Tagging estimates of abundance at age for the northern region red drum stock.

Noel Cadigan
CIE Expert
Fisheries and Oceans Canada

Lee Paramore
North Carolina Division of Marine Fisheries

Abstract

Trends in estimates of abundance derived from tagging estimates of fishing mortality rates (F) and independent estimates of catch-at-age were consistent with the general understanding of stock trends for northern red drum. However, we found that catch-curve estimates of F from tagging abundance-at-age estimates suggested lower F's overall than the tagging-F's themselves, although the trends in F's were similar. Until these discrepancies are resolved, it seems more prudent to use the tagging-F to assist in estimating a SCCA. Tagging-F's and their standard errors can be treated as direct inputs and fitted to SCCA model estimates of F. Fitting to *log(F)* may be reasonable but requires some investigation. Tagging-F's should only be compared with the appropriate F component in the SCCA.

Introduction

Bacheler et al. (2008) gave estimates of fishing mortality (F) for North Carolina (NC) recreational and commercial fisheries based on recaptures from tagging experiments conducted during 1983-2006. These estimates were adjusted for tag loss and reporting rates and should be unbiased for the northern region red drum stock components in NC. It is felt that these components comprise the majority of this stock, and that the F estimates are indicative of the stock as a whole. These F's can be used to estimate stock abundance (at age which can be used in the statistical catch at age (SCCA) model as tuning indices with catchabilities (q's) fixed at one. Alternatively, the F's can be used directly to "fit" to SCCA model F. Pro's and Con's on these approaches are provided in the **Discussion**.

Bacheler et al. (2008) provided estimates of F for caught and kept fish, and also an F′ for fish caught and released, although the latter was not directly a source of mortality. Bacheler et al. (2008) assumed that 10% of released fish died, and they estimated an adjusted age-based annual fishing mortality rate,

$$F_{adj,ay} = F_{ay} + 0.1F'_{ay}.$$

Methods

The estimates of $F_{adj,ay}$ and F_{ay} can be used with an estimate of the kept catch at age (C_{ay}) to estimate stock size,

$$C_{ay} = \frac{F_{ay}(1 - S_{ay})\hat{N}_{ay}}{F_{adj,ay} + M_{ay}},\ S_{ay} = \exp(-F_{adj,ay} - M_{ay}).$$

In this equation, S_{ay} is the annual survival fraction and $(1\text{-}S_{ay})N_{ay}$ is the total deaths, of which the fraction $F_{ay}/(F_{adj,ay} + M_{ay})$ are due to kept catch. A more direct expression for the stock size estimate is

$$\hat{N}_{ay} = C_{ay}\frac{F_{adj,ay} + M_{ay}}{F_{ay}(1 - S_{ay})},\ S_{ay} = \exp(-F_{adj,ay} - M_{ay}). \quad (1)$$

Bacheler et al. (2008) assumed the following natural mortalities, $M_1 = 0.3$, $M_2 = 0.22$, $M_3 = 0.16$, and $M_{4+} = 0.10$. These are different from the values proposed for the SCCA assessment model. However, if $Z_{ay} = F_{adj,ay} + M_{ay}$ is small then $1 - S_{ay} = 1 - exp(-Z_{ay}) \approx Z_{ay}$ and

$$\hat{N}_{ay} \approx \frac{C_{ay}}{F_{ay}}. \quad (2)$$

Hence, we expect the estimates of N_{ay} to be fairly insensitive to the values used for M_{ay}, and we illustrate this in the **Results**. Note that the tagging estimates of *F* may not be insensitive to the choice of *M*, but we could not evaluate this.

Standard errors

Equation (2) also suggests a simple approximation for standard errors for *N*. Using the delta method it can be shown that

$$\begin{aligned} SE(\hat{N}) &\approx \hat{F}^{-1}\left\{Var(C) + \hat{N}^2 \times Var(\hat{F})\right\}^{1/2} \\ &\approx \hat{N} \times CV(\hat{F})\left\{1 + \frac{CV^2(C)}{CV^2(\hat{F})}\right\}^{1/2}. \end{aligned} \quad (3)$$

where *CV* is the coefficient of variation, *CV = SE/mean*. If there is no error in catch then

$$SE(\hat{N}) \approx \hat{N} \times CV(\hat{F}).$$

For simplicity, we did not include subscripts in the above equations, but in fact, tagging estimates of *F* are available by year and for ages 1, 2, 3, and 4+. Bacheler et al. (2008) used a separable model for *F*, with selectivity estimated for three time periods (*p*):

$$F_{a,y} = F_{\max.y} S_{a,y \in p}.$$

$F_{max,y}$ is the fully recruited annual *F*, and $S_{a,p}$ is the age-selectivity for each period $p=1,2,3$. Bacheler et al. (2008) provided SE's for the $F_{max,y}$ and $S_{a,p}$ estimates. Covariances were not available to us. We used the following approximation for the SE of the $F_{a,y}$ estimates,

$$SE(\hat{F}_{a,y}) \approx \left\{\hat{F}^2_{\max,y} Var(\hat{S}_{a,y\in p}) + \hat{S}^2_{a,y\in p} Var(\hat{F}_{\max,y})\right\}^{1/2}, and$$
$$CV(\hat{F}_{a,y}) \approx \left\{CV^2(\hat{S}_{a,y\in p}) + CV^2(\hat{F}_{\max,y})\right\}^{1/2}.$$

If $COV(F_{max,y},S_{a,p}) = 0$ then the SE's and CV's approximations should be reasonable.

Confidence intervals

An approximate (1-2α)100% confidence interval for *N* is

$$(\hat{N}_L, \hat{N}_U) = \hat{N} \pm Z_{1-\alpha} SE(\hat{N}),$$

where $Z_{1-\alpha}$ is the 1-α quantile from a normal distribution. For example, if there is no error in the catch, i.e. $CV(C) = 0$, and the CV for *F* is 25% then a 95% confidence interval for *N* would be ± 50% of the estimate. If there is no error in the catch then an alternative confidence interval method is the direct application of equation (2) to confidence intervals for F.

Results

The estimates of *F* and F_{adj} from Bacheler et al. (2008) are given in Table 1a and 1b and Figure 1. The results indicate that fishing mortality declined substantially in the early 1990's and varied little since then, except at age 2 in which F increased substantially in 2001 and 2002. Selectivites are shown in Figure 2 for the three periods. The overall trend is increasing selection of age 2 fish.

The assessment workshop concluded that the best estimates of M were 0.20, 0.13, and 0.12 for ages 1-3. We used 0.07 as an average value for age 4+ M. Using these values and the catch data (commercial + recreational harvest) given in Table 2, population abundance was estimated using equation (1). These results are shown in Table 3 and Figure 3. This figure also illustrates the insensitivity of the population abundance estimates to the M values used in the tag-return model (Bacheler et al. 2008) versus those M values proposed for the SCCA assessment model.

Age specific population abundance estimates (Figure 4), while quite variable from year to year, generally suggested an increase in abundance since the early 1990's, especially at ages 2 and 3. Population abundance estimates for ages 1 to 3 will be provided as a potential tuning index in the SCCA assessment model. The confidence intervals in Figure 2 (and Table 4) were based on the assumption that $CV(C) = 0$, which is clearly not correct. However, estimates of the CV for catch at age were not available. The CV's for F averaged 22% over all years and ages. If the catch CV's are about the same as the F CV's then equation (3) suggests that the confidence intervals should be increased by about $2^{½}$ = 1.4. If the catch CV is 50% then the confidence intervals should be increased 2.5 fold.

Stock size does not decrease with age for all cohorts in Table 3. This could be simply caused by estimation error; however, to investigate for systematic discrepancies we computed total mortality at ages 1 and 2 (i.e. catch curve Z's) and subtracted the AW M's to give total F implied by the tagging estimates of stock size (tagging-N). This should correspond closely with the tagging estimates of F (tagging-F). The Z values were more variable since the early 1990's and, particularly for 1992-1994, the negative values indicate possible discrepancies between tagging F's and catches. This could be caused by, for example, bias in the F-selection pattern estimated from tagging, or bias in the age compositions of the catches. The tagging-N estimates of F were usually lower than the tagging-F's, especially at age 1. Since the early 1990's tagging-N estimates of F have often been negative.

Discussion

The tagging estimates of stock size (tagging-N's) were fairly noisy, with interannual variation that probably exceeds that in the stock. However, the trends in tagging-N's were consistent with the general understanding of stock trends, and the amount of noise was not excessive compared to other abundance indices available. Hence, the tagging-N's could be used to assist in estimating a SCCA. However, a problem is that catch-curve estimates of F from tagging-N's suggest lower fishing mortality overall than the tagging-F's themselves, although the trends in F's were similar. There are several possible explanations for this. Until these discrepancies are resolved, it seems more prudent to use the tagging-F's to assist in estimating a SCCA. This is described in more detail below.

The assumption of 10% release mortality by Bacheler et al. (2008) is different from the value the Assessment Workshop concluded was most appropriate (i.e. 8%). However, stock size estimates should be relatively insensitive to the value used for % release mortality, for the same reason they are relatively insensitive to the values used for M; that is, $F_{adj,ay}$ is not involved in equation (2).

More accurate methods such as the bootstrap or even the delta method based on the full covariance matrix for all tag-return model parameter estimators and equation (1) could be used to produce standard errors for tagging-N's and tagging-F's. However, these approaches are considerably more complex than the approaches we used, in part because the tagging model contains a fairly large number of parameters.

Incorporating tagging-N's into a stock assessment model such as SCCA is straightforward. Basically, they are treated the same as other indices, except the tagging-N catchability (Q) is fixed at one. This provides a valuable absolute scale to a stock assessment model. This scale can otherwise be difficult to fix if the time series is short or fishing mortalities are low, especially on older ages. A disadvantage of using tagging-N's is that they involve two sources of error: (1) the tagging-F's and (2) catch-at-age estimation. Accounting for the catch-at-age errors is not straightforward when these errors have to be estimated in the SCCA. Also, the catch data is already used in a SCCA, and using it a second time to produce tagging-N's may lead to false precision and other insidious problems that can occur if total catch estimates are biased in some years. This is analogous to the biases that can occur using a CPUE index to estimate a VPA when catch is under-estimated.

Using tagging-F's directly in a SCCA involves a more direct separation of information. Tagging-F's are not affected by measurement error in catch. SCCA attempts to account for catch estimation error, and providing independent estimates of F should improve SCCA in this regard. Using tagging-F's directly is simpler than using tagging-N's because tagging-F's and their standard errors are treated as direct inputs to the SCCA; however, SCCA software probably requires modification to use F inputs for estimation. Fitting to *log(F)* may be reasonable but requires some investigation. Bacheler et al.

(2008) provided estimates of F for two fishery components, commercial+recreational and recreational release mortality. Care must be taken to compare tagging-F's with the appropriate F component in the SCCA.

Tables and Figures

Table 1a. Fishing mortality rates for kept catch (commercial plus recreational) estimated from an age dependent tag return model from 1983-2004.

	Age			
Years	1	2	3	4+
1983	2.519	3.806	1.393	0.117
1984	1.776	2.683	0.982	0.082
1985	0.898	1.357	0.497	0.042
1986	0.825	1.246	0.456	0.038
1987	1.478	2.233	0.817	0.068
1988	1.528	2.309	0.845	0.071
1989	2.564	3.873	1.418	0.119
1990	1.987	3.002	1.099	0.092
1991	0.499	0.755	0.276	0.023
1992	0.177	0.653	0.192	0.030
1993	0.259	0.952	0.280	0.044
1994	0.121	0.446	0.131	0.021
1995	0.087	0.320	0.094	0.015
1996	0.070	0.257	0.076	0.012
1997	0.126	0.463	0.136	0.022
1998	0.165	0.606	0.178	0.028
1999	0.026	0.437	0.104	0.001
2000	0.034	0.558	0.133	0.001
2001	0.065	1.080	0.257	0.003
2002	0.071	1.168	0.278	0.003
2003	0.026	0.422	0.101	0.001
2004	0.015	0.256	0.061	0.001

Table 1b. Total fishing mortality rates (F_{adj}) estimated from an age dependent tag return model from 1983-2004.

	Age			
Years	1	2	3	4+
1983	2.519	3.806	1.393	0.117
1984	1.787	2.700	0.989	0.083
1985	0.898	1.357	0.497	0.042
1986	0.832	1.256	0.460	0.039
1987	1.488	2.249	0.823	0.069
1988	1.534	2.318	0.849	0.071
1989	2.584	3.904	1.429	0.120
1990	2.021	3.053	1.118	0.094
1991	0.530	0.797	0.292	0.024
1992	0.183	0.674	0.198	0.031
1993	0.273	1.006	0.296	0.047
1994	0.161	0.593	0.175	0.028
1995	0.110	0.405	0.119	0.019
1996	0.078	0.287	0.084	0.013
1997	0.139	0.510	0.150	0.024
1998	0.177	0.650	0.191	0.030
1999	0.028	0.467	0.111	0.001
2000	0.036	0.600	0.143	0.002
2001	0.068	1.129	0.269	0.003
2002	0.073	1.204	0.287	0.003
2003	0.027	0.447	0.106	0.001
2004	0.016	0.266	0.063	0.001

Table 2. Total kept harvest (commercial + recreational) for ages 1 through 4+ for the period of 1983 to 2004.

Year	1	2	3	4+
1983	177,636	64,786	5,875	3,999
1984	112,852	73,880	14,143	2,911
1985	41,760	26,086	3,011	1,726
1986	92,581	43,611	2,417	5,802
1987	135,831	59,062	4,221	939
1988	165,296	50,021	6,573	7,156
1989	65,172	76,983	7,016	4,944
1990	71,079	24,039	2,626	2,466
1991	86,545	25,284	725	1,044
1992	2,843	65,823	4,142	436
1993	4,882	71,226	29,953	1,050
1994	2,431	25,939	20,789	3,997
1995	12,858	109,157	15,154	1,974
1996	15,875	31,163	10,948	1,497
1997	7,544	10,619	4,005	902
1998	10,972	207,423	5,481	2,189
1999	12,373	117,516	31,544	139
2000	2,492	69,955	63,489	182
2001	2,055	19,606	34,429	820
2002	21,375	92,695	4,051	1,128
2003	668	44,215	16,908	36
2004	8,671	15,483	20,330	2

Table 3. Population abundance estimates derived from fishing mortality rates from an age-dependent tagging model.

Year	1	2	3	4+
1983	205,257	68,335	8,120	37,563
1984	146,303	82,803	23,630	38,155
1985	76,591	36,932	8,048	43,846
1986	179,987	64,695	6,919	160,299
1987	190,324	69,354	7,908	14,683
1988	227,759	58,055	12,040	108,353
1989	75,433	81,626	9,658	45,707
1990	89,107	26,589	4,133	29,037
1991	244,137	51,404	3,170	47,274
1992	19,291	146,731	24,947	15,046
1993	23,682	125,165	129,527	25,029
1994	23,898	81,682	181,243	201,448
1995	172,096	440,743	179,409	138,156
1996	260,350	148,257	158,534	129,946
1997	70,692	31,047	33,232	43,694
1998	79,993	493,012	35,450	81,291
1999	522,727	357,256	336,446	126,251
2000	82,772	176,700	538,521	129,984
2001	35,817	31,933	160,204	302,149
2002	345,007	143,692	17,565	384,237
2003	29,190	137,752	186,036	34,268
2004	622,705	73,388	362,209	2,956

Table 4. Coefficient of variation associated with the population abundance estimates. The CV's do not include uncertainty in catch.

Year	1	2	3	4+	Combined
1983	0.4972	0.4844	0.4944	0.4845	0.3411
1984	0.4331	0.4183	0.4299	0.4184	0.2566
1985	0.4426	0.4281	0.4394	0.4282	0.2539
1986	0.2604	0.2351	0.2551	0.2352	0.1507
1987	0.2278	0.1983	0.2217	0.1984	0.1616
1988	0.2208	0.1903	0.2145	0.1904	0.1367
1989	0.2258	0.1961	0.2197	0.1962	0.1183
1990	0.2540	0.2280	0.2485	0.2281	0.1637
1991	0.2237	0.1937	0.2175	0.1938	0.1626
1992	0.1231	0.1207	0.1266	0.1209	0.0885
1993	0.1127	0.1101	0.1165	0.1103	0.0685
1994	0.1166	0.1141	0.1202	0.1143	0.0679
1995	0.1031	0.1002	0.1072	0.1005	0.0572
1996	0.1714	0.1697	0.1739	0.1698	0.0892
1997	0.1416	0.1396	0.1447	0.1398	0.0750
1998	0.0972	0.0941	0.1015	0.0944	0.0693
1999	0.1163	0.1157	0.1181	0.1157	0.0632
2000	0.1137	0.1131	0.1156	0.1131	0.0729
2001	0.1288	0.1282	0.1304	0.1282	0.0838
2002	0.2081	0.2078	0.2091	0.2078	0.1252
2003	0.2566	0.2563	0.2574	0.2563	0.1565
2004	0.4117	0.4115	0.4122	0.4115	0.2810

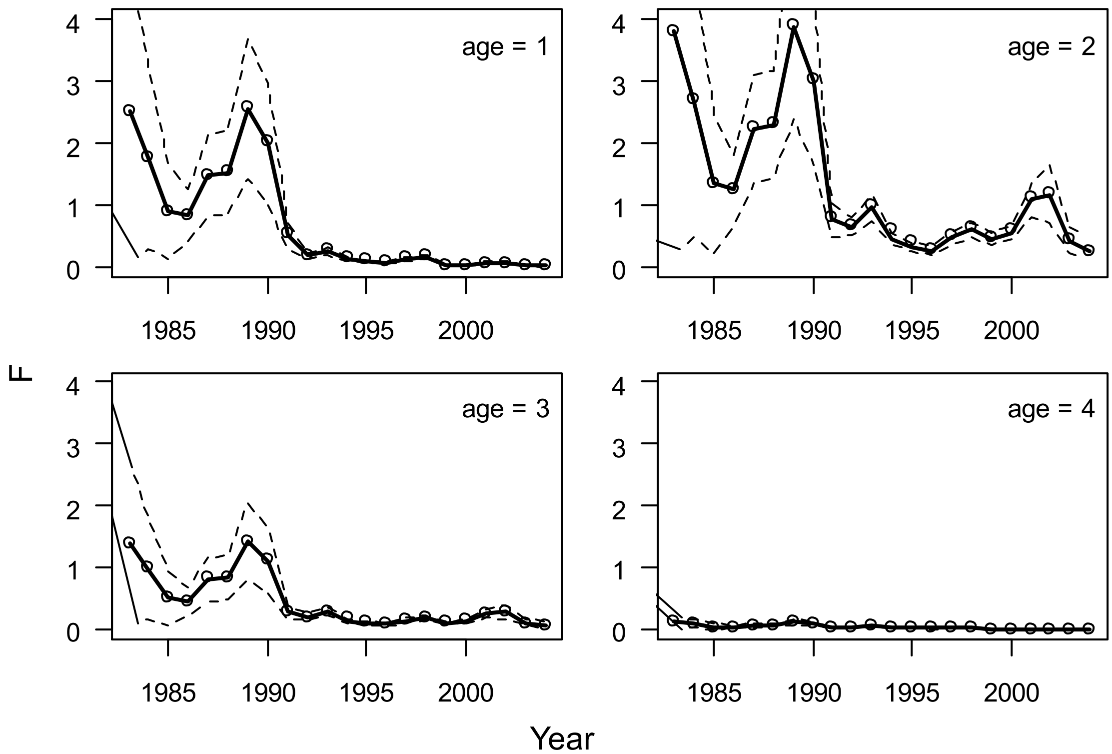

Figure 1. Adjusted total fishing mortality (points) and harvested fishing mortality (solid lines) from an age-dependent tag-return model. Dashed lines represent 95% confidence intervals for harvested fishing mortality.

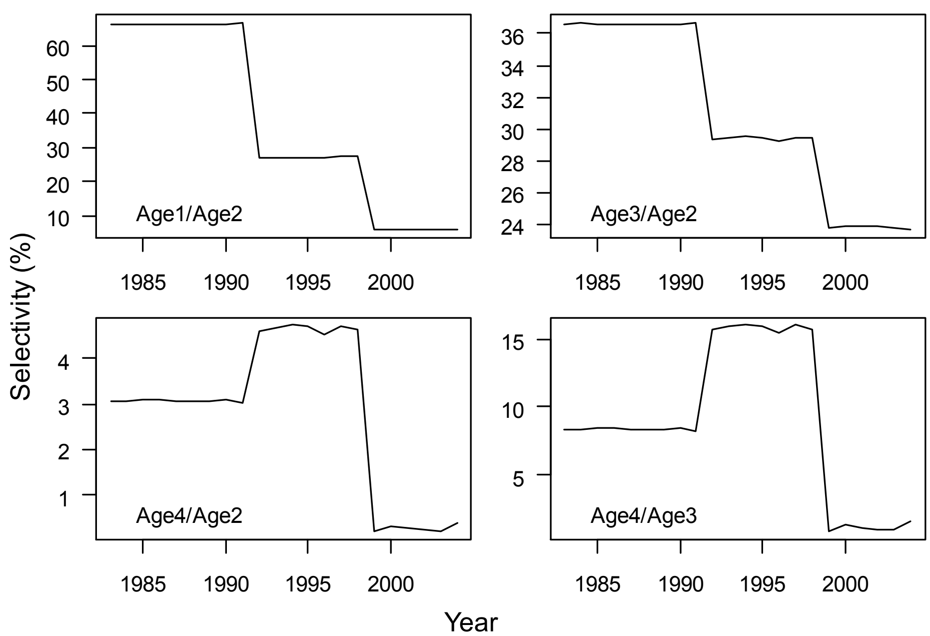

Figure 2. Selectivity patterns in adjusted fishing mortality from an age-dependent tag-return model. Age 2 is fully selected.

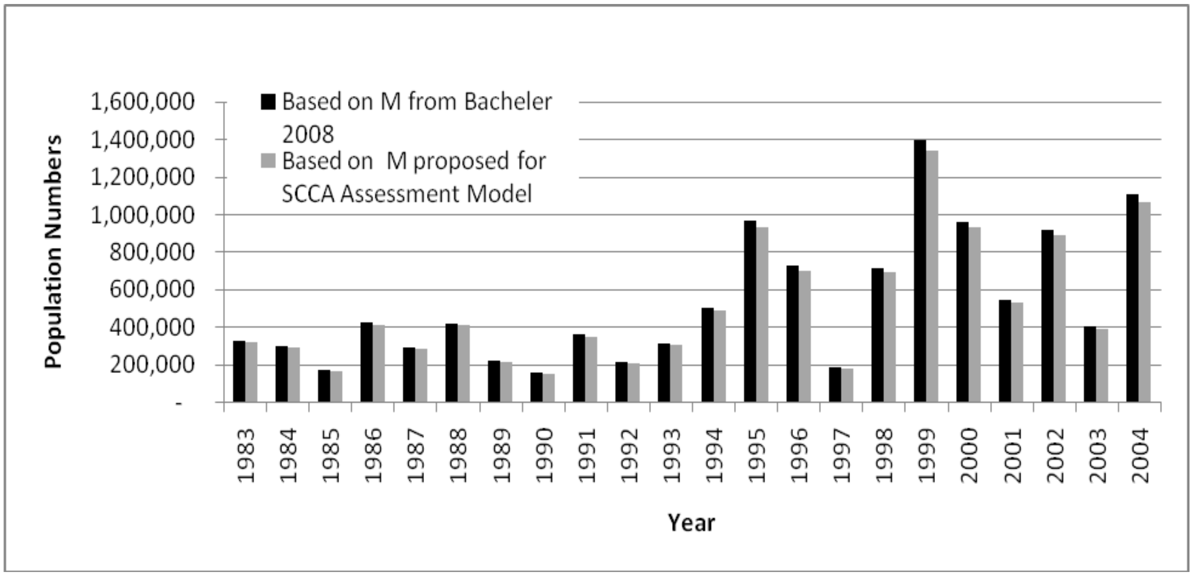

Figure 3. Population abundance (ages 1-4+ aggregated) estimates for the northern region red drum stock based on total harvest (commercial+recreational) and fishing mortality rates (F) estimated using an age-dependent tag-return model.

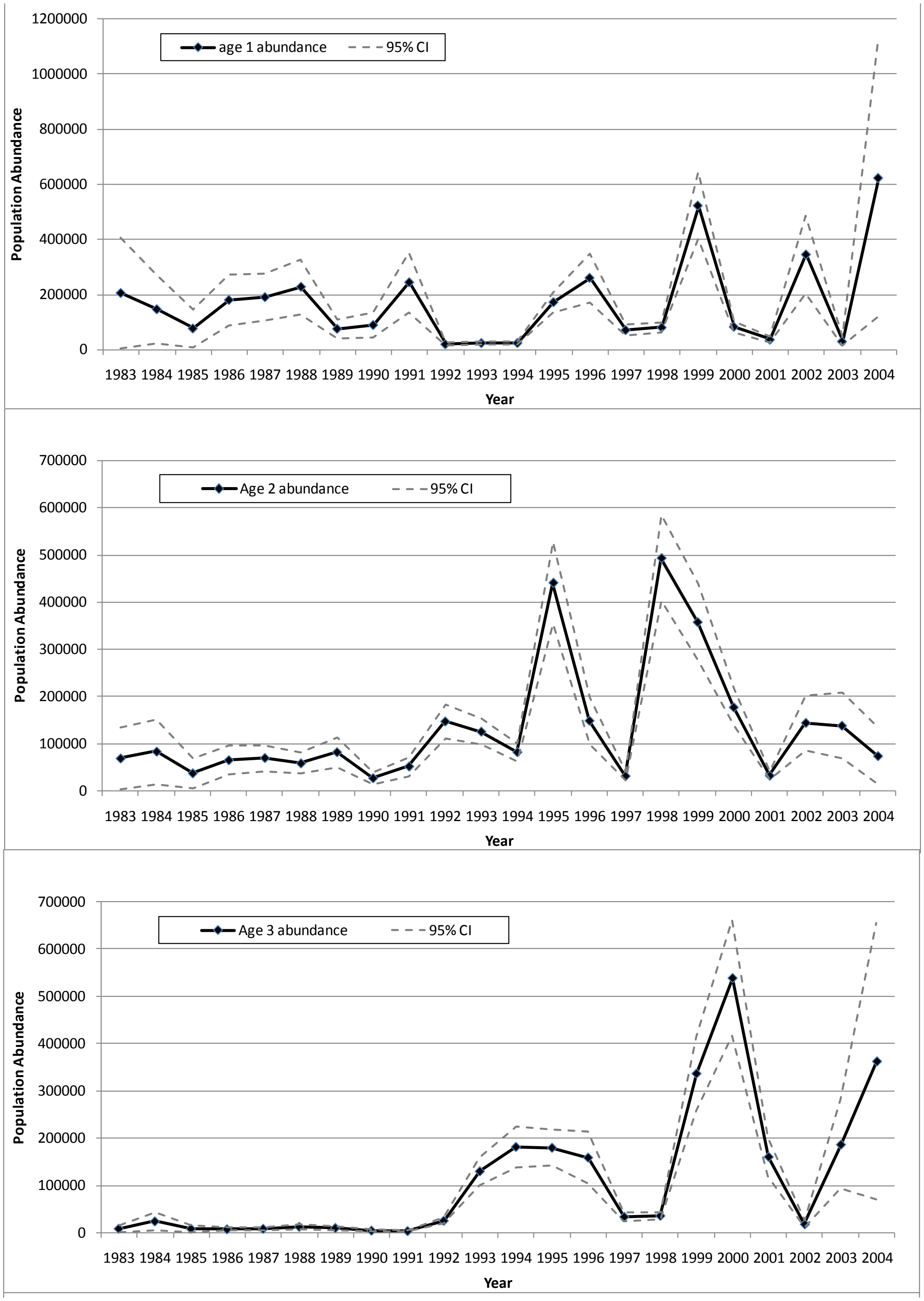

Figure 4. Population abundance estimates by age (ages 1-3) for the northern region red drum stock based on total harvest (commercial+recreational) and fishing mortality rates (F) estimated using an age-dependent tag-return model.

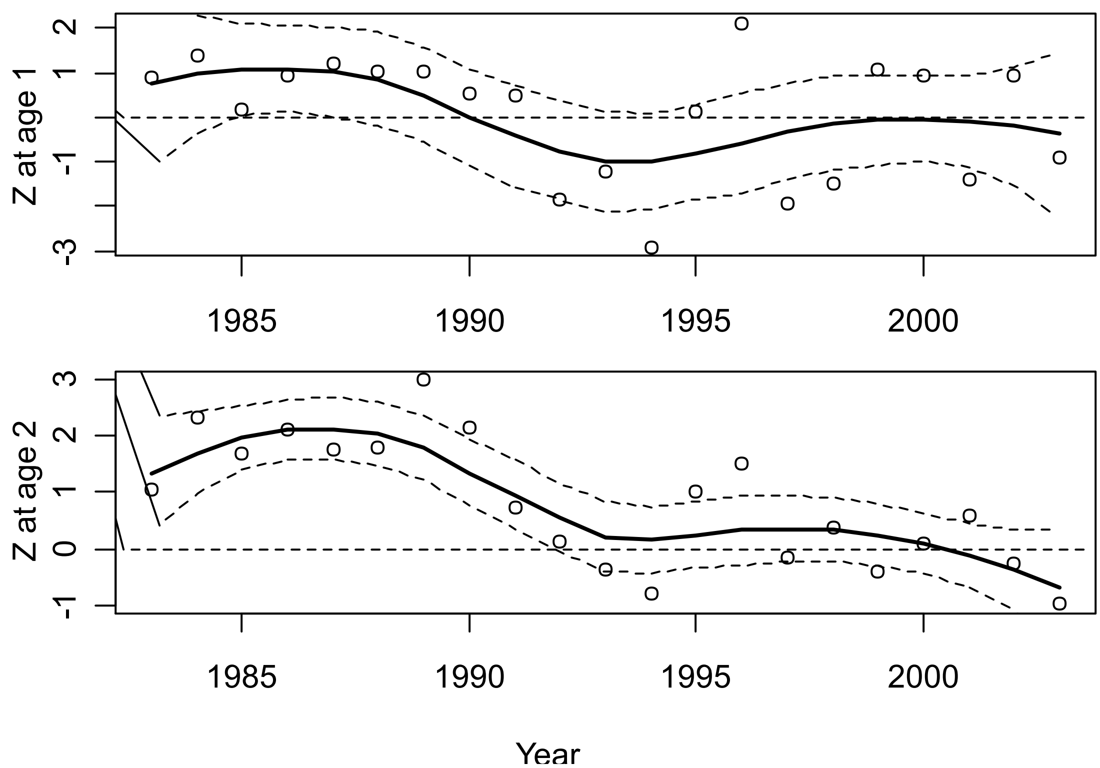

Figure 5. Catch curve estimates of Z (points) from tagging estimates of abundance at ages 1-3. The solid lines are loess smooths of the Z estimates, and the dashed lines are 95% confidence intervals for smooth mean Z.

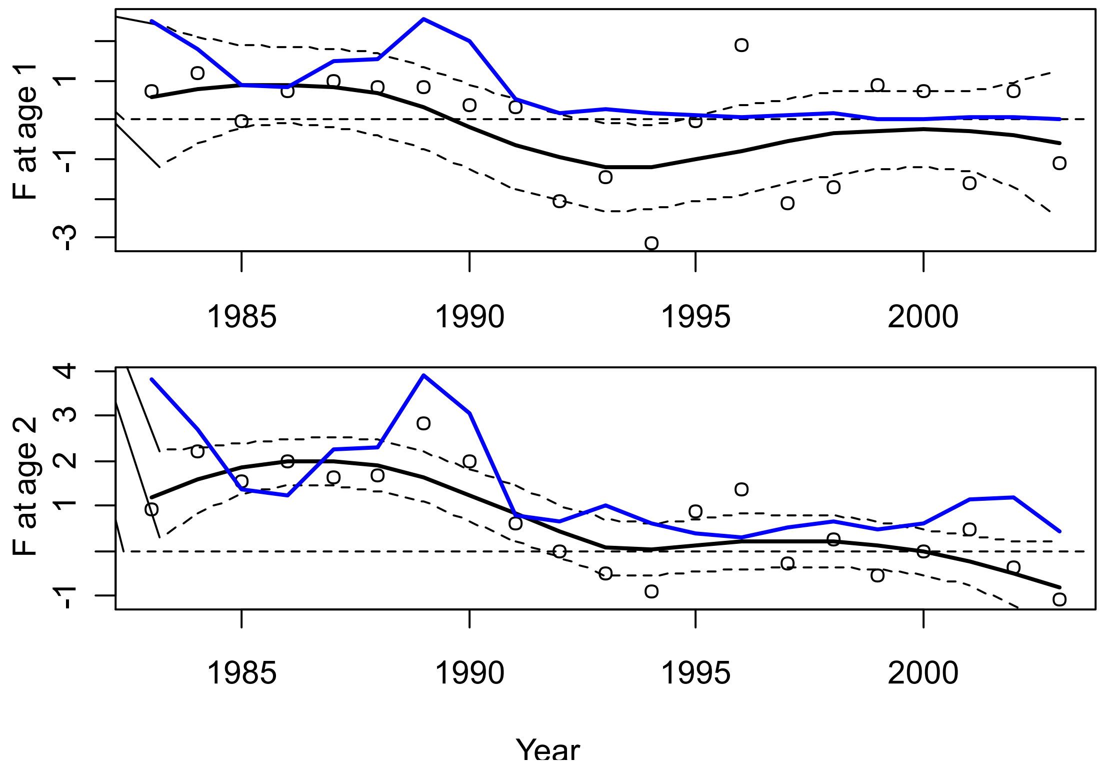

Figure 6. Catch curve estimates of F (points) from tagging estimates of abundance at ages 1-3. The solid lines are loess smooths of the Z estimates, and the dashed lines are 95% confidence intervals for smooth mean Z. The blue lines show the estimates of F obtained directly from the age-based tagging model.

References

Bacheler, N.M., Hightower, J.E., Paramore, L.M., Buckel, J.A., Pollock, K.H., 2008. Age-dependent tag return model to estimate mortality and selectivity of an estuarine-dependent fish with high rates of catch and release. Trans. Am. Fish. Soc. 137, 1422-1432.