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PRELIMINARY INVESTIGATION OF THE EFFECTS OF WEIGHTING CPUE INDICES ON ESTIMATES OF FISHING MORTALITY FROM THE CAL VPA PROGRAM

D. S. Vaughan, S. C. Turner**, J. M. Hoenig****

**NMFS, Southeast Fisheries Center, Pivers Island, Beaufort, North Carolina, U.S.A.*

***NMFS, Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida, U.S.A.*

****Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida, U.S.A.*

SUMMARY

This study addresses the question of applying unequal weights to each set of CPUE indices when more than one set is used in CAL (Parrack 1986). The original version of CAL assumes equal weights among CPUE indices. The method of weighting proposed here is based on the inverse of the total sum of squares from CAL when only one set of CPUE indices is used. A series of simulations are made to investigate the central tendency and dispersion of the estimated full F (age 7 in 1985) for the weighted and unweighted versions of CAL. Estimates of full F from CPUE indices having different levels of introduced error have less bias (estimated value minus true value) when obtained from CAL with unequal weights than with equal weights. Deterministic simulations with CPUE indices containing both biased and unbiased CPUE indices reproduce the correct full F only from the weighted version of CAL, although little difference is noted between estimated full F from weighted and unweighted CAL once substantial error is introduced. Further simulations are recommended that explore aspects of the CPUE indices not considered here.

RESUME

La présente étude traite de l'application d'une pondération inégale aux différents jeux d'indices de CPUE lorsque plus d'un jeu est utilisé dans le CAL (Parrack, 1986). La version originale du CAL suppose une pondération égale des indices de CPUE. La méthode de pondération proposée dans le présent travail se base sur l'inverse de la somme totale des carrés provenant du CAL lorsqu'un seul jeu d'indices de CPUE est utilisé. Une série de simulations est effectuée pour rechercher la tendance centrale et la dispersion des valeurs estimées du F de plein recrutement (l'âge 7 en 1985) pour les versions pondérée et non pondérée du CAL. Les estimations du F de plein recrutement à partir d'indices de CPUE qui présentent un niveau différent d'erreur introduite ont moins de biais (valeur estimée moins valeur réelle) lorsqu'elles proviennent d'un CAL avec pondération inégale que d'un CAL avec pondération uniforme. Les simulations déterministes avec des indices de CPUE contenant à la fois des indices biaisés et non biaisés ne reproduisent la valeur correcte du F de plein recrutement que pour la version pondérée du CAL, bien que peu de différence soit observée entre la valeur estimée du F de plein recrutement des CAL pondéré et non pondéré une fois qu'une erreur substantielle a été introduite. D'autres simulations sont recommandées pour explorer les facettes des indices de CPUE qui ne sont pas examinées dans le présent travail.

RESUMEN

El estudio trata sobre la aplicación de pesos desiguales a cada conjunto grupo de índices de CPUE en el caso de que para el CAL (Parrack 1986) se emplee más de un conjunto. La versión original del CAL presupone pesos iguales entre los índices de CPUE. El método de cálculo que aquí se propone se basa en el inverso de la suma total de cuadrados derivada del CAL, en el caso de que se emplee un solo conjunto de índices de CPUE. Se efectúan una serie de simulaciones para investigar la tendencia central y la dispersión de la F total estimada (edad 7 en 1985) en las versiones ponderada y no ponderada de CAL. Las estimaciones de la F total derivadas de los índices de CPUE, al tener diferentes niveles de introducción de error, presentan menos sesgo (valor estimado menos valor real) al obtenerse por medio de CAL con pesos desiguales que cuando se obtienen con pesos iguales. Las simulaciones deterministas con índices de CPUE que contienen índices de CPUE tanto sesgados como sin sesgo, reproducen la F total correcta solamente con la versión ponderada de CAL, si bien, se observa escasa diferencia entre las estimaciones de la F total obtenidas por medio del CAL ponderado y sin ponderar, una vez que se ha introducido un error sustancial. Se recomienda efectuar más simulaciones que exploren aspectos de los índices de CPUE no considerados en este estudio.

INTRODUCTION

Parrack (1986) describes a procedure (CAL) for calibrating virtual population analysis estimates of stock size and fishing mortality rates developed from age-specific catches and observed indices of abundance (i.e., catch per unit effort, CPUE). Vaughan et al. (1988) investigated the usefulness of this computer program based on two general types of simulations: deterministic and stochastic. Deterministic simulations demonstrated whether CAL could recover the correct estimates of stock size and fishing mortality rates under various scenarios, but with no stochastic error. Subsequent stochastic simulations showed the effect of increasing error in one of the inputs (i.e., catch matrix, partial recruitment vector, and CPUE indices) on the accuracy (bias: estimated value minus true value) and precision (dispersion: 75th percentile minus 25th percentile) of estimates of stock size or fishing (and natural) mortality rate.

During the November 1988 meeting of ICCAT in Madrid, Spain, the question was raised as to the assumption of equal weighting among CPUE indices inherent in the current use of CAL (Collie 1988). It was suggested that some means be developed to determine appropriate weightings for CPUE indices in CAL (Anonymous 1988). Because weighted regressions are not new in the realm of statistics (Draper and Smith 1966), this preliminary study was begun to assess one such weighting scheme for use in CAL.

METHODS

The CAL program seeks to minimize the total sum of squares (TSS) obtained from the expression:

$$\sum_k \sum_i (I_{ik} - \hat{I}_{ik})^2, \qquad (1)$$

where I_{ik} is the kth CPUE index set for the ith index year. The estimated CPUE index is given by:

$$\hat{I}_{ik} = q_k N_i,$$

where q_k is the catchability coefficient estimated for the kth CPUE index and N_i is the population estimate in year i summed over the ages represented by the kth CPUE index in the ith index year. Expression (1) can be rewritten to allow for unequal weights (w_k) among the different CPUE indices:

$$\sum_k \sum_i w_k(I_{ik} - \hat{I}_{ik})^2, \qquad (2)$$

where the w_k sum to one. The weighting scheme used in this study is based on the inverse of the total sum of squares from expression (1) (adjusted for number of index years, $w_k = n_k/TSS_k$) obtained by running CAL separately with each CPUE index. The weightings are further adjusted so they sum to one. The rationale is that small weight should be given to a CPUE index having large system error (TSS) left unexplained in a separate run of CAL on that index.

The catch at age matrix (1970-1985) and partial recruitment vector (ages 1-30) are identical to those used in simulations by Vaughan et al. (1988). The rationale for not updating these with 1986 and later data was for simplicity and comparability with the earlier simulation study.

Two versions of CAL were used in this study. Unweighted CAL is equivalent to that used in Vaughan et al. (1988) which effectively gave equal weightings to each CPUE index [expression (1)]. A second version, weighted CAL, was modified to calculate full F (age 7 in 1985) and TSS for each CPUE index separately, calculate the appropriate weighting, and then calculate full F and TSS for the combined weighted CPUE indices [expression (2)]. Parallel computer simulations were made with both versions of CAL (weighted and unweighted).

Simulations were restricted to introduced error in the CPUE indices, the error was lognormally distributed and was introduced independently and identically as follows (Vaughan et al. 1988):

$$X' = X*\exp(s*n(0,1) - s^2/2),$$

where n(0,1) is normally distributed with mean 0 and variance 1, s is the introduced error, and X' is lognormally distributed with mean X and variance which is a function of X and s. Standard deviations for the underlying normal distributions were restricted to: 0.1, 0.3, and 0.5. For this preliminary study CPUE indices were restricted to one age range (6-9) and one range of years (1975-1985). Only simulations of 100 iterations were made. Bias in estimated full F is the difference between the median of the estimated full F and true full F. Dispersion in full F is the 75th minus the 25th percentiles.

As in Vaughan et al. (1988), a perfect CPUE index based on ages 6-9 for years 1975-1985 was created (Table 1). Unweighted CAL was run with this single index and the estimated full F equaled the true full F (0.42).

A series of four simulations (a-d) were made with this perfect CPUE index replicated as a set of three identical CPUE indices but with different underlying standard deviations for the introduced error (Table 2). The purpose of these simulations is to determine whether differing variability in basically "good" CPUE indices can be corrected for by weighting these indices in CAL.

A second CPUE index (Table 1) was developed from this perfect index by adding different numbers so as to create an index with a trend indicating a greater population decline. Unweighted CAL was run with this single index to obtain its corresponding full F (1.25). Nine sets of CPUE indices were created containing 2, 3, or 4 CPUE indices (Tables 3 - 6). Three sets of indices contained only replicates of the "good" or perfect CPUE index. Six additional sets of indices contained one or more replicates of the "bad" index and the remaining one to three indices were replicates of the "good" index. Parallel simulations with unweigted and weighted versions of CAL were made with each of these sets of CPUE indices. The purpose of these simulations is to determine whether the weighted version of CAL can overcome a "bad" index among one or more "good" indices.

RESULTS AND DISCUSSION

Deterministic Analysis:

When CAL is run separately with the "good" CPUE index (no error), full F is estimated at 0.42 and TSS is 0.245 x 10^{-6}. When CAL is run separately with the "bad" CPUE index (again no error) full F is estimated at 1.25 and TSS is 0.576 x 10^{-2}. With the above TSS estimates, it is clear that the relative weighting for a "good" CPUE index will be much larger than for a "bad" index.

When unweighted CAL was run without error (deterministic) with three CPUE indices (including one or two "bad" indices), full F was estimated at 0.58 (one "bad" index) and at 0.83 (two "bad" indices). However, when these same runs were repeated with weighted CAL, full F was estimated at 0.42 in both cases, the same as with "good" indices only. Hence, in the deterministic situation, weighting the CPUE indices is clearly superior to not weighting them.

Stochastic Analysis:

When error is introduced into the CPUE indices and simulations are repeated 100 times, estimates of F and TSS from both weighted and unweighted CAL become variable and the results less certain (Vaughan et al. 1988). The results of weighted CAL on three "good" indices having different standard deviations are summarized in Table 2. Simulation run d (standard deviations of 0.3, 0.3, and 0.5) did worst with respect to bias in F (0.02 compared to 0.0-0.005 for the other simulations), dispersion in F (0.380 compared to 0.115-0.180), and TSS (0.060 compared to 0.007-0.017). Weighting values reflected the different levels of introduced error.

Tables 3-6 summarize the results from a series of parallel simulations exploring weighted CAL's ability to adjust to one or more "bad" CPUE indices with one or more "good" CPUE indices.

The median bias in full F (Table 3) is estimated as the difference between the median and 0.42. The median full F from simulation with only "good" indices are fairly consistent among themselves whether CAL is weighted or unweighted. This would be expected, because all indices are "good" and have the same underlying error. As more "bad" indices are introduced, greater bias appears. The proportion of "good" to "bad" indices also appears to be important. One "bad" index among three "good" indices causes less bias than one "bad" index with one "good" index. The median full F from weighted CAL is uniformly better (less bias) than from unweighted CAL when one or more "bad" indices are used for introduced error having standard error of 0.1, but no consistent pattern is noted for estimated full F from weighted and unweighted CAL when greater error is introduced. The proportion of "bad" indices had greater effect on the median full F than the level of introduced error.

Dispersion in estimated full F (Table 4) is estimated from the difference between the 75th percentile and the 25th percentile. Dispersion increases with increasing introduced error in the CPUE indices (standard deviation: 0.1, 0.3, 0.5) and with increasing number of "bad" indices. Again, the proportion of "bad" indices to "good" indices is important. However, introduced error appears to be more important than number of "bad" indices in affecting the size of the dispersion in estimated full F. Also, no consistent pattern is noted in comparing the dispersion in estimated full F from weighted and unweighted CAL.

The median TSS (Table 5) reflects the overall error in the system. TSS for unweighted CAL were divided by the number of CPUE indices to be equivalent to the TSS for weighted CAL; that is, if unweighted CAL was run with equal weights then each term in the sum of squares for unweighted CAL [expression (1)] should be divided by the number of CPUE indices. TSS also increases with increasing introduced error (standard deviation: 0.1, 0.3, 0.5) and number of "bad" indices, with the former factor dominating. However, TSS from the unweighted CAL uniformly exceeds that from the weighted CAL, indicating some improvement in minimization from the weighting approach.

Median weights (Table 6) for the weighted CAL simulations are compared to the equivalent equal weights based on number of CPUE indices; i.e., an equal weight of 0.5 for two indices, 0.333 for three indices, and 0.25 for four indices. The median weight for the "bad" CPUE index is always lower for the standard deviation of introduced error of 0.1, and it is almost always lower at 0.3. There also occur occasions with all "good" indices where the resultant median weight for one index appears substantially smaller than the others (e.g., 4 all "good" indices and standard deviation of introduced error where index #4 is 0.195 and indices #1-3 range from 0.225 to 0.248). When the introduced error has a standard deviation of 0.5, the weight of the "good" and "bad" indices can not be distinguished. This apparently occurs because the variability in the indices masks the quality of the underlying index.

CONCLUSIONS

The results presented are intended as preliminary, and only apply to the situation where all CPUE indices cover the same ages and years. Future computer simulations are planned for investigating the situation where CPUE indices cover different ages and/or years, either overlapping or non-overlapping.

For CPUE indices that cover identical ages and years, the preliminary results are summarized as follows:

1.) Weighted CAL is significantly better than unweighted CAL in estimating full F from a mixture of "good" and "bad" CPUE indices when no error is introduced into any of the input data (e.g., deterministic simulations).

2.) Weighted CAL leads to improved estimated full F, smaller dispersion of full F, and smaller TSS when "good" CPUE indices with different introduced error are run in simulations together.

3.) When "good" and "bad" CPUE indices are mixed and error is introduced, then some improvement is noted in the weighted versus unweighted CAL with respect to estimating full F or the dispersion in estimated full F provided the amount of introduced error is small.

4.) However, when "good" and "bad" CPUE indices are mixed and the same level of error is introduced into each index, some improvement is noted in minimizing TSS from the weighted CAL compared to the unweighted CAL even when considerable variability is introduced into each index.

5.) For low standard deviation in introduced error, weights of "bad" CPUE indices are usually lower than for "good" CPUE indices.

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Table 1. Two CPUE indices for ages 6-9 and years 1975-1985 used in simulation study. The "good" index was obtained from Vaughan et al. (1988) giving a full F (age 7 in 1985) of 0.42. The "bad" index was derived from the "good" index and gives a full F of 1.25.

Year	"Good" Index	"Bad" Index
1975	0.309	0.359
1976	0.361	0.401
1977	0.431	0.461
1978	0.446	0.466
1979	0.348	0.358
1980	0.266	0.266
1981	0.173	0.163
1982	0.093	0.073
1983	0.075	0.045
1984	0.076	0.036
1985	0.107	0.057

Table 2. Median and dispersion (75th minus 25th percentiles) of estimated full F, TSS, and weights from 100 simulations based on three sets of identical CPUE indices for ages 6-9 and years 1975-1985 where true full F is 0.42. Different standard deviations (STD) for underlying normal distribution were used for the three indices within the same simulation runs.

Parameters	Simulation Run			
	a	b	c	d
STD for Index				
1	0.1	0.1	0.1	0.3
2	0.3	0.1	0.5	0.3
3	0.5	0.5	0.5	0.5
Median F	0.415	0.420	0.420	0.440
Dispersion F	0.155	0.115	0.180	0.380
TSS	0.0159	0.0074	0.0175	0.0600
Weights for Index				
1	0.828	0.489	0.852	0.365
2	0.105	0.471	0.019	0.399
3	0.032	0.023	0.040	0.117

Table 3. Median estimated full F from 100 simulations based on CPUE indices for ages 6-9 and years 1975-1985 where true full F is 0.42. Simulation runs are based on equal (EW) and unequal (UW) weightings.

Number and Types of CPUE Indices	Standard Deviation					
	0.1		0.3		0.5	
	EW	UW	EW	UW	EW	UW
All "Good"						
2	0.410	0.435	0.420	0.390	0.390	0.415
3	0.420	0.420	0.480	0.400	0.475	0.440
4	0.420	0.420	0.420	0.400	0.480	0.420
1 "Bad"						
2	0.670	0.610	0.670	0.705	0.585	0.725
3	0.580	0.530	0.670	0.515	0.650	0.710
4	0.530	0.490	0.520	0.490	0.650	0.610
2 "Bad"						
3	0.840	0.735	0.980	0.740	0.875	0.940
4	0.680	0.610	0.650	0.670	0.745	0.770
3 "Bad"						
4	0.900	0.860	0.885	0.940	1.020	0.990

Table 4. Dispersion (75th minus 25th percentile) about median estimated full F from 100 simulations based on CPUE indices for ages 6-9 and years 1975-1985 where true full F is 0.42. Simulation runs are based on equal (EW) and unequal (UW) weightings.

Number and Types of CPUE Indices	Standard Deviation					
	0.1		0.3		0.5	
	EW	UW	EW	UW	EW	UW
All "Good"						
2	0.120	0.130	0.385	0.360	0.780	0.750
3	0.090	0.080	0.325	0.280	0.515	0.500
4	0.095	0.070	0.295	0.210	0.670	0.430
1 "Bad"						
2	0.220	0.270	0.910	0.630	2.175	2.740
3	0.155	0.130	0.520	0.380	0.880	0.730
4	0.135	0.105	0.430	0.240	1.010	0.620
2 "Bad"						
3	0.275	0.305	1.095	0.730	1.770	2.520
4	0.195	0.175	0.710	0.460	2.705	0.780
3 "Bad"						
4	0.300	0.290	1.175	0.830	2.590	1.145

Table 5. Median total sum of squares (TSS) from 100 simulations based on CPUE indices for ages 6-9 and years 1975-1985 where true full F is 0.42. Simulation runs are based on equal (EW) and unequal (UW) weightings.

Number and Types of CPUE Indices	Standard Deviation 0.1 EW	0.1 UW	0.3 EW	0.3 UW	0.5 EW	0.5 UW
All "Good"						
2	0.007[a]	0.006	0.057	0.045	0.163	0.110
3	0.007	0.006	0.059	0.040	0.178	0.116
4	0.007	0.005	0.063	0.041	0.166	0.121
1 "Bad"						
2	0.011	0.009	0.060	0.049	0.180	0.112
3	0.010	0.007	0.062	0.043	0.189	0.117
4	0.009	0.007	0.067	0.044	0.164	0.123
2 "Bad"						
3	0.012	0.009	0.068	0.045	0.197	0.119
4	0.011	0.008	0.069	0.045	0.172	0.127
3 "Bad"						
4	0.012	0.010	0.073	0.044	0.174	0.129

[a] TSS for equal weights is adjusted to correspond to TSS for unequal weights by dividing TSS by number of CPUE indices.

Table 6. Median weights by CPUE index from 100 simulations based on CPUE indices for ages 6-9 and years 1975-1985 where true full F is 0.42.

Numbers and Types of CPUE Indices	Index #	Standard Deviation 0.1	0.3	0.5
All "Good"				
2	1	0.518	0.544	0.541
	2	0.482	0.456	0.459
3	1	0.288	0.297	0.296
	2	0.348	0.328	0.327
	3	0.288	0.322	0.255
4	1	0.228	0.211	0.211
	2	0.248	0.211	0.241
	3	0.225	0.248	0.171
	4	0.195	0.201	0.222
1 "Bad" [a]				
2	1	0.320	0.472	0.519
	2	0.680	0.528	0.481
3	1	0.162	0.286	0.292
	2	0.422	0.323	0.311
	3	0.379	0.335	0.261
4	1	0.140	0.179	0.183
	2	0.300	0.221	0.277
	3	0.255	0.250	0.184
	4	0.215	0.210	0.234
2 "Bad" [a]				
3	1	0.234	0.294	0.309
	2	0.250	0.277	0.261
	3	0.485	0.368	0.273
4	1	0.170	0.185	0.182
	2	0.160	0.203	0.274
	3	0.326	0.256	0.196
	4	0.286	0.217	0.229
3 "Bad" [a]				
4	1	0.208	0.192	0.192
	2	0.186	0.213	0.267
	3	0.167	0.226	0.197
	4	0.337	0.223	0.226

[a] "Bad" indices appear before "good" indices; that is, when one index is "bad" it appears as index #1 or when two indices are "bad" they appear as indices #1 and #2.