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# Analyses of survey catchability and fishery selectivity in the SPA for the Northern Gulf of St. Lawrence (3Pn, 4RS) cod stock.

# Analyse de la capturabilité et la sélectivité de pêche des relevés avec l'ASP pour le stock de la morue du nord du golfe du Saint-Laurent (3Pn, 4RS).

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## ABSTRACT

We explore two issues in the sequential population analysis (SPA) for the cod stock in the Northern Gulf of St. Lawerence (3Pn+4RS). In recent assessments the SPA for this stock has been an ADAPT formulation. The first issue we explore involves how to model the fishing mortality at the oldest age in the SPA. The second issue involves possible changes in the catchability of indices used in the SPA to estimate stock size. We conclude that there is some evidence from the SPA that the fishery selectivity has changed since the moratorium, and now has a ”dome” shape. We also conclude that there is statistically significant evidence in the SPA that the catchability of the NGulf indices is not constant over time. This nonstationarity is somewhat consistent with annual changes in the spatial distribution of the stock, which may have become more concentrated in inshore areas. The Sentinel gillnet index has an opposite trend to that predicted by the SPA.

## RÉSUMÉ

Nous avons étudié deux problèmes qui surviennent dans l’analyse séquentielle de population (ASP) pour le stock de morue du nord du golfe du Saint-Laurent (3Pn+4RS). Dans les dernières évaluations de ce stock, une formule ADAPT a été utilisée pour l’ASP. Comment modéliser dans l’ASP la mortalité par pêche exercée sur la plus vieille classe d’âge est le premier problème que nous avons étudié, le deuxième étant les changements possibles dans la capturabilité indiquée par les indices utilisés dans l’ASP pour estimer la taille du stock. Nous concluons que l’ASP démontre dans une certaine mesure que la sélectivité de la pêche a changé depuis le début du moratoire et qu’elle est maintenant en forme de dôme. Nous concluons en outre qu’il existe des éléments probants statistiquement significatifs dans l’ASP à l’effet que la capturabilité indiquée par les indices pour le nord du golfe n’est pas constante au fil du temps. Cette absence de stationnarité concorde quelque peu aux changements annuels dans la distribution spatiale du stock, qui est peut-être devenu plus concentré dans les secteurs côtiers. L’indice de pêche sentinelle aux filets maillants montre une tendance opposée à celle prédite par l’ASP.

# 1 Introduction

Estimation in sequential population analysis (SPA) requires consistent time-series of stock indices; that is, the constant of proportionality (called catchability) between the index and stock size should not change over time. However, in practise catchability may change because of changes in the fishing protocols that an index is based on, or because of changes in the characteristics and behavior of the stock. The latter phenomena can even affect the catchability of a fishery-independent survey based on standardized fishing protocols. For example, if the spatial distribution of the stock at the time of the survey changes from year to year, and if the survey does not cover the entire stock range, then the catchability of the survey will also vary from year to year. If the spatial distribution changes systematically over time then this could result in biased SPA estimates of stock size. Other changes, such as in growth rates, can also affect the catchability of an index.

The cod (*Gadus morhua*) stock in NAFO Subdivision 3Pn and Divisions 4R and 4S (NGulf cod) is assessed using SPA based on five indices, none of which covers the entire range of the stock. It has been suggested (pg. 18 and Figure 31b in Fréchet et al., 2003) that the proportion of the stock inshore of the area represented by some of the indices used in the SPA has changed over time. In this paper we propose an SPA-based method to model and account for changes in the stock distribution. Our approach is outlined in the next section.

# 2 NGulf SPA

We used the common SPA cohort model (Pope's approximation)

$$N_{a+1\,y+1} = N_{ay}e^{-M_{ay}} - C_{ay}e^{-M_{ay}/2}, \tag{1}$$

where $N_{ay}$ is the stock numbers at age $a$ in year $y$, $C_{ay}$ is the commercial catch, and $M_{ay}$ is the natural mortality. The reported commercial catches for ages $a = 2, ..., 13$ from $y = 1974$ to $y = 2003$ were assumed to be known without error. We used the values for

$M_{ay}$ suggested by Fréchet et al. (2003),

$$M_{ay} = \begin{cases} 0.2, & y \leq 1985, \\ 0.4, & y > 1985. \end{cases}$$

The same values were used for all ages.

If estimates of stock numbers-at-age in the last year (survivors) plus stock numbers at the oldest age in the SPA are available then (1) can be used to reconstruct stock size for all ages and years. The survivors and other parameters can be estimated using stock size indices, although a common approach is to use an approximation to specify the numbers at the oldest age. We used a penalty-based approach to constrain estimates of stock size at the oldest age. This is described at the end of this section. Survivors in 2003 were estimated freely for ages $2-13$.

Five indices of stock size were provided prior to the 2003 assessment meeting to fit SPA's. These were:

1. Needler, $1990-2003$, ages $2-13$,
2. Mobile Sentinel July Survey (SNL_Jul), $1995-2003$, ages $2-13$,
3. Mobile Sentinel October Survey (SNL_Oct), $1995-2002$, ages $2-13$,
4. Sentinel Gillnet (GLN_SNL), $1995-2003$, ages $3-13$,
5. Sentinel Linetrawl (HnL_SNL), $1995-2003$, ages $3-13$.

Let $R_{say}$ denote the random value of the $s$th index for age $a$ and year $y$. We explored SPA's based on the assumption

$$E(R_{say}) = q_{sa} N_{ay}. \tag{2}$$

The $q_{sa}$ term is referred to as the catchability of the $s$th index, and is typically unknown and age-dependent, but nominally assumed to be the same from year to year. The constant proportionality assumption in (2) is commonly used when estimating SPA's, and has been used in previous assessments of NGulf cod (see Fréchet et al., 2003).

# 3 SPA Modifications

Often a stock size index is not based on measurements from the entire stock range. For example, an index may be based on only information from trawlable areas and not important inshore areas that are not trawlable. We refer to this as a partial index. The five indices for NGulf cod are partial indices. Although it is not necessary for a reliable stock index to be based on measurements of the entire stock, they are more vulnerable to violations of the constant catchability assumption (see equation 2). A common problem with partial indices results when the spatial distribution of the stock at the time of the survey changes from year to year. This causes the catchability to vary annually which increases the uncertainty about stock trends. If the spatial distribution changes systematically over time then this could result in biased SPA estimates of stock size.

## 3.1 Catchability Model

We propose a new catchability model that may be useful for partial indices that, collectively, cover the entire stock distribution. We only consider the situation where the stock range consists of two areas, and both areas are surveyed separately. This is roughly the situation for NGulf cod, because three of the indices cover offshore regions (Needler, SNL_Jul, SNL_Oct) of the stock area, and the other two indices cover inshore regions. We assume that an annually varying portion of the stock is found in the inshore and offshore regions. Let $Q_{ay}$ denote the fraction of age $a$ fish in the stock that are found in the offshore region in year $y$. The number of fish in the offshore region is $Q_{ay}N_{ay}$, and the number of fish in the inshore region is $(1-Q_{ay})N_{ay}$. The new catchability model for offshore indices is

$$E(R_{say}) = q_{sa}Q_{ay}N_{ay}(t),\ s \in \text{Offshore}, \tag{3}$$

and for inshore indices is

$$E(R_{say}) = q_{sa}\left(1-Q_{ay}\right)N_{ay}(t),\ s \in \text{Inshore}. \tag{4}$$

The $Q$ parameters are estimable when both inshore and offshore indices exist; otherwise, the fraction offshore cannot be uniquely estimated. The $Q$ parameters are also not estimable if they are constant from year to year.

The new catchability model can also be motivated as follows. Consider a survey that covers the entire stock range. A naive attempt to increase the amount of data available for the stock assessment is to split the survey into two areas of equal size (regions 1 and 2), and take the two surveys as replicate measurements of stock size. Of course this is naive because the surveys may not be replicates; that is, if the catchability of the complete survey is $q_a$ then the catchability of the split surveys may not each be $q_a/2$. If the stock is not homogeneously distributed throughout it's range for all age classes then $q_{1a} = q_a Q_{ay}$ and $q_{2a} = q_a(1 - Q_{ay})$, where $Q_{ay}$ is the fraction of the stock numbers at age $a$ that are in region 1 in year $y$. Splitting the survey does not create more information because, although the number of survey points is doubled, the number of unknown parameters has increased by the same amount, so that the split surveys provide no additional information about stock size. For example, if the survey totals in each region are Poisson distributed then the conditional distribution of $R_{1ay}$ given $R_{ay} = R_{1ay} + R_{2ay}$ is Binomial with probability $Q_{ay}$, i.e. $E(R_{1ay}|R_{ay} = r_{ay}) = Q_{ay} r_{ay}$, and this distribution supplies no information about stock size. All of the information about stock size is contained in the marginal distribution of $R_{ay}$, which is $Poi\{q_a N_{ay}(t)\}$. Most researchers would agree that the appropriate approach to use for inferences about stock size is to add the surveys back together, which controls for and removes the nuisance parameters $Q_{ay}$'s. One could also estimate $N_{ay}(t)$, $q_a$, and $Q_{ay}$ directly using the joint distribution of $R_{1ay}$ and $R_{2ay}$ for all $a$ and $y$. The stock size estimates would be identical to those based on the marginal distribution of $R_{ay}$; however, a challenge is to account for uncertainty about the values of $Q_{ay}$ in statistical inferences about stock size when the dimension of the $Q_{ay}$'s is large.

If there is some homogeneity in the stock distribution (e.g. year invariant) then there may be some inferential validity in splitting the survey information. In this case it may be appropriate to split to the tow level; however, further consideration of this is beyond the scope of this paper.

If different gears were used in each split survey then there is an additional problem, because it no longer makes sense to add the surveys together because the $q$'s will likely be gear specific. One must use a different method to account for the $Q_{ay}$ parameters, and the obvious approach is to estimate them and account for the estimation in inferences about stock size. Another complication that is introduced if $q$ is different in both regions is that there is some confounding between $q$'s and $Q$'s. We further consider the confounding below. However, this discussion does suggest that partial indices can be used jointly for inferences about stock size even when the stock distribution changes from year to year, although using such indices increases the model complexity in terms of the number of parameters and the precision of estimators. If spatial/temporal heterogeneity in the stock distribution appears significant and can be accounted for in a simple way, i.e. with a small number of $Q$ parameters, then we suggest that this is preferable to simply assuming that the stock is homogeneously distributed (i.e. $Q_{ay} = 1/2$ for all $a, y$). If the spatial/temporal heterogeneity is complicated then the indices may have little utility for inferences about stock size.

For simplicity we assumed for the NGulf data that the fraction offshore was constant for all ages; that is,

$$Q_{ay} = Q_y \text{ for all ages.}$$

Another simplifying assumption we used is that the fraction offshore was constant throughout the year. We do not advocate that these assumptions are reasonable for NGulf cod. Rather, we propose that our simple approach provides some assessment of the direction and magnitude of the effect of changes in NGulf cod spatial distribution on SPA estimates of stock size. We consider this more in the **Discussion** section.

## 3.2 Fit Function

We estimated parameters using the quasi-likelihood (QL) method. The resulting estimators have some optimality properties (see McCullagh and Nelder, 1989) that suggest they should provide reasonable SPA inference. Quasi-likelihood estimators are not fully parametric because they are based only on assumptions about the mean and variance of the indices. Means, $E(R_{say}) = \mu_{say}$, are given by either (2), (3) or (4). We used a Negative-Binomial type quadratic variance function,

$$Var(R_{say}) = \phi_s \left\{ \theta\mu_{say} + (1-\theta)\mu_{say}^2 \right\}, \tag{5}$$

where $\phi_s$ is an estimated over-dispersion parameter and $\theta$ is an estimated variance parameter, $\theta \in [0,1]$, that controls the weight of the linear and squared terms in the variance function. We have found in SPA simulations that this approach provides reasonable estimates for a wide variety of data distributions ranging from normal to lognormal. Another potential advantage of using this fit function is that zero's in the indices can be accommodated directly without any adjustment. The variance parameter $\phi_s$ was estimated separately for each index $s$. This is a form of self-weighting or intrinsic weighting that attempts to accommodate indices of varying quality. However, the quadratic variance function parameter $\theta$ was assumed to be the same for all indices. This estimation method is described more fully for SPA's in Cadigan (2000). It is based on $-2\times$ the extended quasi-likelihood fit function, which we denote as $\Lambda$.

### 3.3 F Shrinkage

If the unknown numbers at the oldest age ($N_{Ay}$) in the SPA are estimated freely then the resulting estimates are usually very poorly determined because of confounding with the $q_{sa}$ parameters. A common practise is to use constraints to help fix the values of the $N_{Ay}$'s. In assessments of groundfish stocks off the east coast of North America, including NGulf cod, the $N_{Ay}$'s are usually constrained so that their fishing mortalities,

$$F_{ay} = \log\left(\frac{N_{ay}}{N_{a+1\,y+1}}\right) - M_{ay}, \tag{6}$$

are proportional to the average for some range of younger ages. In effect,

$$N_{Ay} = \alpha_y \frac{C_{Ay} e^{M_{Ay}/2}}{1 - e^{-F_{\text{ave }y}}},$$

where $F_{Ay} = \alpha_y F_{\text{ave }y}$. Note that $F_{\text{ave }y}$ is a function of $N_{a\,y+1}$'s, so the end result of the $F$ constraint is that $N_{Ay}$'s are constrained to be functions of unknown $\alpha_y$'s and survivors, and known catches and $M$'s. In this approach the unknown parameters in the cohort model are the survivors and the $\alpha_y$'s. There are potentially as many $\alpha_y$'s as there are $N_{Ay}$'s; however, it is often reasonable to constrain the $\alpha_y$'s. In many assessments the $\alpha_y$'s are all assumed to be equal to a constant, usually one.

We did not fix the values of the $\alpha_y$'s; however, we did not freely estimate these parameters either. We added a term to the $\Lambda$ fit function that penalized against variation in the $\alpha_y$'s from one. The penalized fit function was

$$\Lambda_p = \Lambda + \lambda \sum_y (\alpha_y - 1)^2,$$

where $\lambda$ was a penalty weight that controls the variation in the estimates of $\alpha_y$'s. For example, if $\lambda = 0$ then the $\alpha$'s are freely estimated, whereas when $\lambda$ is very large then the $\alpha$'s are fixed at or very close to one. We choose $\lambda$ as the value that resulted in a 4 unit increase in $\Lambda$ from the value found at $\lambda = 0$. The value of four was arbitrary, but the rationale was to find good estimates of stock size (i.e. those that gave a low value of $\Lambda$) that had as little variation in $\alpha$'s from one as possible. $F$'s at age 13 in $1994 - 2002$ were penalized (i.e. shrunk) to the average $F$'s for ages 10 to 12. A common value for $\alpha_y$ was used for $F$'s at age 13 prior to 1994; however, this value was also shrunk to one but with the penalty weight increased by four to account for the four years with survey information ($1990 - 1993$; see below) available to estimate this $\alpha$. Hence, ten $\alpha$'s were estimated, although not freely.

## 3.4 Comparison with ADAPT Formulation

The are four main differences between the CQ model we use and the standard ADAPT approach used for this stock. The first is the use of Pope's approximation (see equation 1). The cohort model in ADAPT is based on directly solving the Baranov catch equation, although Pope (1972) showed that his approximation is very close to the Baranov solution unless $Z = F + M$ is large (i.e $> 1.5$). Using either the Baranov catch equations or (1) should make little difference on population estimates for NGulf cod. The second difference is self-weighting the tuning indices. Although the most recent version of ADAPT has this capability, it is not used in the NGulf assessment. Self-weighting can result in substantially different estimates of stock size, although it is not clear when self-weighting is preferable over equal-weighting. The QL fit function is also different than the fit function in ADAPT, which is based on the log error sum of squares. Un-reported simulations we have conducted suggested that the quadratic QL fit function produced more accurate estimates of stock size under distributional mis-specification compared to the lognormal approach, although if the lognormal variance assumption appears reasonable in residual plots then either approach may be equally as good. The final difference is the shrinkage estimation of the $\alpha$'s. In the NGulf assessment these parameters are fixed as one each year. The shrinkage approach we use is similar to that used in XSA, which is the most common assessment package used for ICES (International Council for the Exploration of the Sea) stocks. Using appropriate levels of shrinkage can produce more accurate estimates of stock size; however, the reverse also hold, and that is using incorrect levels of shrinkage can lead to less accurate estimates of stock size. External information about fishery selectivity is very helpful for determining appropriate amounts of shrinkage.

The VQ formulation differs from the ADAPT formulation similar to the CQ formulation, but with an additional difference in the catchability model (compare equation 2 with equations 3 and 4).

# 4 Results

SPA estimates of stock size are shown in Figure 1. Estimates are shown for the constant catchability model (CQ; see equation 2), the inshore/offshore catchability model (VQ; see equations 3 and 4), and the same ADAPT formulation used in Fréchet et al. (2003). The ADAPT run produced slightly lower estimates of stock size, followed by the CQ and VQ runs. The estimate of 2003 SSB was 33 Kt for the ADAPT run, 52 Kt for the CQ run, and 66 Kt for the VQ run.

Both the CQ and VQ runs produced very similar estimates of SSB prior to 1990, but they were somewhat different than the ADAPT SSB estimates in this period because the F-shrinkage used in the CQ and VQ runs resulted in different F constraints; that is, F at age 13 in 1974-1993 was approximately equal to 0.83 times the average F at ages 10-12. In the ADAPT formulation F at age 13 was constrained to equal to the average F at ages 11-12. F-shrinkage resulted in a slightly more “domed” commercial fishery partial recruitment (PR; see Figure 2) in recent years, which suggests that the fishery selectivity may have changed since the moratorium. We examined whether the $\alpha$ parameters were significantly different from one. The increase in fit (77.8 chi-square units) was very significant for less than 10 degrees of freedom. The reason the degrees of freedom is less than 10 is that the 10 $\alpha$ parameters were not freely estimated.

The estimates of $Q_y$ in (3) are shown in Figure 3. Note that we constrained $Q_{1990}, ..., Q_{1994}$ to all have the same value. This was because for these years there were no surveys in the inshore region, and in this case annual $Q$ estimates simply reflected year effects in the Needler index. The estimates in Figure 3 suggest that the proportion of the stock offshore decreased in the mid 1990’s but has been stable, albeit variable, since then. The value for 2002 was determined by an external lower bound of 0.2. We consider this further in the **Discussion**. The VQ model explained significantly more variability in the surveys compared to the CQ model because the fit decreased by 42.6 chi-square units based on 10 additional $Q$ parameters.

Residual analyses indicated a problem with the inshore indices. The trend in the Sentinel gillnet index (top panel, Figure 4) is opposite of that predicted by the SPA. This trend is fairly consistent across all ages (see Figure 5). In this figure the change in fit statistic is positive only for the gillnet index, which indicates that the VQ model fit this index more poorly than the CQ model. Note that the distribution of residuals each year indicates that the VQ model does not always fit the surveys better every year, although overall the VQ model fits four of the five indices better.

It is possible that the gillnet catch rates may not reflect trends in abundance because of fishery effects. For example, in other areas like 3Ps and 3KL some fishermen have suggested at RAP meetings that commercial fisheries reduce their Sentinel catch rates because of gear competition. This process is consistent with the large increase in NGulf

Sentinel Gillnet catch rates in 2003 during which there was a moratorium on commercial fishing. If this is true then including this index could bias stock size estimates; hence, we investigated SPA's that did not use this index for estimation.

SPA estimates obtained without the Sentinel Gillnet index are shown in Figure 6. For comparison purposes we also plotted the ADAPT estimates shown in Figure 1, although these estimates were obtained using the gillnet index. The estimate of 2003 SSB was 57 Kt for the CQ run, and 80 Kt for the VQ run. The estimates of $Q_y$ shown in Figure 7 are substantially different than those in Figure 3, both in scale and trend. For example, the average of the values in Figure 3 is 0.29, while the average of the values in Figure 7 is 0.51. This suggests that there is substantial estimation error associated with the $Q_y$'s, and that there may be some confounding between the average of the $Q_y$ values and the $q$ catchability parameters. Note that the value of 0.8 for 1990-1994 was an external upper bound. We consider this further in the next section. The VQ model explained significantly more variability in the surveys compared to the CQ model; the fit decreased by 70.4 chi-square units based on 10 additional free parameters. The improvement in fit occurred for all indices (see Figure 9), but not for all years (also see Figure 8).

# 5 Discussion and Conclusions

The main conclusions from our analyses are as follows.

1. There is statistically significant evidence in the SPA that the catchability of the NGulf indices is not constant over time. This nonstationarity is somewhat consistent with annual changes in the spatial distribution of the stock, which may have become more concentrated in inshore areas.

2. The Sentinel gillnet index has an opposite trend to that predicted by SPA. Factors affecting catch rates in this program require further study.

3. There is some evidence from the SPA that the fishery selectivity has changed since the moratorium.

Note that the Needler index produced before the 2003 RAP meeting was revised during the RAP meeting to address concerns in the way some missing strata were adjusted for. We did not update our analyses with the revised index, although we do not anticipate that this would greatly affect our conclusions. We do expect that the estimates of 2003 stock size we have provided will be more sensitive to the revised index.

We strongly emphasize that the SPA estimates based on the inshore/offshore catchability model are illustrative and should not be directly used when assessing the status of NGulf cod. This model requires further investigation before we could advocate using it for assessment purposes. For example, the efficacy of the method should be simulation-tested. Ideally the approach should better account for knowledge about the temporal and spatial behavior of this stock in the locations and times represented by the various indices. Changes in spatial distribution may depend on age as well. A problem that needs to be resolved is the confounding between the average value for the $Q_y$'s and the $q_a$'s. We feel that this is the reason why estimates of $Q_y$ are at boundary constraints in some years. Essentially, estimates of $Q_y$ are only relative to the year that the constraint is met. This suggests that we may only be able to reliably estimate trends in the fraction offshore relative to a fixed reference value; however, this requires further research. We did not provide confidence intervals for the $Q_y$ parameters, and this is also a useful area for future research.

The inshore/offshore catchability model addresses issues with year effects. Others have also considered this problem. For example, Myers and Cadigan (1995) utilized a correlated errors approach to deal with year effects. When the correlation is large then their approach is similar to fitting a fixed effect for each year, which downweights the importance of annual variations in the magnitude of indices. The approach we have presented here involves a more restricted modification of the catchability model than Myers and Cadigan (1995), and we feel our approach is be better when year effects are caused by changes in spatial distribution.

Cadigan, N.G. 2000. QLSPA estimates of Greenland Halibut stock size. NAFO SCR

Doc. 00/23.

Fréchet, A., Gauthier, J., Schwab, P., Bourdages, H., Chabot, D., Collier, F., Grégoire, F., Lambert, Y., Moreault, G., Pageau, L. and Spingle, J. 2003. The status of cod in the Northern Gulf of St. Lawrence (3Pn, 4RS) in 2002. DFO Canadian Science Advisory Secretariat Research Document 2003/065.

McCullagh, P., and Nelder, J. A. (1989) *Generalized linear models.* 2nd ed. London: Chapman and Hall.

Myers, R.A., and Cadigan, N.G. 1995. Statistical analysis of catch-at-age data with correlated errors. *Can. J. Fish. Aquat. Sci.* **52**: 1265-1273.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. *ICNAF Res. Bull.* **56**: 65-74.

# 6 Figures

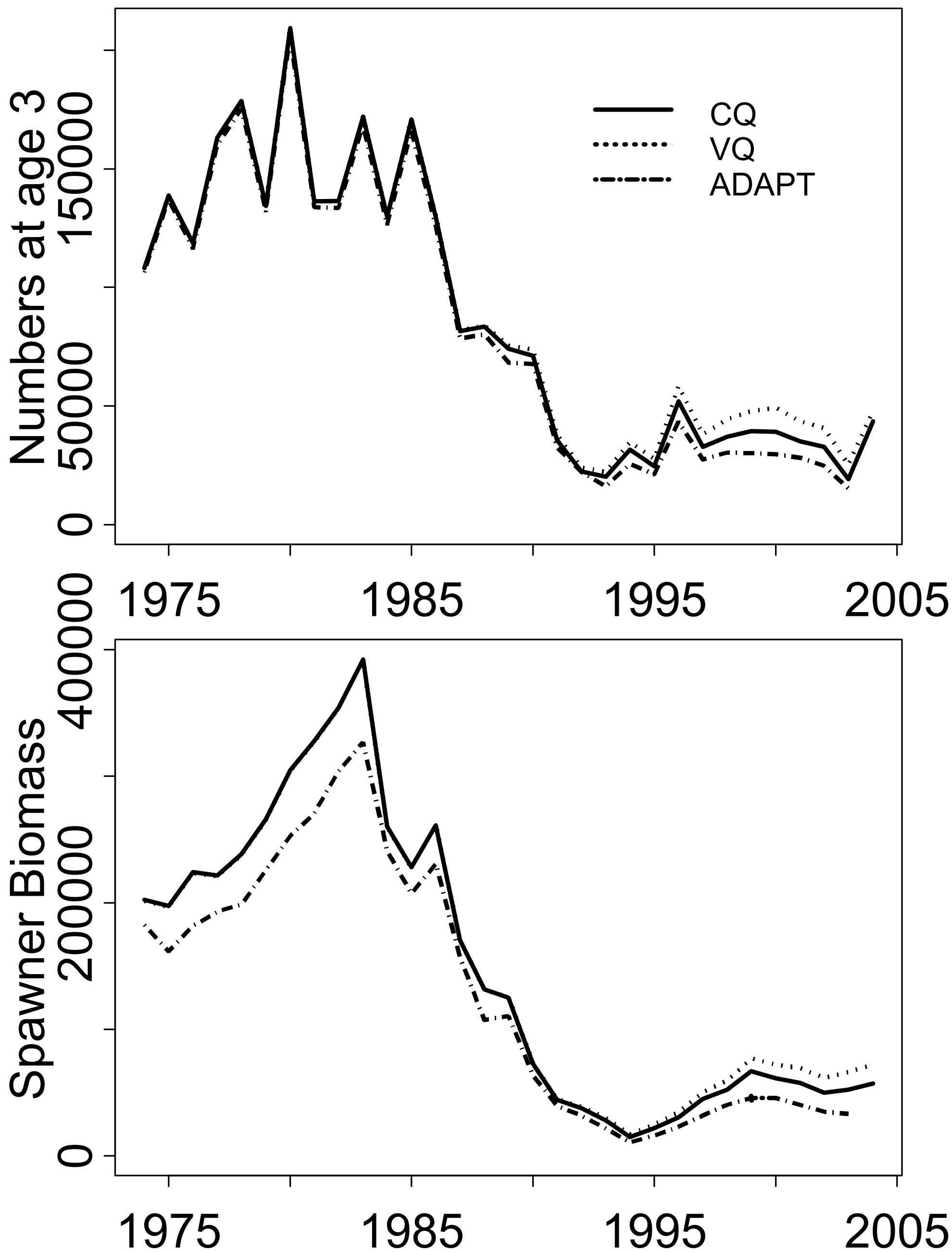


Figure 1: NGulf cod SPA recruitment estimates (numbers at age 3; top panel), and spawner biomass estimates (tonnes; bottom panel). CQ refers to quasi-likelihood estimates based on the constant catchability model; VQ estimates are based on the Inshore/Offshore catchability model; ADAPT estimates are based on the formulation used for the 2003 assessment of NGulf cod.

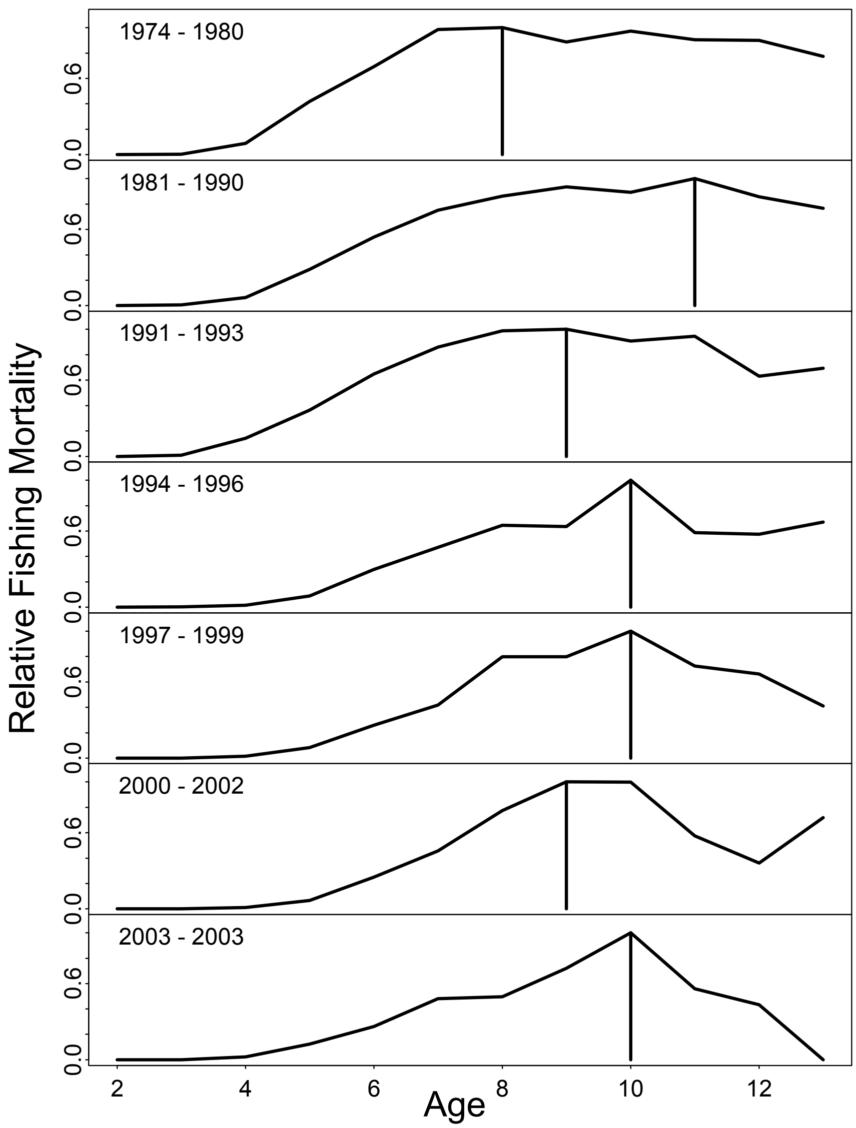


Figure 2: NGulf cod SPA estimates of the total fishery age selectivity (PR). Each panel shows the PR averaged for a block of years. The vertical solid line indicates the fully recruited age.

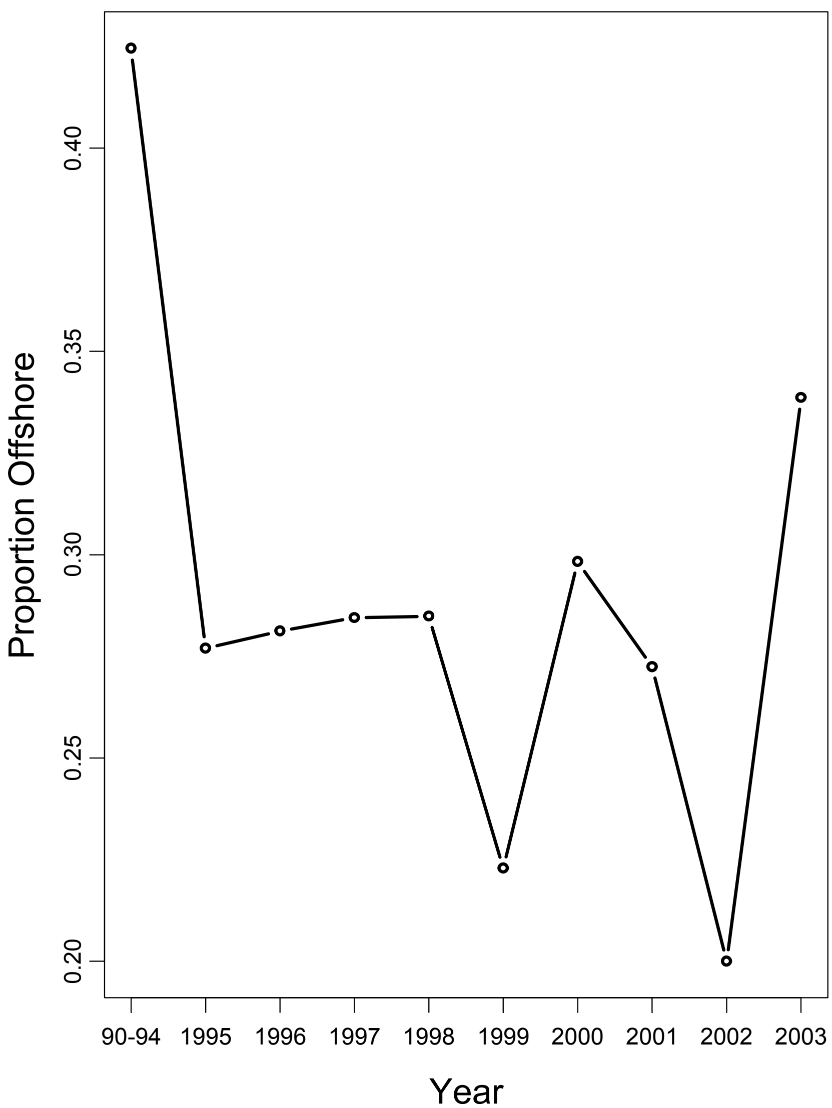


Figure 3: NGulf cod SPA estimates of the proportion of the stock offshore.

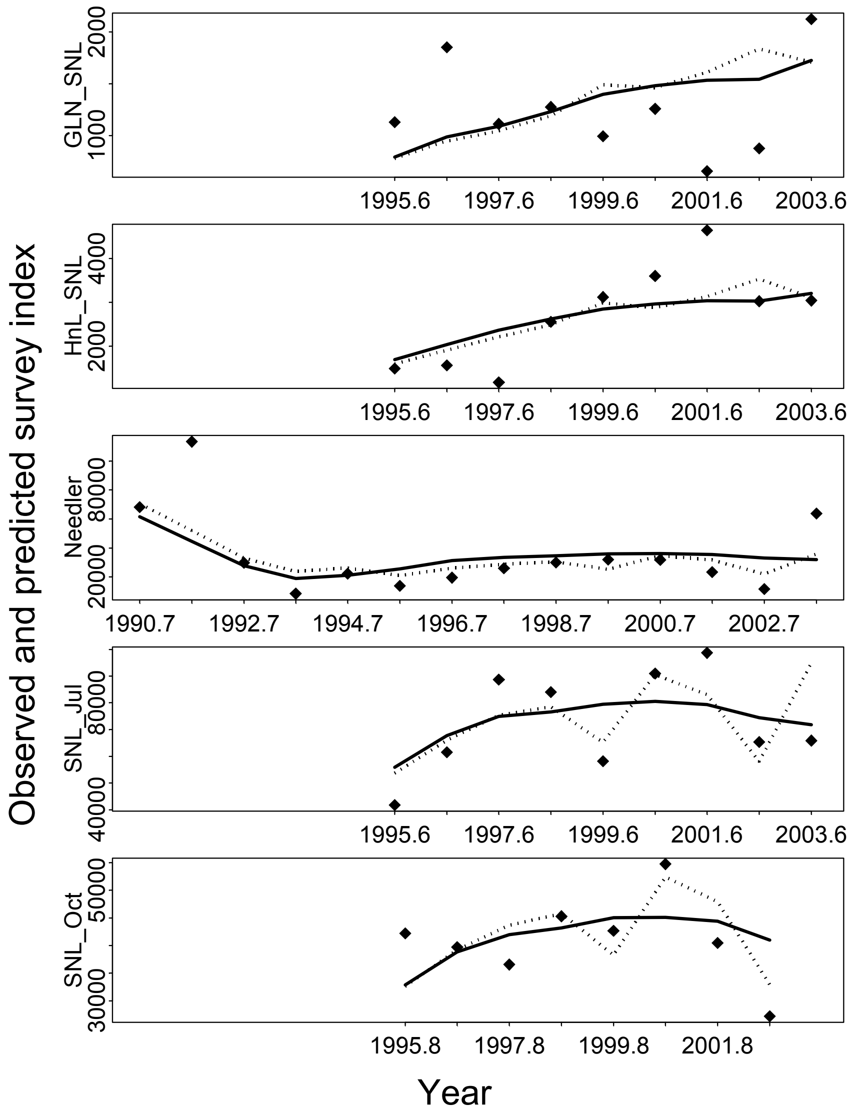


Figure 4: Total observed (points) and predicted indices. Solid line - constant catchability (CQ); dotted line - inshore/offshore catchability (VQ). Each panel shows the results for an index time series.

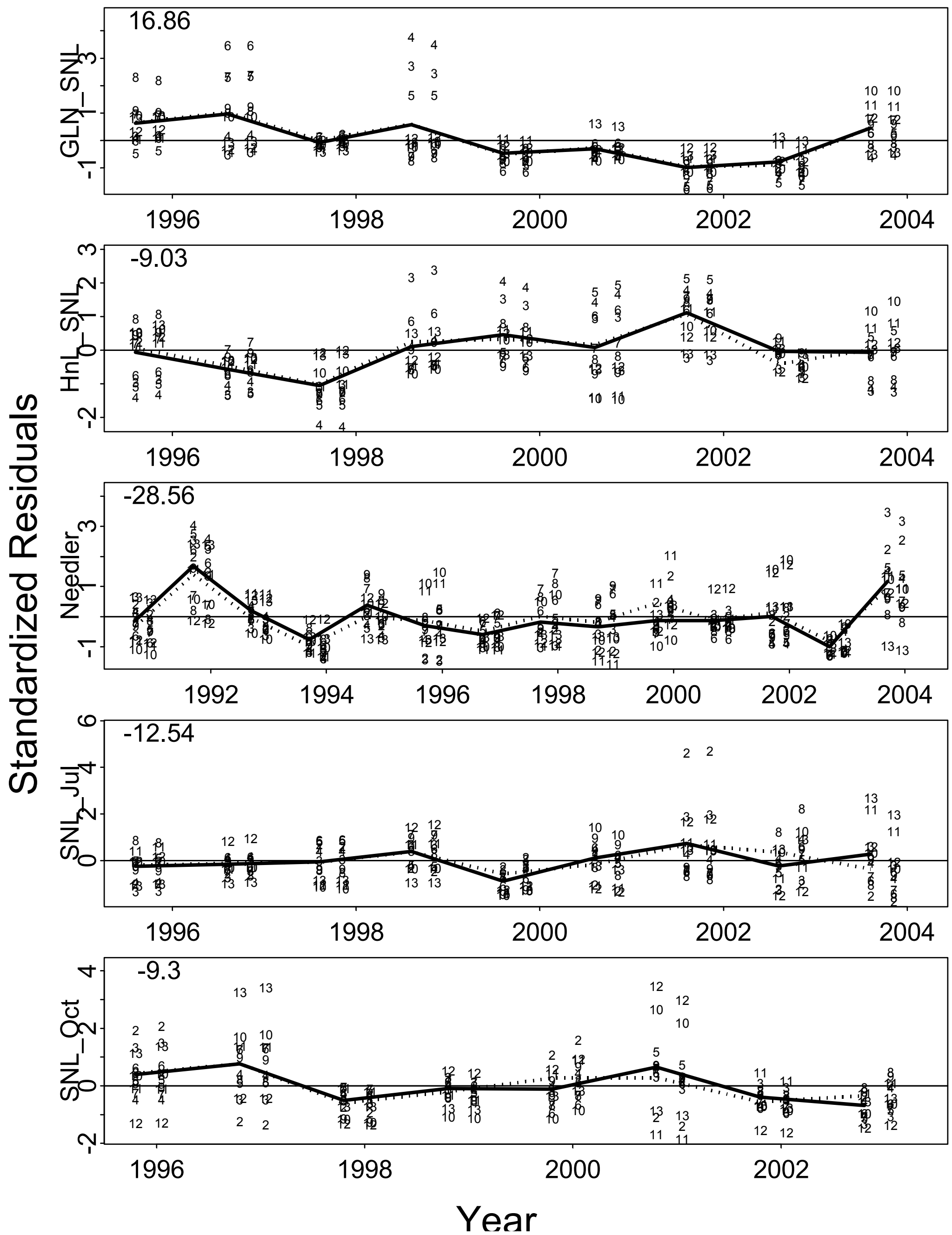


Figure 5: Standardized residuals for each index, age, and year. Residuals are plotted versus year, and the plotting symbol represents age. Lines connect the average residual each year. Residuals are left jittered for the constant catchability model (CQ, solid line), and right jittered for the inshore/offshore catchability model (VQ, dotted line). The change in fit (VQ-CQ) for each index is shown at the top left-hand corner of each panel.

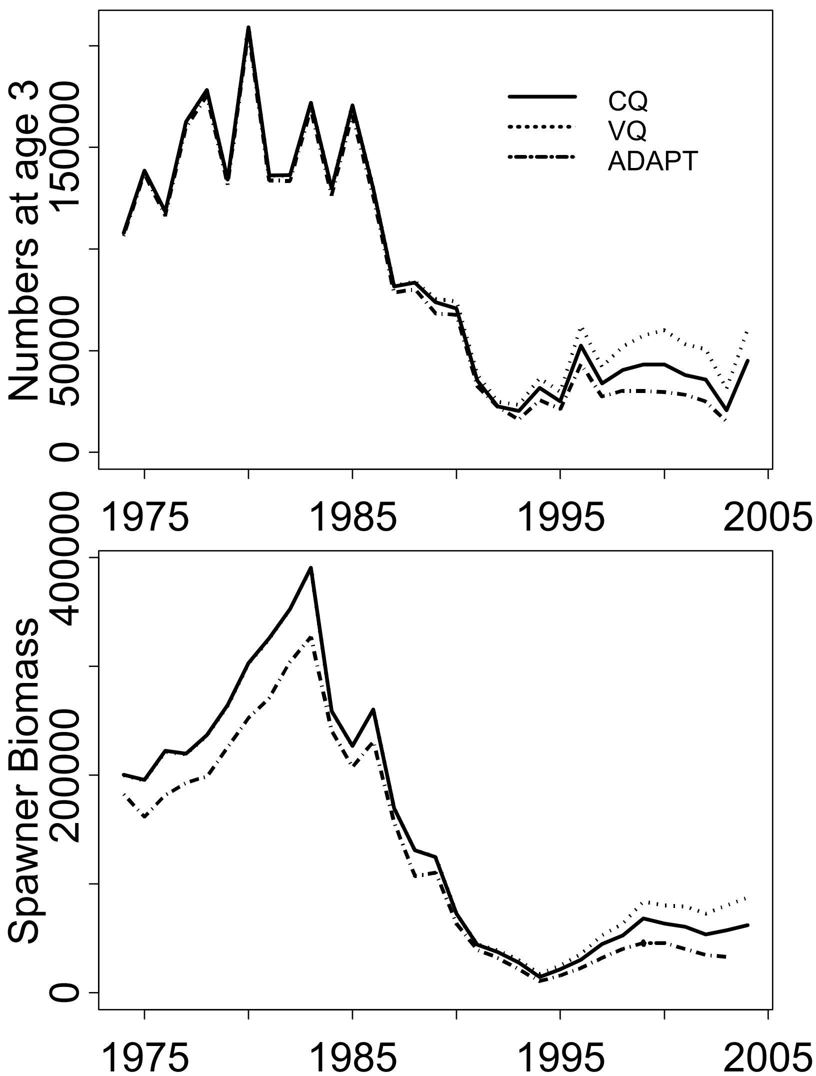


Figure 6: NGulf cod SPA recruitment estimates (numbers at age 3; top panel), and spawner biomass estimates (tonnes; bottom panel). CQ refers to quasi-likelihood estimates based on the constant catchability model; VQ estimates are based on the Inshore/Offshore catchability model; ADAPT estimates are based on the formulation used for the 2003 assessment of NGulf cod The QLSPA estimates were obtained without the Sentinel Gillnet index.

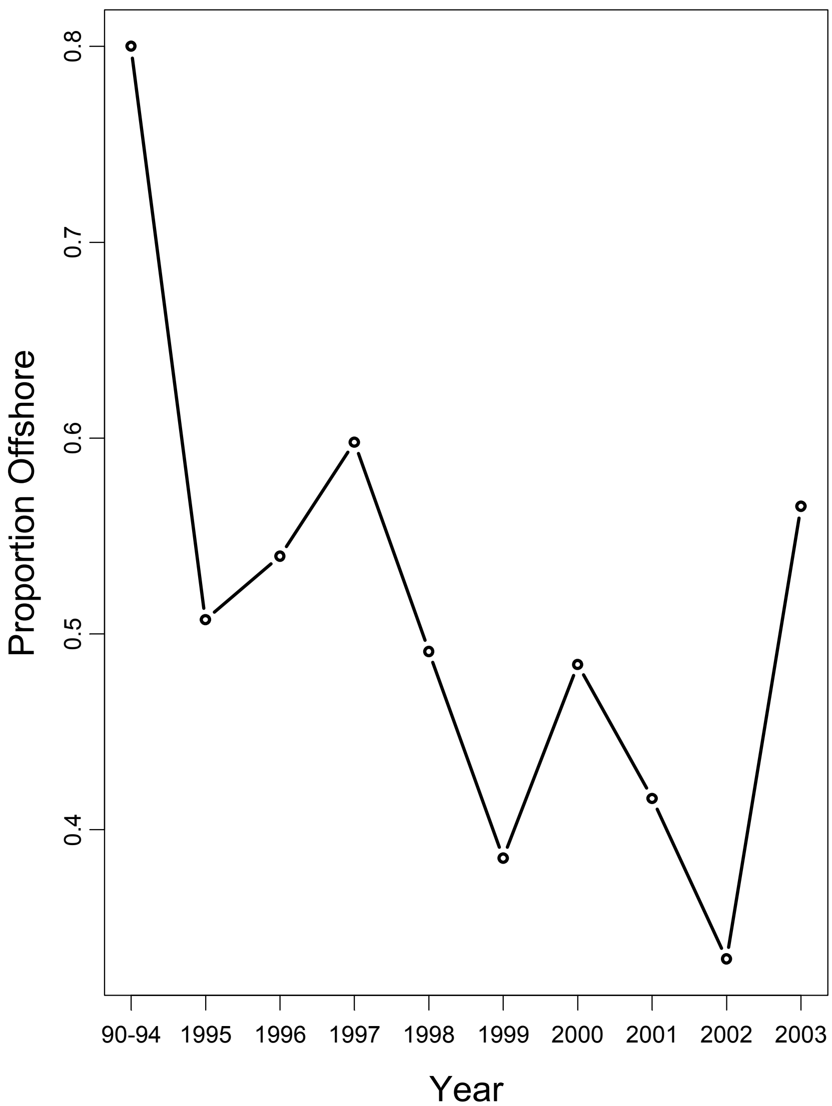


Figure 7: NGulf cod SPA estimates of the proportion of the stock offshore. Estimates were obtained without the Sentinel Gillnet index.

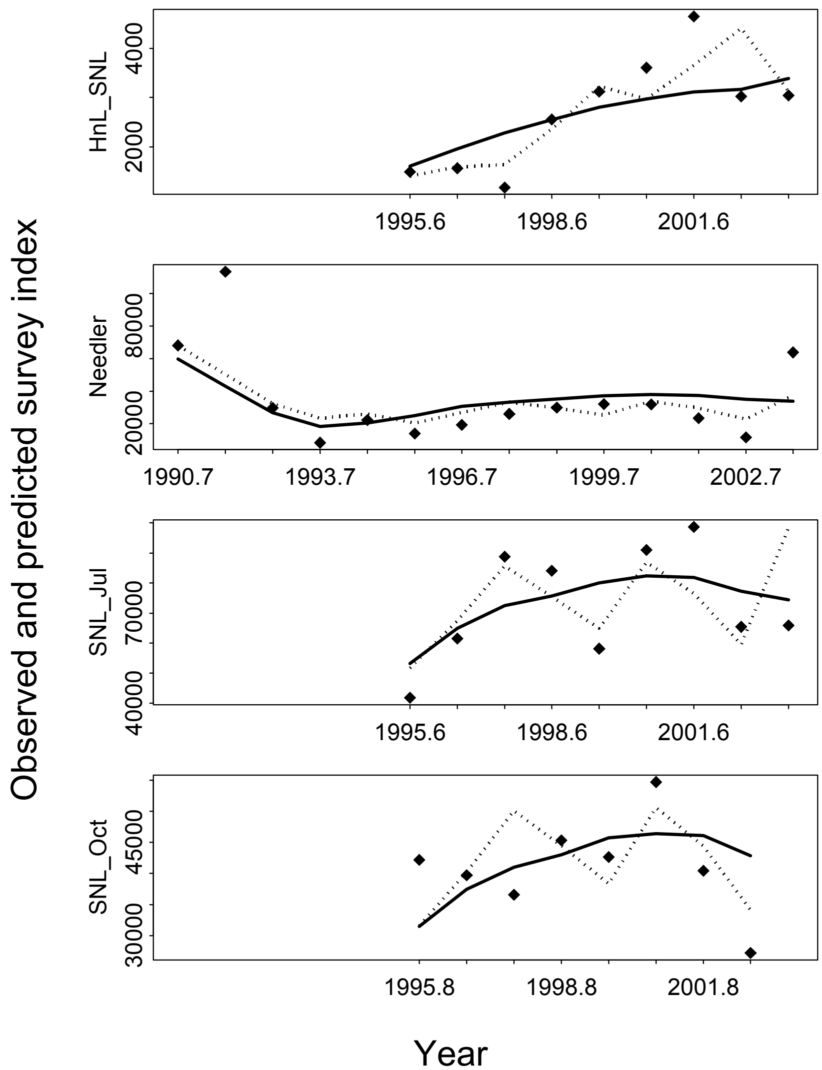


Figure 8: Total observed (points) and predicted indices. Solid line - constant catchability (CQ); dashed line - inshore/offshore catchability (VQ). Each panel shows the results for an index time series.

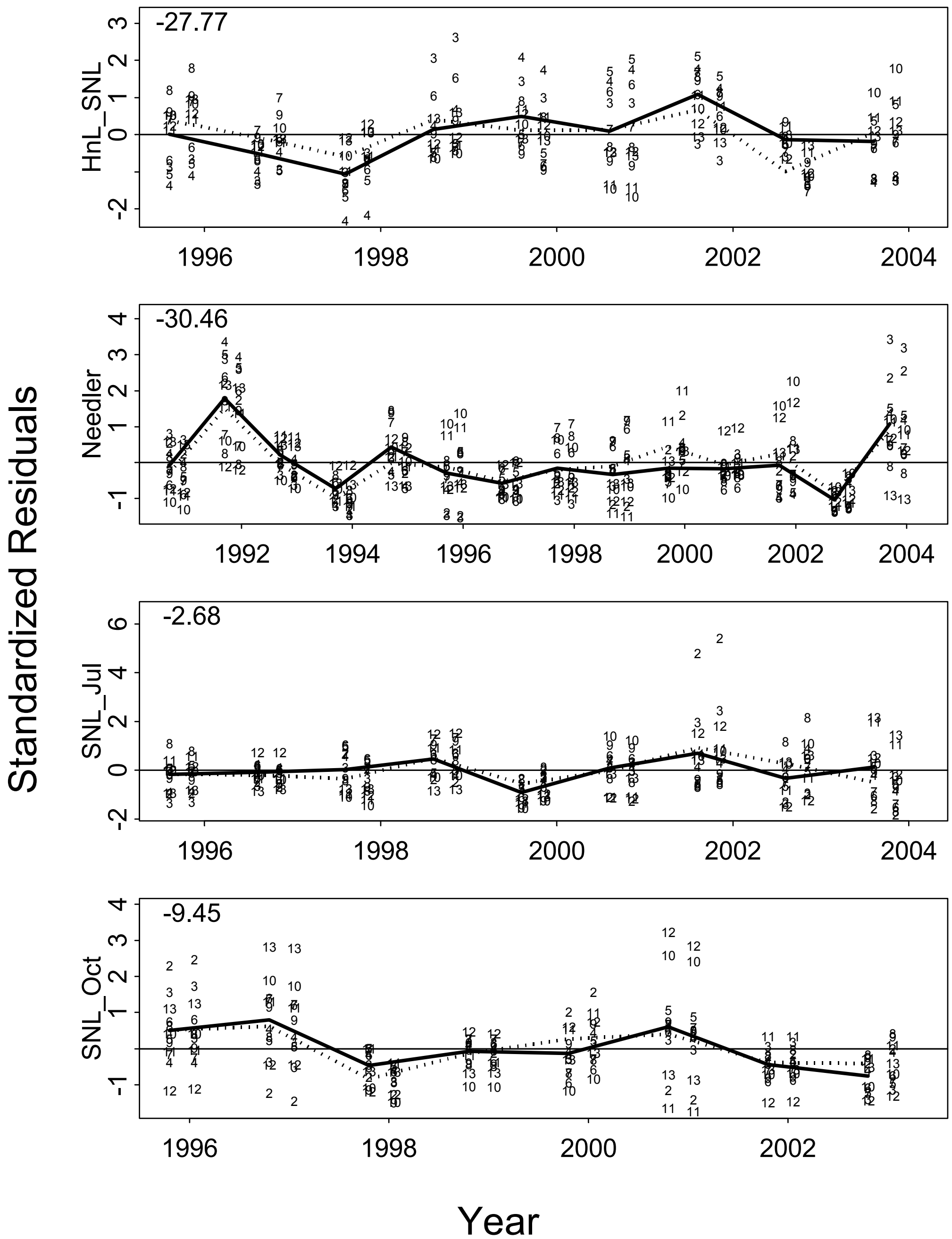


Figure 9: Standardized residuals for each index, age, and year. Residuals are plotted versus year, and the plotting symbol represents age. Lines connect the average residual each year. Residuals are left jittered for the constant catchability model (CQ, solid line), and right jittered for the inshore/offshore catchability model (VQ, dotted line). The change in fit (VQ-CQ) for each index is shown at the top left-hand corner of each panel.