement stock assessment model. The first, the procedure currently used, included all test fishing data from 1972 to the present. The second excludes data from samples taken before 1980. These data were excluded because survival curves suggested size-selective test fishing before 1980. The first two procedures use running mean age-specific survival rates. The third method uses a regression which estimates age- and year- specific apparent adult survival rates based on the 1980-1996 data. The current procedure overestimates returning adult biomass by 28%. The second and third procedures underestimate biomass by 19 and 17% respectively. Residual analysis showed that the second and third methods underestimated biomass consistently. All procedures provided returning biomass estimates of acceptable accuracy.



## Résumé

À l'aide des résultats des pêches d'essai, des données sur les prises et des estimations de la biomasse de géniteurs du stock de hareng de la côte ouest de l'île de Vancouver, on a comparé trois méthodes différentes d'estimation du taux apparent de survie jusqu'à l'âge adulte quant à leur effet sur la performance du modèle d'estimation des échappées. La première méthode, celle qui est utilisée actuellement, utilise toutes les données des pêches à l'essai depuis 1972. La deuxième exclut les données des échantillons prélevés avant 1980, parce que les courbes de survie semblent indiquer une sélection en fonction de la taille dans les pêches à l'essai avant 1980. Les deux premières méthodes utilisent des moyennes mobiles des taux de survie selon l'âge. La troisième méthode applique une régression pour estimer les taux apparents de survie selon l'âge et l'année à partir des données de 1980 à 1996. La méthode utilisée actuellement surestime la biomasse des adultes qui retournent de 28 %. Les deuxième et troisième méthodes la sous-estiment de 19 et 17 % respectivement. D'après l'analyse des résidus, les sous-estimations sont cohérentes. L'exactitude des estimations de la biomasse des retours est acceptable pour toutes les méthodes.

## INTRODUCTION

The escapement model (Schweigert and Stocker 1988) is one of the two stock assessment models which provide herring pre-fishery biomass estimates. It estimates the number of spawners using egg deposition information, a relative fecundity assumption of 200 eggs x $g^{-1}$ total mass, age composition of the stock and mean mass-at-age. The number of returning spawners is forecast using long-term age- and stock assessment area- specific apparent survival rates, based on data from 1972 to the last fishing season. The apparent survival rates actually describe more than natural mortality. They also include the effects of availability and partial recruitment beyond age 3, which is the currently accepted age of maturity.

Tanasichuk (1996) suggested that the apparent survival rates used to forecast the returning adult biomass for the southwest coast Vancouver Island (SWCVI) herring stock are biased. He suggested two potential sources of bias. The first was due to sampling ending before the younger and later spawning fish had arrived on the spawning grounds. Tanasichuk (1997) reported that the relationship between sampling time and spawning time does not bias the age composition of this stock. The second source of bias is size-selective fishing. Test fishing activities, which endeavoured to collect unbiased samples of the spawning aggregations, began in 1980. Before then, most samples came from commercial catches where the skippers had the option to release a set. Because roe value increases with roe size, and larger fish are more mature at any given time (Ware and Tanasichuk (1989), skippers likely released catches of smaller fish. Samples were taken only from the sets kept.

The goal of this study was to compare the performance of the escapement model using three apparent survival rate estimates to forecast returning adult biomass. The first estimate is the one used now. The second estimate is similar to the first in that it is a running mean of age-specific survival rates over time. The difference is that it is based on data from 1980 onward, therefore excluding 1972-79 samples which may be biased by size-selective fishing. The third estimate is from a regression which calculates year- and age-specific survival rates as a function of fish size and sea temperature. The regression is based on data collected from 1980 onward and follows the one estimated by Tanasichuk (1996). Before we began this analysis, we examined catch curves for evidence of size-selective fishing.

## MATERIALS AND METHODS

We used biological data from samples taken by test fishing and from the commercial seine and gillnet fisheries in the west coast Vancouver Island stock assessment area. Samples were frozen and returned to the laboratory and thawed for routine biological sampling. This included measuring standard length (mm) and total and gonad mass (g), recording sex and stage of maturity as well as removing three scales from under the left pectoral fin for ageing. Numbers of fish-at-age caught commercially were estimated using hailed catch (tonnes) and age composition from samples taken by each commercial gear type. Number of fish-at-age spawned was estimated using the escapement model estimate of spawning biomass, relative fecundity and mean mass-at-age estimates, and the age compositions from the test fishing samples. Apparent survival rates (S) were estimated as:

$$S_{a+1,i}=T_{a+1,i+1}/Sp_{a,i},$$

where T is the total number of fish-at-age which were caught commercially or spawned, Sp is the total number of fish-at-age which spawned, a is age and i is year.

We used multiple regression analyses to examine whether biotic or abiotic factors influenced survival rate. Mean weight-at-age was estimated from the sampling data. Environmental variables were mean monthly sea surface temperature and salinity estimates based on lighthouse data from Amphitrite Point. Offshore temperatures and salinities at 50 m depth were calculated using relationships between oceanographic data for Amphitrite Point and a sub-surface mooring located on 40-Mile Bank, part of La Perouse Bank. (Lower west coast Vancouver Island herring summer in the La Perouse Bank area.) Estimates for 50 m were calculated because herring migrate diurnally between the bottom (100 m) and the surface. We calculated an equation for temperature $TB=TA+(-4.88*\cos((-0.33*(m-26.61))))$, where TB=mean monthly temperature on 40-Mile Bank at 50 m, m=numeric value for month (e.g., January=1) and TA=mean monthly sea surface temperature at Amphitrite Point. The equation for salinity was $SB=SA+(-0.84*m+0.05*m^2+6.41)$, where SB=mean monthly salinity on 40-mile Bank at 50 m and SA=mean monthly surface salinity at Amphitrite Point. Non-linear parameter estimation (Systat 1992) was used to estimate both equations. Mean temperature and salinities were calculated for monthly and consecutive 2 through 8 month intervals over the period (March-October) when mortality should be greatest. The environmental variables represented the summer before capture or spawning. We used arc sin transformed survival rate values and the STEPWISE regression procedure (SAS 1985). Bonferroni-adjusted critical values (0.05/no. of tests) were used for multiple comparisons (Systat 1992). The statistical significance of adding independent variables was tested using the procedure described by Sokal and Rohlf (1981). Regressions were re-estimated annually by adding observed survival rate, size and oceanographic data. We began with data from 1980-86 because we considered shorter time series to be too small.

The retrospective analysis consisted of comparing observed estimates of adult (age 4+) biomass with those forecast using the three estimates of S (1972-1996 data, 1980-1996 data, regression estimate), $Sp_{a-1,i-1}$ and $W_{a+1,i}$, where W is mean mass (g). Year- and age-specific S estimates were running means for all previous years in the time series or were estimated using the regressions. Observed age- and year-specific biomass (O) was estimated as:

$$O_{a,i}=T_{a,i}*W_{a,i}$$

These were summed over ages 4 through 10. Age-and year-specific forecasted biomass (B) was estimated as:

$$B_{a,i}=Sp_{a-1,i-1}*S_{a,i-1}*W_{a+1,i}.$$

These were also summed over ages 4 through 10.

## RESULTS

(a) Survival curves

Survival curves for year-classes of southwest coast of Vancouver Island herring caught between 1964 and 1994 show various trends (Fig. 1). The incomplete curves for the 1962-68 year-classes illustrate no sampling during the years the fishery was closed. Curves for the 1969-76 year-classes show no reduction of numbers of fish with age over a number of years for adults and/or age 4 as age-at-recruitment. Excluding the 1985 year-class, all year-classes after 1976 show age 3 as the age-at-recruitment and a progressive decline in numbers of fish as age increases.

(b) Regression analyses

Mean mass and October sea temperatures persisted over all years as the independent variables which best describe variations in age- and year-specific apparent survival. Table 1 presents parameter estimates for regressions estimated using additional years of data. The parameter estimates were stable. Therefore, the performance of the regression survival estimates was not confounded by changes in the regression parameters over time.

(c) Retrospective analysis

Trends in observed and forecasted adult prefishery biomasses, over the years in common for all three survival rate estimates, are presented in Fig. 2; the biomass estimates are given in Table 2. The current version of the escapement model, which uses running mean survival rate estimates, overestimated the adult prefishery biomass by 28% (6094 tonnes). The version of the model using survival rate estimates based on 1980-96 data underestimated adult biomass by an average of 19% (5883 tonnes). The version of the model which used survival rates estimated by the regression underestimated adult biomass by 13% (4803 tonnes).

Residuals (observed-forecast) for the model estimates are presented in Fig. 3. The current version of the model varies between over- and underestimating prefishery adult biomass while the other forms of the model tend to underestimate biomass consistently. These latter versions also showed the largest residual for the 1989 adult biomass estimate.

## DISCUSSION

All forms of the escapement model provide a level of accuracy which we suggest is acceptable. The version of the model using regression estimates is the most accurate. However, it is impractical because the environmental data required is non-existent at the time the stock assessments are done. Part of our regression analysis consisted of searching for other measures of sea temperature which would be available at the time of stock assessment and would provide accurate survival rate estimates. We found none. We expect that the estimates based on the current form of the model and that based on the version using the 1980-96 data will converge over time as the effect of size-selective fishing is diluted by additional data over time. We suggest that this analysis be extended to the other major herring stocks to test the apparent survival rates currently used to forecast returning adult biomass.

There were instances when each form of adult biomass forecast did not forecast adult biomass well. For the current version, this took place in 1982. We interpret this as reflecting the influence of sampling bias on survival rate estimation. If the forcast for 1982 is excluded, then the current method overforecasts adult prefishery biomass by 3366 tonnes (19%). The procedures which included the 1980-96 data did not forecast the 1989 biomass well. The increase in biomass is due to the strong 1985 year-class. We suggest it is fortuitous that the current version of the model gave a reasonable estimate. If the 1989 forecasts are excluded, then the running mean- and regression-based versions underforecast adult prefishery biomass by 4400 tonnes (17%) and 3200 tonnes (10%) respectively. All versions underforecast adult biomass in 1995 and 1996. This could be due to changes in fish distributions off the southwest coast of Vancouver Island. Herring have been more widespread recently possibly reducing their interaction with adult herring predators.

We suggest that the differing trends in survival curves reflect size-selective fishing. Curves for the 1969-76 year classes generally show no reduction of number of fish until age 6 at least. Considering the high exploitation rates then, a size-selective fishing explanation is more plausible than a dramatic difference in age-at-maturity.

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Table 1. Parameter estimates for regression of age- and year-specific survival rates on mean mass (W, g), and October sea temperature (O) All regressions are statistically significant ($p<0.05$, Bonferroni-adjusted probabilities) and $R^2_{adj}>0.34$. S (%) is the estimated survival rate for a 120 g fish and an October sea temperature of 8.5° C. Regressions began with 1980-86 time series because sample size was considered to be too small for shorter time series.

| Data to year x | W | O | Intercept | S |
|---|---|---|---|---|
| 1986 | -0.29 | -17.20 | 236.50 | 51 |
| 1987 | -0.22 | -19.52 | 245.87 | 54 |
| 1988 | -0.19 | -21.44 | 259.20 | 54 |
| 1989 | -0.21 | -21.96 | 265.78 | 54 |
| 1990 | -0.22 | -22.11 | 270.43 | 56 |
| 1991 | -0.22 | -22.11 | 270.43 | 56 |
| 1992 | -0.22 | -17.62 | 229.98 | 54 |
| 1993 | -0.22 | -18.98 | 244.47 | 57 |
| 1994 | -0.22 | -17.96 | 235.66 | 57 |
| 1995 | -0.22 | -17.87 | 234.10 | 56 |
| 1996 | -0.22 | -17.43 | 230.28 | 56 |

Table 2. Returning adult biomass estimates (tonnes) for southwest coast Vancouver Island herring.

| | | Biomass | | |
|---|---|---|---|---|
| Spring | Observed | Current S | 1980-96 S | Regression S |
| 1982 | 27890 | 74501 | 43573 | 28818 |
| 1983 | 17160 | 31177 | 17456 | 21273 |
| 1984 | 14798 | 14659 | 9008 | 12335 |
| 1985 | 10790 | 22387 | 12034 | 12519 |
| 1986 | 20933 | 33027 | 15411 | 22813 |
| 1987 | 34425 | 44267 | 25129 | 29408 |
| 1988 | 26041 | 26925 | 18039 | 18445 |
| 1989 | 49661 | 44182 | 23566 | 22424 |
| 1990 | 39452 | 42077 | 29843 | 28355 |
| 1991 | 29495 | 36613 | 24718 | 31313 |
| 1992 | 26660 | 23247 | 17480 | 18055 |
| 1993 | 27237 | 35105 | 23589 | 28112 |
| 1994 | 22152 | 26586 | 19076 | 20405 |
| 1995 | 25071 | 17516 | 14166 | 17542 |
| 1996 | 25472 | 21198 | 15901 | 13377 |
| All years | | | | |
| Prop. observed | | 1.28 | 0.81 | 0.87 |
| Residual | | -6094 | 5883 | 4803 |

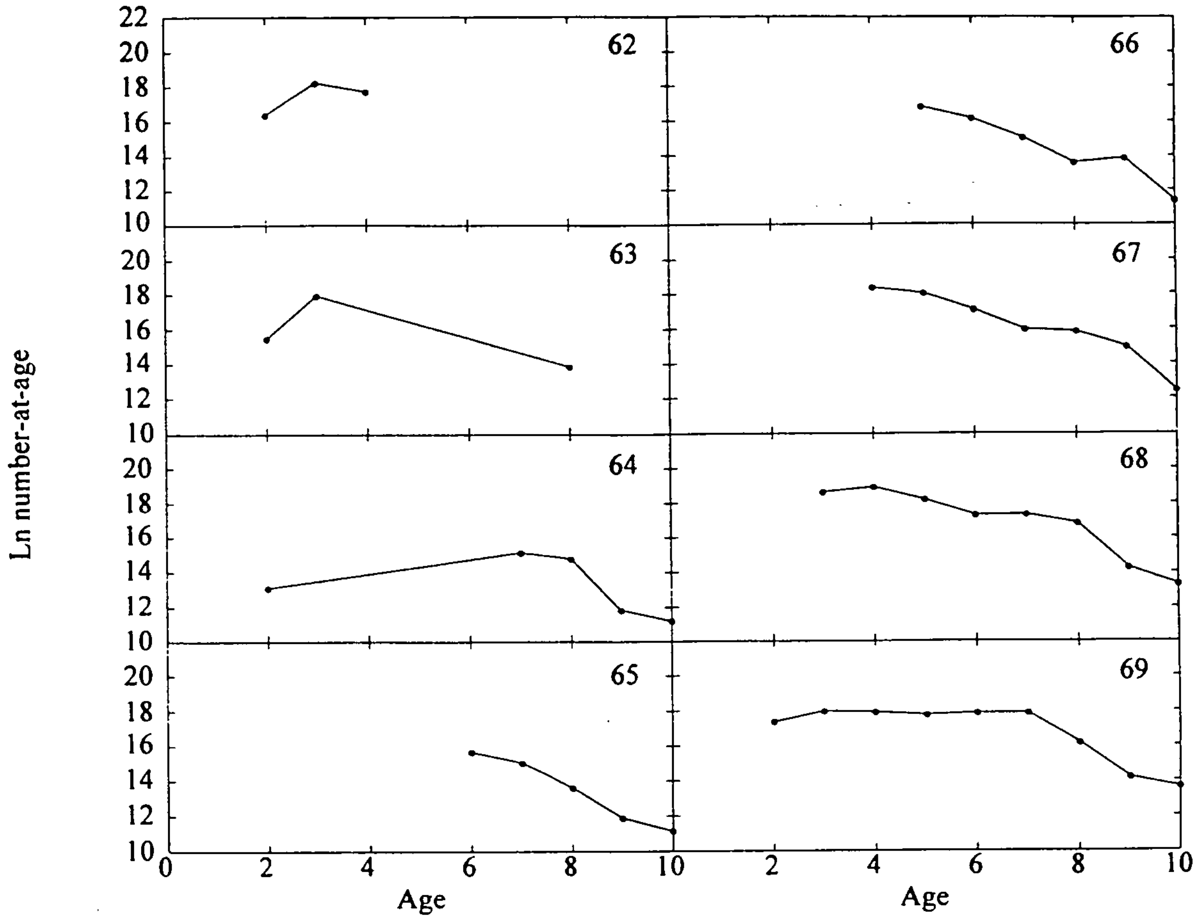
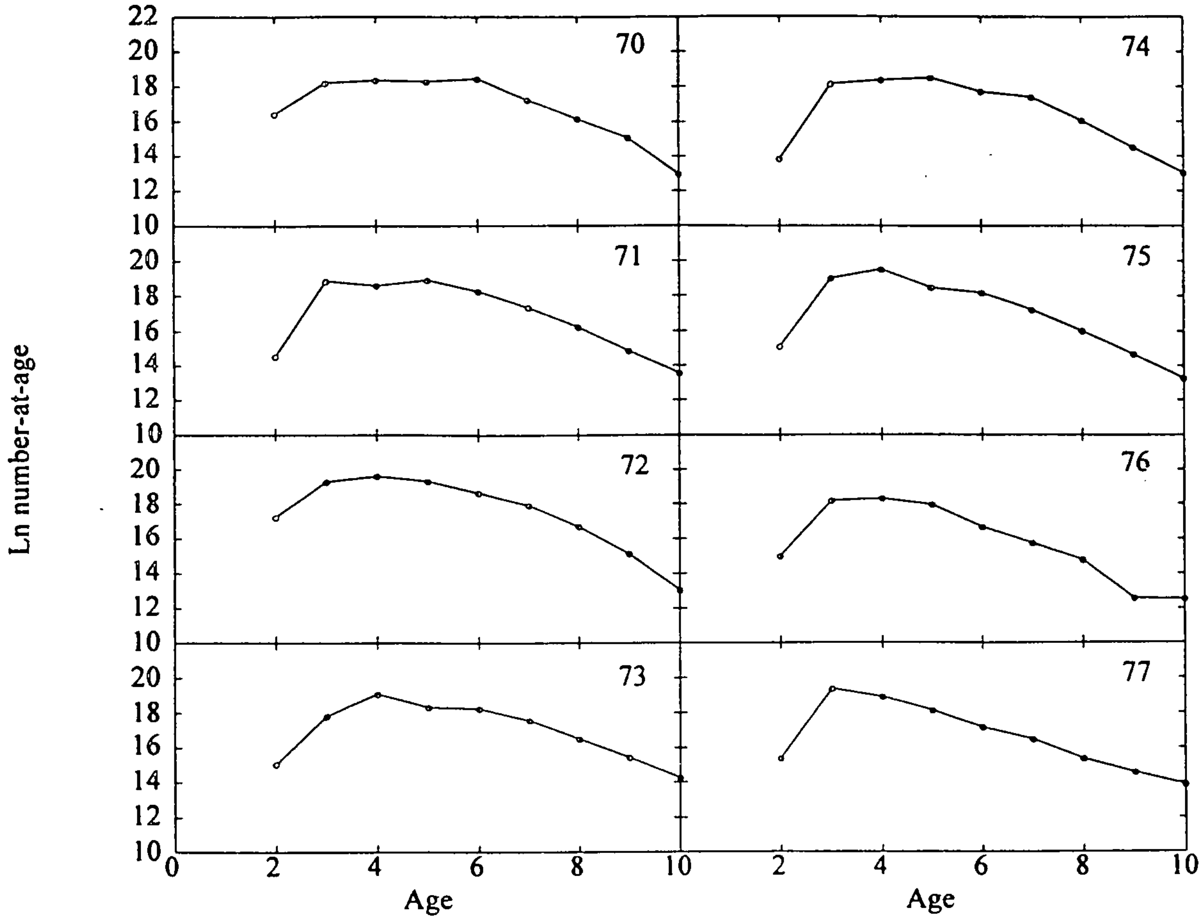



Figure 1 Survival curves for southwest coast Vancouver Island herring. Values are year-class.

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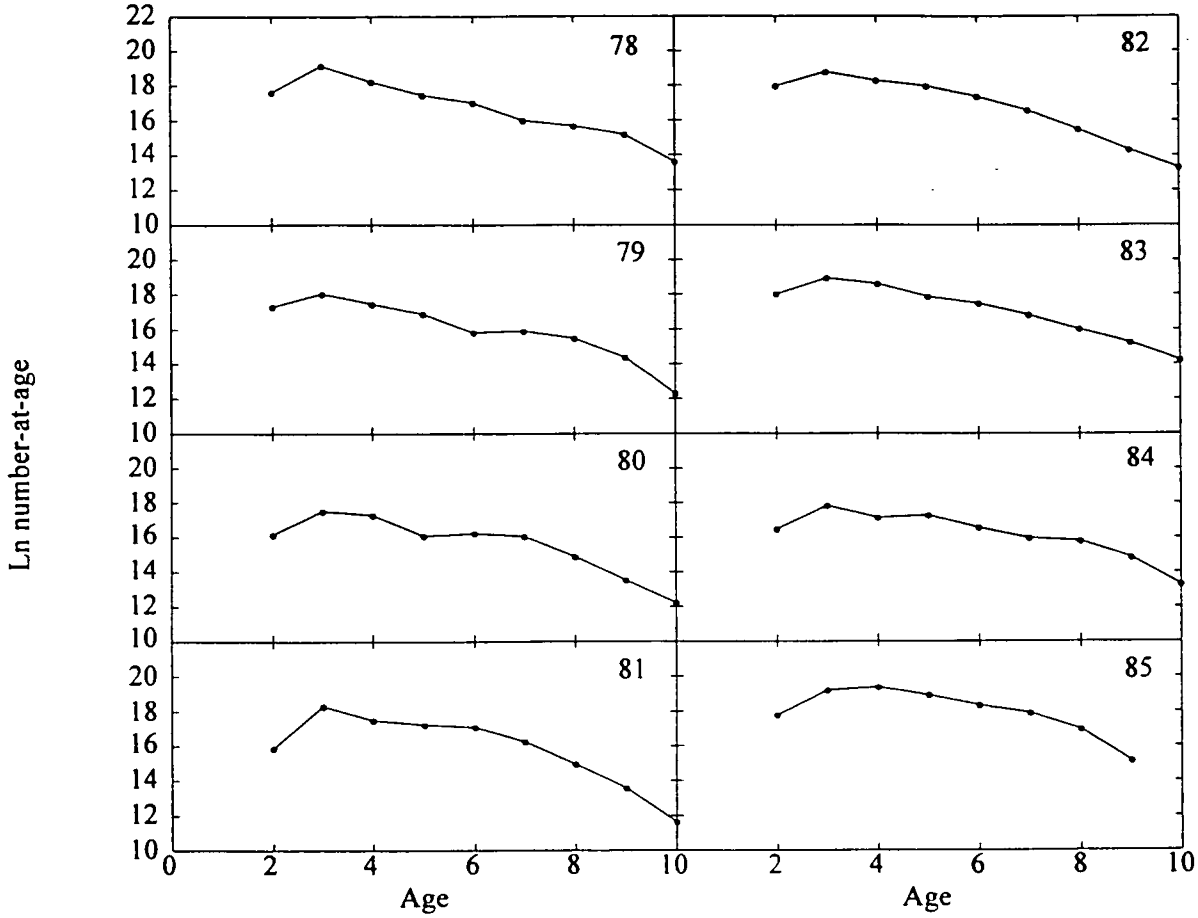


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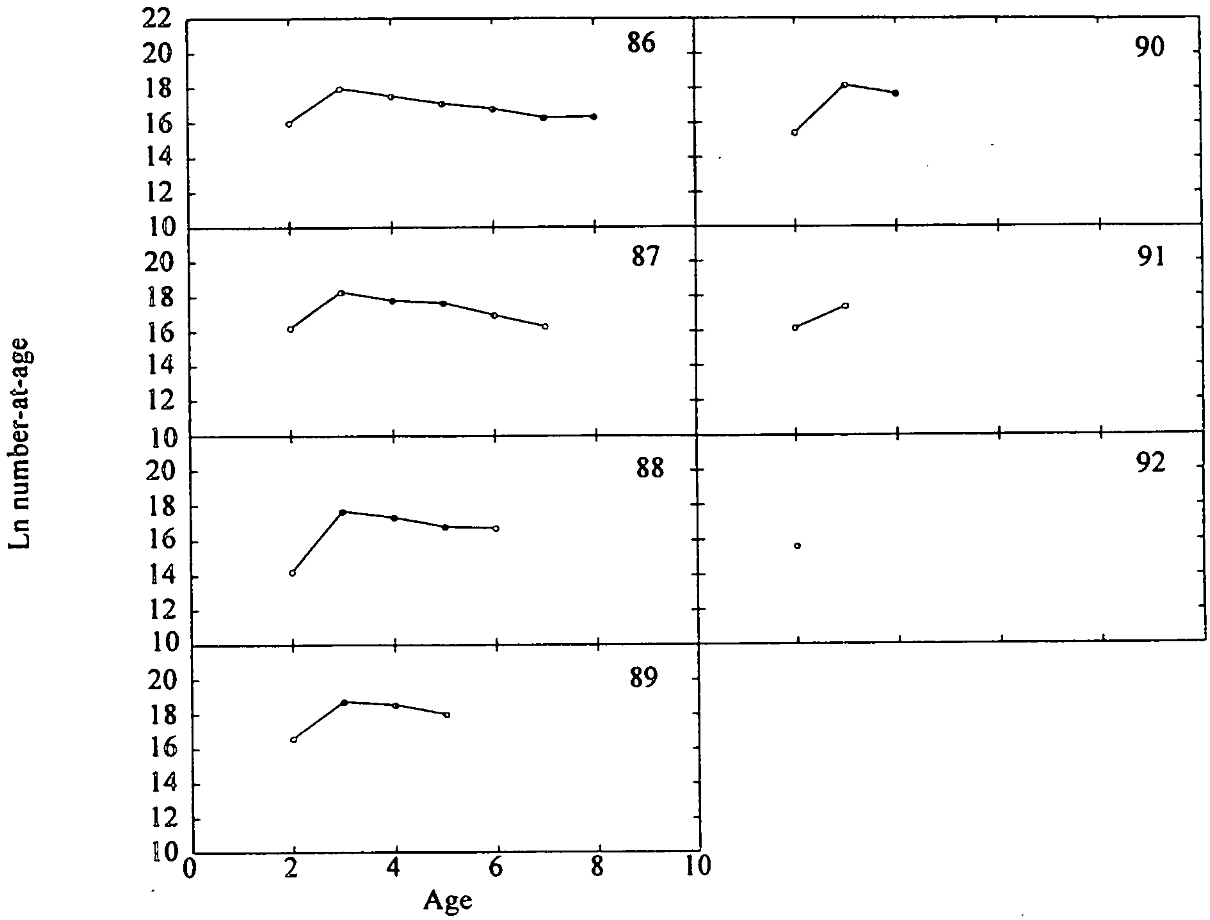


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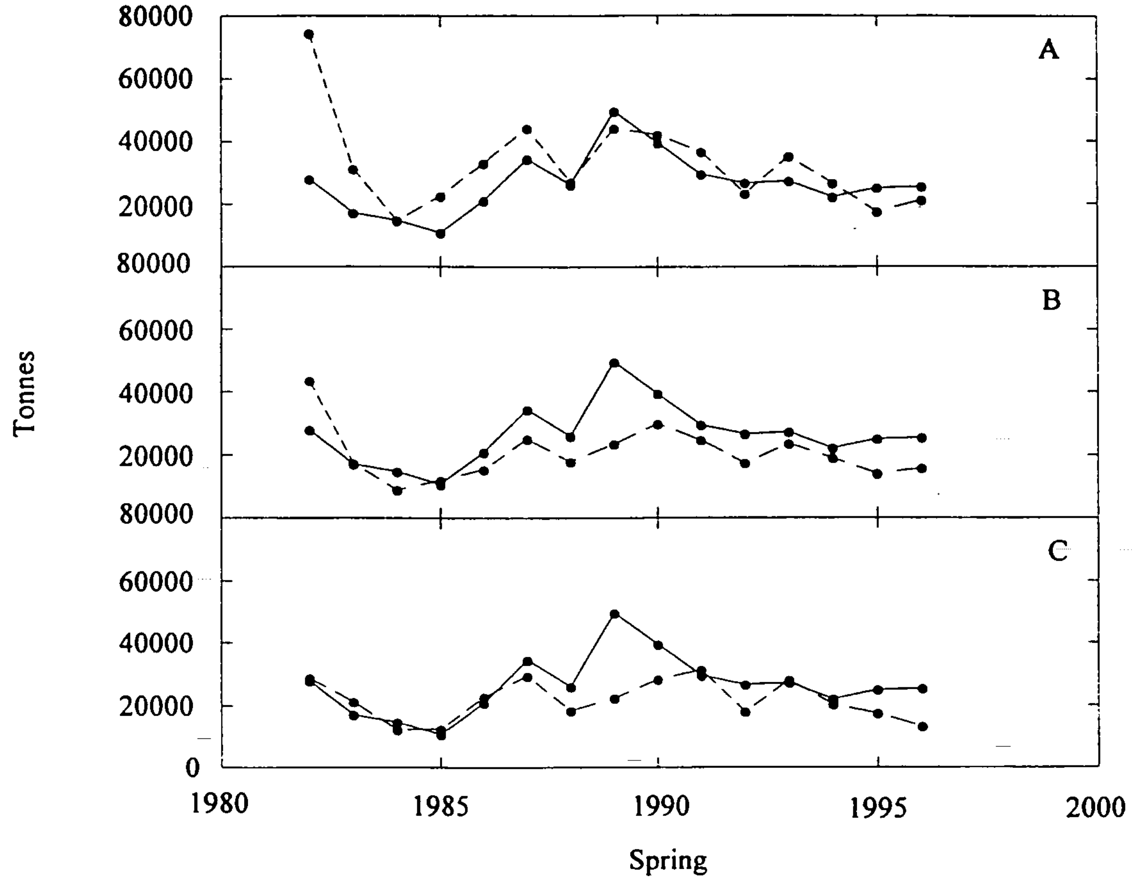


Figure 2 Observed (—) and forecasted (---) prefishery adult biomass. (A) 1972-1996 survival rate estimates. (B) 1980-1996 survival rate estimates. (C) Regression survival rate estimates.

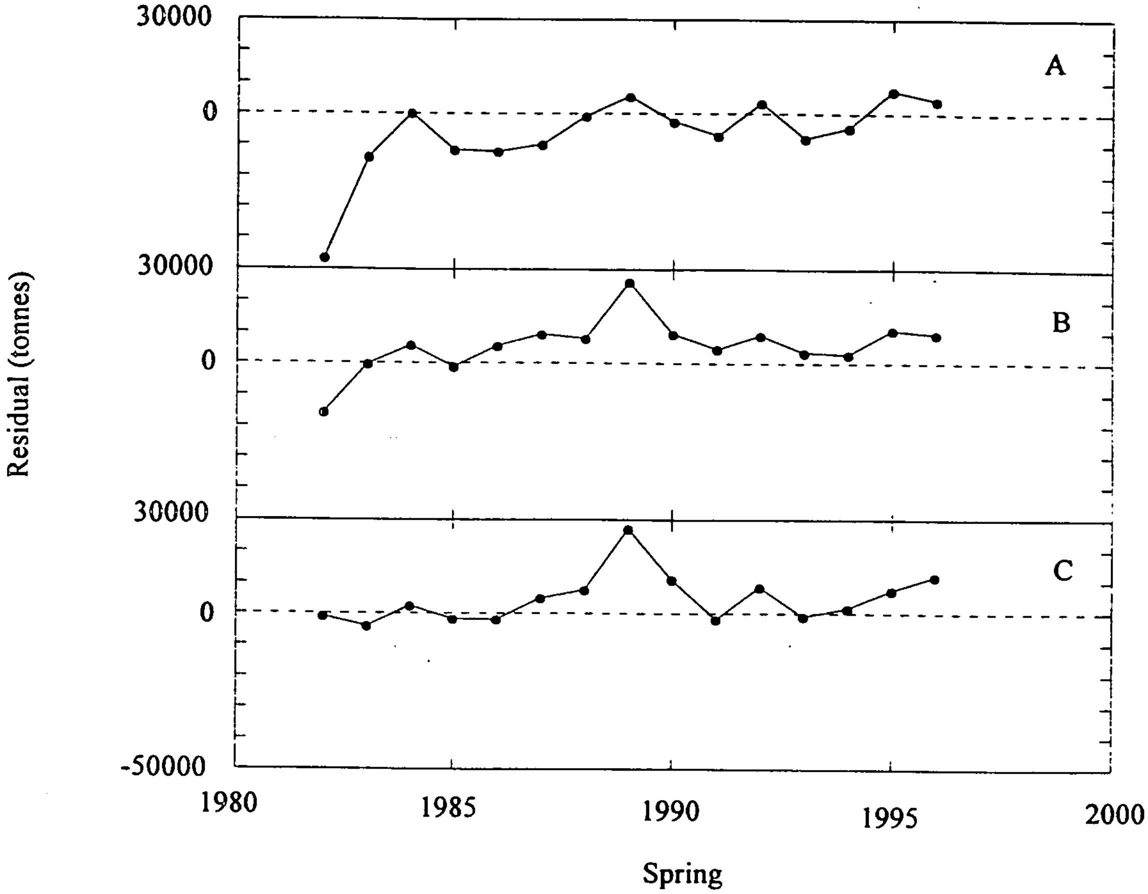


Figure 3 Residuals for forecasted prefishery adult biomass estimates. (A) 1972-1996 survival rate estimates. (B) 1980-1996 survival rate estimates. (C) Regression survival rate estimates.